Université Paris 1 Panthéon-Sorbonne – Paris School of Economics

Thèse

pour l'obtention du titre de Docteur en Sciences Économiques

Présentée et soutenue publiquement le 2 novembre 2020 par :

Thomas DOUENNE

ESSAIS SUR L'ÉCONOMIE DES POLITIQUES ENVIRONNEMENTALES : PRÉFÉRENCES, CROYANCES, ET REDISTRIBUTION

Directrice de thèse : Mme. Katheline SCHUBERT

Composition du jury :

Président du jury	Stéphane GAUTHIER	Professeur à l'Université Paris 1 Panthéon-Sorbonne - PSE
Rapporteurs	Lucas BRETSCHGER	Professeur à l'ETH Zurich
	Frederick VAN DER PLOEG	Professeur à l'Université d'Oxford
Examinateurs	Christian GOLLIER	Professeur à la TSE
	Fanny HENRIET	Chargée de recherche au CNRS - PSE
	Philippe MARTIN	Professeur à Sciences Po.
Directrice de thèse	Katheline SCHUBERT	Professeure à l'Université Paris 1 Panthéon-Sorbonne - PSE

Université Paris 1 Panthéon-Sorbonne – Paris School of Economics

Ph.D. Thesis

Submitted for the Degree of Doctor of Philosophy in Economics

Prepared and defended at Paris School of Economics on November 2, 2020 by :

Thomas Douenne

Essays on the economics of environmental policies : preferences, beliefs, and redistribution

Thesis advisor : Mrs. Katheline Schubert

Jury :

President	Stéphane Gauthier	Professor at University Paris 1 Panthéon-Sorbonne - PSE
Reviewers	Lucas Bretschger	Professor at ETH Zurich
	Frederick van der Ploeg	Professeur at the University of Oxford
Examinators	Christian Gollier	Professeur at TSE
	Fanny Henriet	Research fellow at CNRS - PSE
	Philippe Martin	Professor at Sciences Po.
Advisor	Katheline Schubert	Professor at University Paris 1 Panthéon-Sorbonne - PSE

Remerciements

Je tiens avant tout à remercier Katheline Schubert qui a été une directrice de thèse exceptionnelle. Ses précieux conseils, et la confiance qu'elle m'a accordée ont été essentiels à ma progression. Dans mes moments d'hésitation, Katheline a toujours su me redonner confiance et me permettre de faire de bons choix. Sa disponibilité, sa gentillesse et sa bonne humeur ont grandement contribué à faire de cette thèse une excellente expérience humaine.

Je tiens également à remercier tout particulièrement Fanny Henriet pour l'aide qu'elle m'a apportée. Fanny s'est impliquée très tôt dans mon projet de recherche. Son enthousiasme et son regard critique m'ont été très précieux. J'espère que nos échanges continueront au-delà de cette thèse.

Je remercie également Lucas Bretschger, Stéphane Gauthier, Christian Gollier, Philippe Martin, et Frederick van der Ploeg d'avoir accepté de faire partie de mon jury. Je voudrais en particulier remercier Philippe Martin pour la confiance qu'il m'a accordée depuis mes débuts en économie à Sciences Po. C'est grâce à son aide que j'ai pu passer une année à Berkeley durant ma licence, puis valoriser de manière très concrète mes travaux de thèse via la CAE. Je lui en suis très reconnaissant.

I would also like to thank Lucas Bretschger and Frederick van der Ploeg for their support. I am very grateful for the consideration they have given to the work of a young graduate student. Their positive feedback has given me more confidence as a researcher and encouraged me to continue on this path. I am also indebted to them for the great help they gave me on the academic job market.

Je suis également très reconnaissant de l'aide que m'ont apportée de nombreux professeurs à PSE. Mes remerciements vont tout particulièrement à Stéphane Gauthier dont l'enseignement et les conseils tout au long de cette thèse m'ont beaucoup apporté. Mes recherches ont également grandement bénéficié des conseils précieux d'Emeline Bezin, Mireille Chiroleu-Assouline, Andrew Clark, Mouez Fodha, Jean Imbs, Nicolas Jacquemet, Jean-François Laslier, David Margolis, David Martimort, Katrin Millock, Hélène Ollivier, et Thierry Verdier. Je tiens également à remercier Véronique Guillotin qui a fait un travail exceptionnel pour accompagner les doctorants de PSE sur le job market. Son excellente organisation et son zèle ont été essentiels dans ce processus, je lui en suis très reconnaissant.

Mes remerciements vont également aux nombreux enseignants qui ont joué un rôle clef dans mon parcours depuis le lycée. Je remercie en particulier Jean-Charles Bricongne et Delphine Prady, mes premiers enseignants en économie à Sciences Po, qui m'ont donné le goût de cette discipline. Je remercie également Gabriel Zucman pour le temps qu'il a accordé au jeune étudiant que j'étais lors de mon année à Berkeley. Sa disponibilité et ses conseils ont joué un rôle important dans ma décision de poursuivre en thèse.

Je remercie également l'ensemble des chercheurs avec qui j'ai échangé lors de nombreuses conférences. Mon engouement pour la recherche vient aussi du plaisir que j'ai à cotoyer mes collègues chercheurs.

Ces années à PSE n'auraient pas été les mêmes sans la compagnie formidable des doctorants de PSE. Je remercie en particulier Adrien Fabre, Maxime Fajeau, Quentin Lippman, Juan Diego Lutsik, Adrien Montalbo, Lennart Stern, Eui Young Jung, et tout le bureau R4-71. De ces amitiés est également née une collaboration fructueuse. Je ne sais comment remercier mon co-auteur et ami Adrien Fabre, chercheur-citoyen passionné. Travailler à ses côtés a été une expérience fantastique.

Le premier chapitre de cette thèse est né d'un travail réalisé au sein de l'Institut des Politiques Publiques. Il est certain que mon programme de recherche n'aurait pas été le même sans cette expérience et sans l'aide précieuse que mes collègues de l'IPP ont pu m'apporter. Aussi je remercie Antoine Bozio pour son accueil à l'IPP, ainsi que pour ses nombreux conseils qui ont contribué à me former en tant que chercheur. Je ne saurais suffisamment remercier Mahdi Ben Jelloul qui m'a formé à l'IPP alors j'étais étudiant en Master. Mahdi a dû redoubler de patience et d'efforts pour me former à la programmation informatique, et s'est toujours montré prêt à m'aider lorsque j'en ai eu besoin. Je lui en suis très reconnaissant.

Je tiens enfin à remercier ma famille et mes amis, et tout spécialement Ysée qui m'a accompagné tout au long de cette aventure.

Je remercie toutes ces personnes qui ont rendu cette thèse possible. Plus que tout, je remercie mes parents pour leur soutien, leur confiance, et leur enthousiasme tout au long de mes études. Cette thèse leur est dédiée.

Résumé

Les quatre chapitres de cette thèse visent à mieux comprendre l'attitude des citoyens vis-à-vis des politiques environnementales, à travers l'étude de l'impact redistributif de ces politiques, l'analyse des perceptions et des préférences vis-à-vis de ces politiques, et de l'attitude des individus face au risque de catastrophes environnementales.

Le premier chapitre évalue l'impact redistributif de la taxe carbone française, et plus particulièrement de ses dernières augmentations avant l'arrêt qui a fait suite aux protestations des Gilets Jaunes. A partir d'un modèle de micro-simulation et d'enquêtes ménages, il montre que la taxe carbone est régressive, mais pourrait être rendue progressive si son revenu était retourné de manière uniforme à tous les ménages. Toutefois, même avec un tel mécanisme de compensation, la politique génèrerait encore d'importants effets redistributifs « horizontaux » (c'est-à-dire entre ménages de même revenu), et pénaliserait une part importante des ménages à revenus modestes. Afin de mieux comprendre les origines de ces effets horizontaux, les déterminants de l'incidence de la taxe sont caractérisés précisément, et des alternatives de transferts ciblés sont simulés sur cette base. Le chapitre montre qu'étant donné l'importance de l'hétérogénéité non observée liée à la consommation d'énergie des ménages, ces effets redistributifs sont nettement plus difficiles à pallier que les effets « verticaux » (c'est-à-dire entre groupes de revenu) communément étudiés.

Le deuxième chapitre co-écrit avec Adrien Fabre s'intéresse également à la taxe carbone française, afin d'analyser les ressorts de son rejet. L'objectif est de comprendre, au-delà des effets objectifs de la mesure, comment celle-ci est perçue par les Français, et comment leurs perceptions expliquent, et sont elles-mêmes expliquées par leur rejet. En utilisant une nouvelle enquête sur un échantillon représentatif de 3,002 Français, nous montrons que quand bien même les recettes de la taxe carbone seraient redistribuées uniformément aux ménages, ceux-ci s'opposeraient massivement à la politique. Ce rejet va de pair avec des perceptions pessimistes des effets de la politique, puisque les ménages surestiment l'impact négatif de la politique sur leur

pouvoir d'achat, pensent à tort qu'elle serait régressive, et ne la perçoivent pas comme efficace pour réduire la pollution et lutter contre le changement climatique. Nous montrons par ailleurs que ces perceptions pessimistes sont fortement ancrées : les répondants acceptent de réviser leurs croyances lorsqu'on leur présente des informations négatives vis-à-vis de la taxe, mais pas lorsque ces informations sont positives. Notre analyse suggère que la défiance des répondants joue un rôle important dans la formation de leurs croyances, et pourrait notamment s'exprimer par des raisonnements motivés conduisant les opposants à former des perceptions trop pessimistes mais plus cohérente avec leur opposition. En utilisant les informations aléatoires fournies aux répondants comme instruments pour identifier des effets causaux, notre analyse économétrique montre toutefois que lorsque les ménages sont convaincus des effets objectifs de la politique — sur leur pouvoir d'achat, sur l'environnement, et en termes redistributifs — leur soutien augmente largement et devient majoritaire. Restaurer la confiance des citoyens envers leurs gouvernants et envers les intentions environnementales de ceux-ci apparaît donc une condition nécessaire au déploiement de la fiscalité carbone.

Le troisième chapitre, basé sur la même enquête que le second et également co-écrit avec Adrien Fabre, a pour objectif d'évaluer les perspectives de la politique climatique française après que la crise des Gilets Jaunes a stoppé l'augmentation prévue de la taxe carbone. L'analyse y est plus descriptive que dans le chapitre précédent, mais nous y analysons un éventail plus large de mesures. Nous étudions tout d'abord les connaissances, perceptions et positions sur le changement climatique, nous examinons les opinions relatives à diverses politiques climatiques, puis analysons le lien entre perceptions du problème et attitudes vis-à-vis des solutions. L'article étudie également en détail les déterminants des attitudes en termes de variables politiques et socio-démographiques. Parmi les nombreux résultats, nous constatons que malgré des connaissances limitées à son sujet, le changement climatique suscite beaucoup d'inquiétude. Nous documentons un large rejet de la taxe carbone, mais un soutien majoritaire en faveur de normes plus strictes et d'investissements verts, et révélons les raisons qui sous-tendent ces préférences. Notre étude comporte des recommandations politiques, en particulier une campagne d'information sur le changement climatique. En effet, nous constatons que la préoccupation climatique renforce le soutien en faveur des politiques climatiques, mais qu'il n'y a aucune preuve que cette préoccupation souffre de biais partisans comme aux États-Unis, ce qui suggère qu'un meilleur accès à la science pourrait favoriser le soutien aux politiques climatiques.

Le quatrième chapitre étudie également le lien entre préférences et politiques environne-

mentales, dans une perspective plus théorique. L'objectif de ce chapitre est de comprendre comment les catastrophes environnementales jouent sur les décisions de consommation, d'investissement, et de protection de l'environnement en fonction de l'attitude des individus face au risque. Ce chapitre présente un modèle de croissance endogène avec désastres endogènes et préférences récursives, et montre qu'il est possible d'obtenir des solutions de forme fermée pour un tel modèle. La distinction est faite entre le risque et la réalisation des désastres, et les nombreux mécanismes au travers desquels ils affectent chacun la croissance via l'investissement sont mis en lumière. Il est montré que séparer l'aversion au risque et l'aversion aux fluctuations inter-temporelles (*a contrario* du modèle standard de l'utilité espérée) a des implications majeures et conduit à des résultats qualitativement plus riches, permettant de mieux comprendre ces mécanismes. La calibration du modèle à partir de l'exemple des États-Unis montre que cette représentation plus flexible des préférences conduit également à des résultats quantitativement différents, notamment vis-à-vis de l'impact des catastrophes sur le sentier de croissance optimal et du niveau optimal des politiques de réduction du risque. Le chapitre suggère donc d'étendre l'usage des préférences récursives à la modélisation des désastres, en particulier les désastres environnementaux tels que ceux liés au changement climatique.

Discipline : Sciences Economiques

Mots-clefs : Croyances ; Effets redistributifs ; Politiques climatiques ; Préférences ; Taxe carbone

Summary

The four chapters of this thesis aim to better understand citizens' attitudes towards environmental policies through the study of the redistributive impact of these policies, the analysis of perceptions and preferences towards these policies, and the attitude of individuals towards the risk of environmental disasters.

The first chapter assesses the redistributive impact of the French carbon tax, and more specifically its latest increases before the Yellow Vests protests led to stop its trajectory. Using a micro-simulation model and household surveys, it shows that the carbon tax is regressive, but could be made progressive if its income were returned uniformly to all households. However, even with such an offsetting mechanism, the policy would still generate significant « horizontal » redistributive effects (i.e. between households with the same income), and would penalize a significant proportion of low-income households. In order to better understand the origins of these horizontal effects, the determinants of the impact of the tax are characterized precisely, and alternative targeted transfers are simulated on this basis. The chapter shows that, given the importance of unobserved heterogeneity related to household energy consumption, these redistributive effects are much more difficult to mitigate than the « vertical » effects (i.e. between income groups) commonly studied.

The second chapter co-authored with Adrien Fabre also looks at the French carbon tax, in order to analyze the reasons for its rejection. The objective is to understand, beyond the objective effects of the measure, how it is perceived by the French, and how their perceptions explain, and are themselves explained by their rejection. Using a new survey on a representative sample of 3,002 French people, we show that even if the revenues from the carbon tax were redistributed uniformly to households, the latter would be massively opposed to the policy. This rejection goes hand in hand with pessimistic perceptions of the effects of the policy, since households overestimate the negative impact of the policy on their purchasing power, mistakenly think that it would be regressive, and do not perceive it as effective in reducing pollution and combating

climate change. We also show that these pessimistic perceptions are strongly entrenched : respondents are willing to revise their beliefs when presented with negative information about the tax, but not when the information is positive. Our analysis suggests that respondents' mistrust plays an important role in the formation of their beliefs, and could be expressed in particular by motivated reasoning leading opponents to form overly pessimistic perceptions that are more consistent with their opposition. Using the random information provided to respondents as a tool to identify causal effects, our econometric analysis shows, however, that when households are convinced of the objective effects of the policy—on their purchasing power, on the environment, and in redistributive terms—their support increases significantly and goes beyond the majority. Restoring citizens' confidence in their governments and in their governments' environmental intentions therefore appears to be a necessary condition for the deployment of carbon taxation.

The third chapter, based on the same survey as the second and also co-written with Adrien Fabre, aims to assess the prospects for French climate policy after the Yellow Vest crisis halted the planned increase in the carbon tax. The analysis is more descriptive than in the previous chapter, but we analyze a broader range of measures. We first examine knowledge, perceptions and positions on climate change, examine opinions on various climate policies, and then analyze the link between perceptions of the problem and attitudes towards solutions. The article also examines in detail the determinants of attitudes in terms of political and socio-demographic variables. Among the many findings, we find that despite limited knowledge about it, climate change is of great concern. We document a broad rejection of the carbon tax, but majority support for higher standards and green investments, and reveal the reasons behind these preferences. Our study includes policy recommendations, in particular an information campaign on climate change. Indeed, we find that climate concern strengthens support for climate policies, but there is no evidence that this concern suffers from partisan bias as in the United States, suggesting that better access to science could help build support for climate policies.

The fourth chapter also examines the link between environmental preferences and policies from a more theoretical perspective. The objective of this chapter is to understand how environmental disasters affect consumption, investment, and environmental protection decisions based on people's attitudes towards risk. This chapter presents a model of endogenous growth with endogenous disasters and recursive preferences, and shows that it is possible to obtain closed-form solutions for such a model. A distinction is made between the risk and the occurrence

of disasters, and the many mechanisms through which each affects growth via investment are highlighted. It is shown that separating risk aversion and aversion to inter-temporal fluctuations (*a contrario* from the standard model of expected utility) has major implications and leads to qualitatively richer results, allowing a better understanding of these mechanisms. Calibration of the model based on the example of the United States shows that this more flexible representation of preferences also leads to quantitatively different results, particularly with regard to the impact of disasters on the optimal growth path and the optimal level of risk mitigation policies. The chapter therefore suggests extending the use of recursive preferences to the modeling of disasters, in particular environmental disasters and climate change.

Discipline : Economics

Mots-clefs : Beliefs ; Carbon Taxation ; Climate Policies ; Distributive effects ; Preferences

Table des matières

Introduction générale

L'approche économique de l'environnement

Les scientifiques ont maintenant apporté des preuves irréfutables du changement climatique et de son lien avec l'activité humaine. Dans son cinquième rapport d'évaluation, le Groupe d'experts Intergouvernemental sur l'Évolution du Climat (GIEC) des Nations Unies confirme que « l'influence de l'homme sur le système climatique est manifeste et de plus en plus forte », et que « plus les activités humaines perturbent le climat, plus les risques de conséquences graves, généralisées et irréversibles pour l'être humain et les écosystèmes (...) sont élevés » (IPCC).

Le changement climatique est donc — au même titre que de nombreux autres problèmes tels que la pollution de l'air, l'épuisement des ressources naturelles, ou la perte de biodiversité — une conséquence de l'activité humaine impactant négativement le bien-être social via la dégradation de l'environnement. Une caractéristique particulière de ces problèmes est qu'ils résultent de décisions d'individus (les pollueurs) qui ne subissent pas la totalité des conséquences de leurs actions[1]. Pour les économistes, ces problèmes constituent des « externalités » (Pigou, 1920), c'est-à-dire des situations dans lesquelles des individus produisent par leurs actions des effets externes qui affectent le bien-être d'autres individus, sans contrepartie. Les externalités constituent donc une forme particulière de « défaillance de marché », au sens où en leur présence le laissez-faire économique conduit à une allocation inefficace des ressources, et notamment à des niveaux de pollution trop élevés.

Puisque les externalités résultent d'un problème de coordination entre les pollueurs et les pollués qui ne peut être résolu en laissant libre cours au marché, leur existence justifie l'intervention publique. L'objectif des économistes de l'environnement est de déterminer la nature exacte de cette intervention, dans la perspective d'améliorer autant que faire se peut le bien-être social.

1. A titre d'exemples, le tabagisme passif, l'exposition aux particules fines ou les nuisances sonores sont autant de situations dans lesquelles les victimes de la pollution (les pollués) n'ont pas entièrement prise sur la décision des pollueurs.

Cet objectif revêt essentiellement deux aspects : d'une part, déterminer des cibles de régulation — c'est-à-dire les niveaux de pollution que la société doit cibler pour maximiser son bien-être — et d'autre part, déterminer comment les atteindre.

La détermination des cibles de régulation

Le choix des niveaux de pollution à cibler est un problème délicat, car il implique de comparer des coûts et bénéfices de différentes natures. Si les effets de la pollution sont nocifs et donc indésirables, les activités l'engendrant peuvent elles-mêmes être par ailleurs bénéfiques. Ainsi, la consommation d'énergie induit diverses formes de pollutions,[2] mais elle permet aussi de se chauffer et de se déplacer. La question que l'économiste se pose lorsqu'une politique de régulation est introduite est donc de savoir quel est l'impact global de cette politique sur le bien-être social. Dans le cas des politiques environnementales, deux éléments doivent être pris en compte : le gain de bien-être associé à une réduction donnée de la pollution, et la perte de bien-être par ailleurs induite par l'introduction de la nouvelle régulation.

Le coût social de la pollution

Le premier élément est directement lié à ce que l'on appelle le coût social de la pollution (CSP). Afin de pouvoir comparer le coût de la pollution avec d'autres coûts, celui-ci est traduit en équivalent monétaire. Cet équivalent monétaire correspond au prix maximum que la société est prête à payer pour réduire la pollution d'un certain niveau. Ainsi, si le CSP estimé est de x€ par unité de polluant, alors la société devrait être prête à dépenser jusqu'à x€ pour éviter l'émission d'une unité supplémentaire de ce polluant. Autrement dit, un bien coûtant 10€ à produire et créant une pollution dont le coût social (CSP) estimé est de 5€ coûtera au total 15€ à la société. Dans la mesure où ce coût supplémentaire de 5€ n'est pas pris en compte par le producteur ou le consommateur, ce bien sera produit et consommé en trop grande quantité. Afin de remédier à ce problème, l'approche dite « pigouvienne » des externalités consiste donc à faire payer directement ce prix supplémentaire — c'est-à-dire la valeur monétaire de l'externalité — au pollueur, via par exemple la mise en place d'une taxe de ce montant.[3]

2. Si l'emploi de différentes sources d'énergie n'implique évidemment pas les mêmes dommages, aucune source n'est parfaitement propre et la transformation de toute énergie primaire en énergie finale induit nécessairement une forme ou une autre de pollution.

3. Dans l'exemple précédent, les personnes impactées par la pollution devraient être prêtes à payer ensemble jusqu'à 5€ pour éviter la production de ce bien. En transférant ce coût au pollueur (producteur ou consommateur), celui-ci va *internaliser* — c'est-à-dire prendre en compte dans sa décision — l'effet négatif qu'il produit sur les pollués. Ce mécanisme permet donc de remédier à la défaillance de marché.

En pratique, l'approche pigouvienne ne peut être pertinente que s'il est possible d'estimer assez précisément le CSP. Cela suppose donc de pouvoir non seulement identifier l'ensemble des conséquences de l'émission d'une unité supplémentaire d'un polluant, mais aussi d'assigner une valeur monétaire à chacune de ces conséquences. Comme le notaient déjà Baumol & Oates (1971), pour l'essentiel des polluants cet exercice s'apparente à une tâche « Herculéenne » tant les nombres de conséquences et de victimes possibles sont importants et difficilement observables. Dans le cas des gaz à effet de serre (GES) responsables du changement climatique, les impacts étant à la fois diffus dans le temps et dans l'espace, la plupart des conséquences sont encore inconnues et/ou non mesurables. En extrapolant à partir de variations climatiques ou météorologiques observées, des études ont pu mettre en évidence des conséquences aussi variées que la hausse des dommages liés aux catastrophes naturelles (Hsiang et al., 2017), un impact négatif sur la croissance et le développement des pays pauvres (Dell et al., 2012), l'augmentation des conflits armés (Burke et al., 2009), un effet néfaste sur la santé et le capital humain (Graff Zivin et al., 2018), ou encore une hausse de la mortalité (Deschênes & Greenstone, 2011). Aucune liste ne saurait toutefois être exhaustive, et comme le suggèrent Weitzman (2009) et Pindyck (2013), le degré d'ambition des politiques climatiques devrait principalement dépendre non pas des conséquences connues du phénomène, mais de l'éventualité de catastrophes majeures altérant largement nos modes de vie. De plus, quand bien même toutes les conséquences seraient connues, le calcul de leur équivalent monétaire — supposé rendre possible des arbitrages et guider la décision politique — constitue une difficulté supplémentaire, *a fortiori* lorsque cela rend nécessaire de comparer des coûts et bénéfices sur une échelle de temps très longue. [4]

Bien qu'insistant sur les limites pratiques de l'approche pigouvienne, Baumol & Oates (1971) suggèrent que l'étude des principales conséquences des polluants permet de définir des niveaux de pollution cibles qui, bien que non-optimaux, induisent une augmentation du bien-être agrégé. Les auteurs prennent notamment l'exemple de l'effet de la pollution de l'air sur la santé pour lequel il est dans certains cas possible d'obtenir une première approximation des dommages, et ainsi fixer un objectif environnemental (certes non-optimal) permettant de limiter les principaux polluants atmosphériques et d'améliorer le bien-être collectif. Dans le cas du chan-

4. Le problème du changement climatique a engendré une littérature abondante visant à déterminer quel poids donner aux générations futures vis-à-vis des générations présentes. Ces discussions ont vu s'opposer deux approches : les partisans de l'approche « descriptive » qui défendent — par un argument d'arbitrage — l'idée que le taux d'escompte social doit être cohérent avec le taux d'intérêt observé sur les marchés financiers, et les défenseurs de l'approche « prescriptive » qui arguent que le taux d'escompte doit être fixé à partir de critères éthiques, en particulier en n'accordant aucune préférence *a priori* pour les générations présentes (*cf.* Gollier, 2013). La controverse entre Stern et Nordhaus (Stern, 2007; Nordhaus, 2007) à ce sujet illustre à la fois les divergences vis-à-vis des choix méthodologiques, et les implications de ces choix sur les recommandations en matière d'action climatique.

gement climatique, une idée similaire est celle du « budget carbone » : plutôt que de tenter de déterminer le coût social du carbone en se basant sur des modèles très incertains et peu informatifs (Pindyck, 2013), les modèles économiques peuvent prendre comme donnée une cible à atteindre (par exemple, un niveau de concentration dans l'atmosphère du CO_2 cohérent avec un réchauffement de +2°C) et déterminer les politiques permettant de satisfaire cette contrainte au moindre coût (Chakravorty et al., 2006). La préférence pour cette seconde approche par rapport à la stratégie pigouvienne dépend notamment de la sensibilité au risque environnemental, puisqu'elle induit généralement des efforts d'abattement plus élevés qu'à l'optimal, mais est cohérente avec un certain principe de précaution vis-à-vis des risques environnementaux qu'on ne peut parfaitement mesurer. [5]

Les effets indirects de la régulation

Le choix du niveau de pollution à cibler ne dépend pas uniquement de la valeur estimée de l'externalité. Afin de déterminer le niveau de pollution permettant de maximiser le bien-être social, on doit également prendre en compte les effets indirects de l'intervention publique, tel que son impact sur l'innovation, l'emploi, ou les inégalités. Ce deuxième aspect dépend du choix spécifique de l'instrument de régulation utilisé, et a donc suscité une importante littérature visant à comparer les mérites relatifs de différentes approches de la régulation environnementale.

Le choix des instruments de régulation

Les différents types d'instruments

Dans certaines situations, le niveau de pollution peut être réduit à un niveau cible efficace en l'absence de politique de contrôle. C'est le cas lorsque les institutions rendent possible la négociation entre le(s) pollueur(s) et le(s) pollué(s), en instituant des droits de propriété sur la pollution (Coase, 1960). Dans cette situation, les pollueurs et les pollués sont à même de s'accorder sur le niveau de pollution en échange de compensations, réparant ainsi la défaillance de marché. [6] Toutefois, pour la majorité des problèmes environnementaux, les pollueurs et les

5. Pour une présentation en français de ces deux approches et leurs implications pour le prix du carbone, voir Schubert (2008).

6. Ainsi, selon qui est le détenteur initial des droits, le pollueur peut payer le pollué pour que celui-ci accepte qu'il émette un certain niveau de pollution, ou le pollué peut payer le pollueur pour qu'il accepte de réduire celle-ci, jusqu'à un niveau « efficient ». L'allocation initiale des droits à l'un ou à l'autre de ces acteurs n'a en théorie pas d'implication sur l'efficacité de l'allocation qui en résulte, mais elle sera évidemment critique d'un point de vue redistributif.

pollués sont en trop grand nombre et/ou trop difficilement identifiables pour que la négociation soit possible. Les décideurs sont donc amenés à prendre des mesures spécifiques pour le contrôle de la pollution, afin d'atteindre les objectifs de réduction d'émission.

En dehors des mesures visant à faciliter la négociation, il existe deux grands types d'instruments de régulation de la pollution : les instruments réglementaires (*command-and-control*) et les instruments de marché (*market-based*) [7]. La première catégorie regroupe les instruments visant à réduire la pollution via des règles imposées sur les modes de production (ex : normes de consommation des véhicules), l'interdiction de certains produits (ex : interdiction de l'usage des chlorofluorocarbones, CFC), ou la réglementation de leur usage (ex : interdiction des véhicules polluants dans les centres villes). La seconde catégorie regroupe les instruments fournissant des incitations économiques à réduire la pollution, tels que les taxes (ex : la taxe carbone) et redevances (ex : pour la collecte des ordures ménagères), les subventions (ex : bonus écologique sur les véhicules moins polluants), ou les quotas d'émissions échangeables (ex : système communautaire d'échange de quotas d'émission). Alors que le premier groupe de mesure impose l'adoption d'un certain comportement, le second groupe vise à induire ce comportement en fournissant les incitations financières adéquates.

Les avantages relatifs de divers instruments

Lorsque le décideur choisit d'intervenir pour réduire la pollution, il peut adapter le niveau de contrainte de la réglementation ou l'importance des incitations économiques mises en place pour atteindre le niveau cible qu'il s'est fixé. Dans la mesure où plusieurs instruments permettent de satisfaire un même objectif environnemental (avec toutefois plus ou moins de précision), le choix des instruments à privilégier dépend essentiellement de l'ensemble de leurs autres coûts et bénéfices. Le double objectif des décideurs est donc de déterminer le ou les instruments permettant d'atteindre un objectif environnemental à moindre coût (objectif d'efficacité), en considérant également la manière dont les instruments conduisent à répartir ce coût entre les agents (objectif d'équité).

Une externalité dans un modèle stylisé

Dans un scénario simplifié dans lequel l'externalité environnementale constituerait la seule défaillance de marché de l'économie, les instruments incitatifs apportent la réponse la plus ef-

7. Pour une présentation exhaustive, voir par exemple Perman et al. (2011), chapitre 6.

ficace au problème causé par la pollution. En imposant un prix uniforme sur l'externalité, c'est-à-dire sur chaque unité de pollution émise, ces instruments incitent l'ensemble des acteurs à réduire leur pollution tant que cet effort leur « coûte » moins que le prix imposé. Si le prix d'une unité de polluant est de *x*€, les agents (ménages et entreprises) préféreront renoncer à leur pollution si elle leur rapporte un bénéfice inférieur à *x*€, mais poursuivront celle liée aux activités qui leur rapportent davantage. Cet égalisation des coûts marginaux d'abattement permet donc d'atteindre un objectif environnemental donné (qui pourra être plus ou moins ambitieux en fonction du niveau du prix) au moindre coût (ces instruments sont dits *cost-effective*) puisque les réductions d'émissions entreprises seront toutes celles — et uniquement celles — nécessitant un effort inférieur au prix de l'externalité (Baumol & Oates, 1971). Pour qu'il en soit de même des instruments réglementaires, il est nécessaire de fixer des normes spécifiques à chaque pollueur en fonction de ses coûts d'abattement. Lorsque les pollueurs sont nombreux et hétérogènes, et plus encore lorsqu'il existe des asymétries d'informations entre les pollueurs et le régulateur vis-à-vis de ces coûts, une telle politique n'est pas envisageable. Les coûts d'abattements de la pollution peuvent ainsi se révéler trop importants pour ceux ayant le plus de mal à changer leur comportement (e.g., une personne vivant à la campagne à qui l'on interdirait de conduire plus de 5000km par an), et trop faible pour les autres qui auraient pu réduire davantage leur pollution (e.g., une personne vivant dans une grande ville à qui l'on fixerait la même contrainte). D'un point de vue *dynamique*, l'égalisation des coûts marginaux d'abattement implique également une meilleure efficacité des instruments de marché via l'innovation. Alors que les instruments réglementaires imposent un cadre binaire (la technologie propre est adoptée ou non), les instruments de marché rendent en théorie profitable toute diminution des émissions, et donc incitent au développement de technologies toujours plus propres. [8]

Sur le plan redistributif, l'effet des instruments de marché tels que les taxes dépend de la manière dont la pollution est initialement répartie dans la population. Lorsque la pollution taxée est liée à la consommation d'énergie (comme c'est le cas pour la taxe carbone), les taxes sont en générales *régressives* car même si les ménages plus modestes consomment en moyenne moins d'énergie (et donc polluent moins), ces dépenses représentent une plus grande part de leurs ressources (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010). Toutefois, ces effets redistributifs peuvent en théorie être compensés au moyen de transferts forfaitaires. Si ces transferts

8. Du point de vue empirique, de nombreuses études soulignent la plus faible efficacité des instruments réglementaires vis-à-vis des instruments de marché lorsque ceux-ci opèrent dans les conditions idéales du modèle stylisé ici décrit. Tietenberg (2006) liste 14 études et montre que pour 12 d'entre elles, le recours aux instruments de marché conduirait à des coûts de 40% à 95% moins élevés qu'avec les instruments réglementaires.

ne sont pas conditionnés à des variables que les contribuables peuvent ajuster, ils n'induiront pas de changement dans les incitations à dépolluer. Ainsi, de nombreux travaux ont montré que lorsque le revenu d'une taxe carbone était redistribué uniformément à tous les ménages, la politique devenait *progressive* : le montant du transfert est en moyenne supérieur aux taxes payées par les ménages les plus modestes, et inférieur à celles payées par les plus aisés (e.g. West & Williams, 2004; Bento et al., 2009; Williams et al., 2015).

Multiples défaillances de marché

Le cadre stylisé précédent met en lumière les mécanismes puissants qui découlent des incitations économiques. Toutefois, ces arguments reposent sur un certain nombre d'hypothèses qui ne sont en pratique jamais complètement satisfaites. Lorsque d'autres défaillances de marché entrent en jeu, les avantages comparatifs des instruments incitatifs doivent être reconsidérés. Dans cette situation dite de *second-best*, « Une combinaison de politiques est susceptible d'être plus efficace et plus avantageuse sur le plan dynamique qu'une politique unique » (Stern & Stiglitz, 2017, traduit depuis l'anglais). Ainsi, des imperfections d'informations peuvent conduire à une mauvaise allocation des efforts d'abattements induits par une unique taxe. C'est notamment le cas lorsque la diffusion de technologies propres est ralentie par des frictions. Dans cette situation, les instruments réglementaires peuvent avoir l'avantage de produire de l'information vis-à-vis des meilleures technologies disponibles. Lorsque les changements de comportements visés par les instruments de marché nécessitent le développement de nouvelles infrastructures (par exemple, pour faciliter le développement du vélo ou de la voiture électrique), des investissements publics peuvent également se révéler des compléments utiles à la fiscalité environnementale. Aussi, lorsque les décisions des consommateurs ne sont pas déterminées par des raisonnements purement rationnels, d'autres instruments tels que les normes ou les labels peuvent se substituer ou compléter efficacement les instruments de marché. Enfin, comme le montre le premier chapitre de cette thèse, lorsque les effets redistributifs concernent un large nombre d'individus hétérogènes sur de multiples dimensions, les transferts forfaitaires constituent une solution imparfaite aux problèmes redistributifs puisque le gouvernement ne peut pas précisément cibler les ménages pour les compenser en fonction de leurs besoins. En l'absence de compensations adéquates, l'atténuation des effets redistributifs — en partie dus à des investissements passés qui ne peuvent être modifiés que par de nouveaux investissements coûteux — ne peut se faire qu'en facilitant la transition vers des modes de consommation moins polluants, par exemple via des aides à la conversion du capital polluant (e.g., véhicules, chaudières au fioul).

Les mérites relatifs des instruments dépendent donc du problème environnemental considéré, et des autres problèmes susceptibles d'entrer en interaction avec ces mesures. De manière générale, les instruments de marché peuvent être considérés nécessaires (bien que non-suffisants) face à des problèmes globaux aux sources diffuses tel que le changement climatique, tandis que les instruments réglementaires sont d'autant plus pertinents qu'il s'agit de lutter contre une pollution dont les sources sont spécifiques et connues. Aussi, plus l'objectif visé est ambitieux (c'est-à-dire proche des 100% d'abattement), plus l'écart d'efficacité entre les différentes approches est susceptible d'être faible (Goulder et al., 1999). En effet, l'interdiction de l'usage d'un polluant est équivalente à une taxe suffisamment élevée pour que plus personne n'en produise et consomme. Dans ces situations où les écarts d'efficacité sont faibles, d'autres critères sont également susceptibles d'être déterminants, tels que les coûts de mise en oeuvre et de gestion de la mesure en question (ex : le coût de surveillance du respect des normes, ou de collecte des taxes). Enfin, lorsque les mesures de régulation sont importantes, leurs effets sur l'économie sont susceptibles d'engendrer des changements dans le système économique au-delà du niveau de pollution. En régulant la pollution des entreprises, les politiques environnementales peuvent par exemple contraindre celles-ci à réduire leur activité, affectant ainsi l'emploi et les salaires. Sur ce point, il est une fois encore difficile de conclure de manière univoque sur les avantages de chaque instrument. Une importante littérature a toutefois mis en évidence l'intérêt des taxes dont le revenu peut être utilisé pour financer de nouvelles dépenses publiques — tels que des investissements verts ou des compensations aux contribuables les plus négativement impactés — ou au contraire pour baisser des taxes existantes (Tullock, 1967; Terkla, 1984). Ainsi, en permettant de remplacer des taxes sur des biens que la société souhaite favoriser (par exemple, l'emploi) par des taxes sur des biens dont elle souhaite diminuer la consommation (ici la pollution), les taxes environnementales permettent dans certains cas d'obtenir un « double-dividende », c'est-à-dire non seulement de réduire la pollution, mais aussi de favoriser l'économie (Pearce, 1991).[9] Cette stratégie visant à minimiser les coûts agrégés d'une

9. Lorsque les gains d'efficacité induits par les baisses d'anciennes taxes excèdent les pertes d'efficacité induites par ces nouvelles régulations, on parle d'un double-dividende *fort*, par opposition à un double-dividende *faible* lorsque les gains d'efficacité induits ne permettent pas de compenser les nouvelles distorsions créées (Goulder, 1995). Si la littérature confirme largement l'existence d'un double-dividende faible, les évidences sont plus mitigées quant à sa version forte, et dépendent fortement des inefficacités pré-existantes prises en compte (*cf.* Freire-González, 2018, pour une récente méta-analyse de la littérature empirique). Les modèles canoniques de Bovenberg & de Mooij (1994a,b) ont rejeté l'hypothèse d'un double-dividende fort en mettant en évidence l'importance des pertes d'efficacité dues à l'interaction entre les taxes environnementales et le reste du système fiscal. Des travaux ultérieurs

réforme environnementale n'est toutefois pas neutre sur le plan redistributif (Williams et al., 2015). Si plusieurs réformes de la fiscalité environnementale sont possibles, elles impliquent un important arbitrage entre la réduction des coûts agrégés et l'équité de leur répartition (Goulder & Parry, 2008).

Les politiques environnementales en pratique

Succès et échecs des politiques environnementales

Les précédentes sections donnent un aperçu du cadre de base fourni par l'analyse économique pour remédier aux problèmes environnementaux. L'application de ces théories a permis par le passé un certain nombre de succès dans la protection de l'environnement. Là où les produits polluants pouvaient le plus facilement être substitués par des alternatives plus propres, l'usage des normes s'est révélé efficace, comme l'illustrent les exemples de l'interdiction des CFC ou des carburants plombés. Les normes sont aussi fréquemment utilisées — parfois de pair avec des instruments de marché — pour le contrôle de la pollution de l'eau (Shortle & Horan, 2013) et de l'air (Kuklinska et al., 2015). Le recours aux instruments incitatifs est plus fréquent pour des problèmes plus diffus, ou lorsque les changements de comportements impliquent un coût important. Ainsi, avant leur interdiction complète, la mise en place de marchés de permis a conduit à réduire progressivement l'usage des CFC et des carburants plombés (Hammitt, 2000; Kerr & Newell, 2003). Ces politiques ont également fait leur preuve dans la gestion de certaines ressources naturelles comme les pêcheries (Hilborn et al., 2005), ou dans la régulation des polluants provenant de la consommation d'énergie. Les actions unilatérales de certains pays pour réduire leur consommation d'énergies fossiles via la taxation du CO_2 se sont par exemple révélées efficaces, comme l'attestent les exemples suédois (Andersson, 2019) et britannique (Leroutier, 2019; Abrell et al., 2019). En France, la hausse de la fiscalité portant sur le diesel a induit un changement important du parc automobile, tandis que la politique de bonus-malus écologique a accéléré la transition vers des véhicules moins émetteurs à un rythme supérieur à celui des projections initiales (d'Haultfoeuille et al., 2011).

Toutefois, pour de nombreux problèmes environnementaux majeurs, à commencer par le

ont nuancé ces résultats, en soulignant notamment le rôle des facteurs de production fixes (Bovenberg & van der Ploeg, 1996; Bento & Jacobsen, 2007) réduisant les nouvelles distorsions et impliquant de possibles effets positifs d'une réforme fiscale verte sur l'économie et l'emploi (pour une revue de la littérature théorique en français, voir Chiroleu-Assouline, 2001). Quoi qu'il en soit, quand bien même le recyclage du revenu des taxes ne permettrait pas de faire d'une réforme environnementale un *free lunch*, il constitue bel et bien un avantage comparatif des taxes vis-à-vis d'autres politiques environnementales ne générant pas de revenu.

changement climatique, les politiques mises en oeuvre demeurent très largement insatisfaisantes, car insuffisantes et souvent inappropriées. Alors que les économistes s'accordent sur la nécessité d'une taxe sur le carbone pour limiter le changement climatique, [10] en 2018 55% des émissions des pays de l'OCDE et du G20 n'étaient soumises à aucun prix (OCDE, 2018). Ainsi, même dans ces pays relativement développés les niveaux de régulation effectifs demeuraient très bas, largement en dessous des recommandations les plus conservatrices de la littérature. Au-delà de leur faible niveau, les politiques de lutte contre le changement climatique frappent également par leur diversité, parfois au prix de l'efficacité. Comme évoqué plus haut, dans un environnement *second-best* l'usage de multiples instruments est justifié à la fois pour des raisons d'efficacité et d'équité (Stern & Stiglitz, 2017; Stiglitz, 2019). Toutefois, le morcellement de politiques sectorielles aux nombreuses exemptions génère d'importants écarts de coûts d'abattement entre pays et entre secteurs, laissant place à des opportunités de réduction significatives des émissions ou de leur coût d'abattement. [11]

Une difficile coordination inter et intra-générationelle

Le problème du passager clandestin

A n'en pas douter, la principale explication à la faible ambition des politiques face aux menaces environnementales est à imputer à un manque de coordination entre les pollueurs et les pollués. Alors que chacun bénéficie de la baisse de pollution des autres, personne n'a intérêt à supporter lui-même les efforts de dépollution. Cette situation engendre donc un problème dit du « passager clandestin » (*free-rider problem*), où les individus ont un intérêt privé à ne pas contribuer à hauteur suffisante à un bien public. Dans le cas du changement climatique, ce problème est accentué par deux facteurs propres aux caractéristiques de ce problème environnemental : sa diffusion dans le temps et dans l'espace. Parce que chaque unité de GES émise à un endroit donné sur terre engendrera des conséquences sur l'ensemble du globe, et ce durant plusieurs siècles, la lutte contre ce polluant rend nécessaire la coopération de tous les citoyens, de tous les pays, sur toutes les générations. Ainsi, en l'absence d'un régulateur ayant autorité sur tous les citoyens du monde et représentant leur intérêt commun — *a fortiori* celui des géné-

10. Le récent appel de plus de 5000 économistes européens et américains à développer rapidement la fiscalité carbone illustre l'existence de recommandations claires adressées aux décideurs en matière de lutte contre le changement climatique.

11. Dans une récente étude, Parry (2020) estime les gains d'efficacité qui pourraient être obtenus en substituant l'actuel mixte d'instruments utilisé par les pays de l'Union Européenne pour réduire leurs émissions de CO_2 par des politiques de marché. Il conclut qu'une telle réforme permettrait, à résultat environnemental égal, de diviser à peu près par deux le coût de ces politiques.

rations futures — la coordination des efforts de lutte contre le changement climatique demeure extrêmement difficile.

Les contributions volontaires

Dans le cas de la lutte contre le changement climatique, les difficultés à coordonner l'action des États ont conduit les décideurs à abandonner au moins temporairement la recherche d'un accord commun fixant des mesures contraignantes (tel que l'accord de Tokyo en 1997), au profit de décisions décentralisées sous la forme de contributions volontaires (la forme adoptée à la COP 21 à Paris en 2015) (Harstad, 2020). En dépit des fortes incitations au *free-riding*, de nombreux pays se sont engagés à prendre des mesures ambitieuses pour le climat. A défaut d'un parfait altruisme de tous les acteurs, ces contributions volontaire sont nécessairement sous-optimales, et les annonces faites lors de l'accord de Paris demeurent insuffisantes pour satisfaire l'objectif annoncé de contenir le réchauffement climatique à un maximum de +2°C (Rogelj et al., 2016). Ces engagements laissent toutefois entrevoir la possibilité de développer des politiques environnementales et climatiques relativement ambitieuses, motivées par des ambitions aussi variées que la recherche de co-bénéfices économiques ou environnementaux, la volonté de prendre une avance technologique, un leadership diplomatique, ou encore l'altruisme ou un sentiment de devoir historique (Keohane & Victor, 2016). Ces promesses des États font également écho à une demande de la part des citoyens dans de nombreux pays, telle qu'illustrée par l'émergence de mouvements de défense du climat dans la société civile [12], ou encore par les propositions de politiques ambitieuses formulées par les citoyens Français lors de la Convention Citoyenne pour le Climat [13].

Un accord sur les fins, des désaccords sur les moyens

En dépit de ces volontés, l'agenda des politiques environnementales — et plus particulièrement des politiques climatiques — peine à avancer. Si une majorité de citoyens de nombreux pays apparaissent inquiets du changement climatique et se disent prêts à agir (*cf.* chapitre 3 de cette thèse), des désaccords sur les moyens persistent. Le mouvement des Gilets Jaunes qui

12. Parmi de multiples exemples, on peut citer le mouvement international de grèves étudiantes pour le climat *« Fridays for Future »*, ou encore les actions juridiques lancées par des citoyens contre l'inaction des États face au changement climatique, comme l'« Affaire du siècle » en France.

13. La Convention Citoyenne pour le Climat est une assemblée composée de 150 citoyens Français tirés au sort. A compté d'octobre 2019 et pendant plusieurs mois, ses membres ont participé à des conférences et débats avec pour objectif d'élaborer des propositions qui permettraient à la France de réduire « d'au moins 40% ses émissions de gaz à effet de serre d'ici 2030 (par rapport à 1990) dans un esprit de justice sociale ». Ses propositions ont été restituées au Président de la République le 29 juin 2020.

s'est fortement opposé au déploiement de la taxe carbone en France fin 2018 a illustré le fossé entre les projets de nombreux décideurs et les attentes des citoyens en matière de lutte contre le changement climatique. Ces oppositions qui ne sont par ailleurs pas spécifiques à la France (*cf.* Carattini et al., 2018) traduisent un certain scepticisme quant à la véritable efficacité des instruments économiques, ainsi qu'un désaccord profond sur la répartition de l'effort de décarbonation (documenté dans les chapitres 2 et 3), conduisant de nombreux citoyens à ne voir la taxe carbone que comme une taxe supplémentaire pesant sur leur pouvoir d'achat.

L'objet de cette thèse

L'objectif des recherches conduites dans le cadre de cette thèse est de mieux comprendre l'attitude des citoyens vis-à-vis des politiques environnementales. Les travaux présentés montrent à la fois que les citoyens se soucient de l'environnement et du climat et soutiennent la mise en place de politiques climatiques ambitieuses (chapitre 3), mais que pour autant ils s'opposent à la mise en place de la taxe carbone (chapitres 2 et 3). Afin de mieux comprendre les raisons de cette opposition, cette thèse explore à la fois des dimensions objectives, tels que les effets redistributifs de la fiscalité carbone (chapitre 1), mais également subjectives en considérant les perceptions qu'ont les citoyens de cette politique (chapitre 2). Le lien entre préférences — en particulier vis-à-vis du risque — et politiques environnementales y est également étudié sous un angle plus théorique, dans un modèle dans lequel l'économie fait face à des catastrophes environnementales récurrentes (chapitre 4).

Contributions

Le premier chapitre étudie les effets redistributifs associés aux dernières évolutions de la fiscalité énergétique (et en particulier de sa composante carbone) en France, c'est-à-dire les dernières augmentations avant l'émergence des protestations des Gilets Jaunes. Cette étude s'ajoute à une littérature bien établie sur les effets redistributifs des taxes sur l'énergie. Elle offre néanmoins une perspective inédite sur le sujet de deux manières. Premièrement, si la littérature s'est largement concentrée sur les effets redistributifs entre groupes de revenus (effets dits « verticaux »), ce chapitre montre que l'incidence de la fiscalité énergétique est plus hétérogène entre ménages de même revenu (effets « horizontaux »). Ce résultat fait écho aux préoccupations soulevées par les Gilets Jaunes à propos de l'impact disproportionné de la taxe carbone sur certaines catégories de ménages, tels que les ménages ruraux et péri-urbains, mais pas nécessairement l'ensemble des ménages modestes. Deuxièmement, le recours à la micro-simulation permet de simuler l'incidence de ces politiques fiscales à l'échelle des ménages, permettant une caractérisation précise de l'incidence fiscale selon de nombreuses dimensions. Sur la base de cette analyse, ce chapitre montre qu'il est beaucoup plus difficile de traiter les effets redistributifs horizontaux que verticaux, car l'hétérogénéité de l'incidence fiscale est mal expliquée par les caractéristiques observables des ménages (qu'elles soient géographiques ou socio-démographiques), et il est plus difficile pour l'État de cibler les compensations en fonction d'autres variables que leur revenu.

Le deuxième chapitre s'intéresse également à la fiscalité carbone en France, et plus particulièrement à la perception qu'en ont les ménages. Dans ce chapitre co-écrit avec Adrien Fabre, nous analysons ces perceptions, nous essayons de comprendre comment elles se forment, et comment elles se traduisent en termes de positionnement vis-à-vis de la taxe carbone. Pour ce faire, nous avons créé et administré un sondage auprès de 3002 personnes représentatives de la population française. Les personnes interrogées se sont vues présenter une politique de taxe avec dividende, c'est-à-dire une taxe carbone dont le revenu est transféré uniformément et entièrement à tous les ménages. Alors que cette politique est largement défendue par les économistes dans la perspective de concilier fiscalité carbone et justice sociale, nous montrons qu'elle est largement rejetée par les Français [14]. Ce rejet va de pair avec des perceptions pessimistes sur les effets de la politique : les Français surestiment son impact négatif sur leur propre pouvoir d'achat, la pensent régressive et inefficace pour réduire la pollution et lutter contre le changement climatique. Nous constatons également que le rejet est fortement corrélé au pessimisme, et montrons que la causalité entre rejet et pessimisme va dans les deux sens. Lorsque l'on fournit aux répondants de nouvelles informations sur la politique, ils tendent à rejeter les informations positives mais à traiter correctement les négatives. Ce phénomène est plus fort pour les personnes les plus opposées (y compris en contrôlant pour leur croyances initiales), en particulier pour les plus diplômées. Ce résultat suggère que les croyances pessimistes pourraient en partie être formées par un raisonnement motivé par lequel les répondants justifieraient leur opposition par les effets qu'ils imputent à la politique. D'autre part, la conception originale de notre enquête nous permet de montrer que les croyances déterminent de manière causale le soutien à la politique. Nous constatons que si les gens étaient convaincus des véritables attributs de la politique, celle-ci serait approuvée par une large majorité. Ce résultat confirme que le rejet d'une

14. La tribune signée par 3 354 économistes américains dans The Wall Street Journal défendait cette stratégie « Pour maximiser l'équité et la viabilité politique d'une taxe carbone croissante » (traduit depuis l'anglais).

taxe carbone avec dividende n'est pas motivé par les préférences intrinsèques des individus vis-à-vis des effets de cette mesure, mais plutôt par des croyances pessimistes auto-entretenues par leur rejet qui renforce leur défiance, augmentant davantage leur pessimisme, et ainsi de suite.

Le troisième chapitre de cette thèse s'appuie sur la même enquête que l'étude précédente. Bien que plus descriptif, ce travail apporte deux contributions utiles à la littérature. Tout d'abord, par l'analyse de questions plus ouvertes, il met en lumière ce qui a pu favoriser l'opposition initiale des Français à la fiscalité carbone, conduisant à l'excès de pessimisme décrit précédemment. Deuxièmement, il met en évidence le lien entre la connaissance et la perception qu'ont les citoyens du changement climatique et leur attitude à l'égard des politiques climatiques, en mettant plus particulièrement l'accent sur l'hétérogénéité des attitudes selon de nombreuses dimensions (socio-démographiques, politiques et territoriales). Cette étude offre donc un panorama assez complet de l'attitude des Français vis-à-vis des problèmes et des solutions au changement climatique, ainsi qu'un certain nombre de pistes pour une décarbonation soutenue par une majorité.

Le quatrième chapitre de cette thèse aborde également la question du lien entre préférences et politiques environnementales. Cette étude plus théorique développe un modèle de croissance endogène dans lequel l'économie est ponctuellement frappée par des catastrophes environnementales elles-mêmes endogènes. La particularité de l'étude vis-à-vis de la littérature qu'elle prolonge est de modéliser l'utilité des individus de manière plus flexible, via l'utilité non-espérée du type Epstein-Zin-Weil (EZW). Cet apport est pertinent pour l'étude des catastrophes environnementales, puisqu'une importante littérature en finance a montré que l'utilité EZW saisit mieux les préférences des individus vis-à-vis du risque. Le parti pris de cette étude est de proposer un modèle stylisé très parcimonieux qui puisse, malgré les complexités intégrées citées plus haut, être entièrement résolu avec des solutions de forme fermée. L'analyse des solutions du modèle montre que l'utilité EZW offre une caractérisation plus riche de la relation entre les catastrophes, la croissance et le bien-être social. La calibration du modèle sur des données des États-Unis montre également sa grande flexibilité. Cette calibration est utile non seulement parce qu'elle permet de quantifier les mécanismes trouvés analytiquement, mais aussi parce qu'elle met en évidence les limites des fonctions d'utilité traditionnelles dans l'étude des désastres tels que les catastrophes environnementales. Les résultats présentés dans ce chapitre suggèrent donc d'étendre l'usage des préférences récursives à la modélisation des désastres, en particulier les désastres environnementaux et le changement climatique.

Les trois premiers chapitres étant directement en lien avec l'actualité politique et le débat citoyen, il m'a semblé important d'exposer leurs conclusions de manière plus concise et moins technique que dans les articles correspondants. Une note de l'Institut des Politiques Publiques (IPP) présente les principaux résultats du premier chapitre (Douenne, 2018), et une note du Cepremap ceux des chapitres 2 et 3 (Douenne & Fabre, 2019a).

Approches méthodologiques

Les recherches conduites dans le cadre de cette thèse reflètent la variété des approches utilisées en sciences économiques. Elles s'appuient sur une large palette de méthodes empiriques et théoriques, permettant de mieux comprendre les croyances et préférences des individus, leurs attitudes vis-à-vis des politiques environnementales, ainsi que l'incidence de ces politiques sur leur budget et leur comportement.

Afin d'étudier les effets redistributifs de la fiscalité énergétique, le premier chapitre utilise le modèle de micro-simulation « TAXIPP » de l'IPP, alimenté par des enquêtes ménages de l'Insee. Le travail fourni dans le cadre de cette étude a permis de développer la partie « fiscalité indirecte » de TAXIPP, afin de simuler précisément l'impact de réformes de la fiscalité indirecte sur le budget des ménages. Ce module a par ailleurs servi pour d'autres travaux de l'IPP, tel que l'évaluation de l'effet de la loi de finances pour 2019 sur le budget des ménages (Ben Jelloul et al., 2019). Pour plus de réalisme, les simulations effectuées dans ce chapitre prennent en compte les réactions comportementales des ménages, c'est-à-dire le changement de leur consommation après l'augmentation des taxes. L'estimation de ces effets comportementaux à partir d'un modèle de demande appliqué aux enquêtes de l'Insee constitue ainsi une des contributions de cette étude [15]. Un important travail sur les données a également été nécessaire afin de pouvoir mesurer précisément les effets redistributifs de la fiscalité énergétique. Bien que l'enquête « Budget de Famille » présente de nombreux avantages pour étudier la consommation des ménages, les informations qu'elle contient conduisent à surestimer l'hétérogénéité de la consommation de carburants. Pour palier ce problème, un appariement statistique avec « l'Enquête Nationale Transports et Déplacements » a été réalisé. Cette nouvelle base appariée a ensuite également servi pour le deuxième chapitre de cette thèse — où elle permet de mesurer les effets objectifs de la politique proposée — ainsi que pour de nouvelles simulations de réformes de la fiscalité énergétique conduites pour le Conseil d'Analyse Économique (Bureau et al., 2019).

15. Le modèle utilisé est le « *Quadratic Almost Ideal Demand System* » (Banks et al., 1997).

Face au rejet massif de la fiscalité carbone exprimé par les Français en novembre 2018, il m'a semblé utile d'analyser non seulement les propriétés objectives de cette politique, mais aussi la perception que les citoyens en ont. Les deuxième et troisième chapitres de cette thèse emploient donc des méthodes et font appel à une littérature plus proche des sciences politiques et comportementales. La réalisation de ce projet a nécessité la création et diffusion d'un sondage sur un large échantillon représentatif de la population française. La conception originale de ce sondage dans lequel nous avons recours à divers traitements nous permet d'identifier des biais dans les croyances, de mettre en évidence certains mécanismes expliquant la formation de ces croyances erronées, et d'obtenir l'effet causal des croyances sur le soutien pour la politique étudiée. Ce dernier aspect repose sur l'estimation de régressions avec variables instrumentales, et de régressions sur discontinuités floues (*fuzzy regression discontinuity design*). Les traitements utilisés comme instruments dans ces régressions font eux-mêmes appel à des techniques originales, puisque outre des informations aléatoires et générales (sur la progressivité de la politique ou son efficacité environnementale) nous fournissions aux répondants des informations personnalisées, telle que l'information que leur ménage aurait 5 chances sur 6 de gagner/perdre en pouvoir d'achat suite à la politique proposée. Cette estimation personnalisée était elle-même réalisée à partir des caractéristiques des répondants, permettant de les comparer (via diverses méthodes telles que des régressions, un appariement statistique, ou un arbre de décision) aux ménages des enquêtes Insee.

Le quatrième chapitre est avant tout une contribution théorique. Ce chapitre s'inscrit dans la littérature du risque de catastrophes macroéconomiques majeures (*rare disasters*, voir par exemple Barro, 2006). La résolution du modèle de croissance proposé fait appel à la théorie de la commande optimale stochastique. La principale difficulté de cet exercice consistait à proposer un modèle suffisamment parcimonieux pour obtenir des solutions de forme fermée, mais suffisamment riche pour obtenir des intuitions originales vis-à-vis de la littérature existante. La partie empirique de ce chapitre présente une calibration du modèle à partir de données des États-Unis. Les paramètres utilisés sont choisis et discutés d'après la littérature, et plusieurs scénarios sont analysés afin de juger de la sensibilité des résultats au choix des paramètres.

Main introduction

The economic approach to the environment

Scientists have now brought compelling evidence of climate change and its link to human activity. In its Fifth Assessment Report, the United Nations Intergovernmental Panel on Climate Change (IPCC) confirms that « human influence on the climate system is clear and growing » and that « the more human activities disrupt the climate, the greater the risks of severe, pervasive and irreversible impacts for people and ecosystems » (IPCC).

Climate change is therefore—along with many other problems such as air pollution, natural resources depletion, or biodiversity loss—a consequence of human activity negatively impacting social welfare through environmental degradation. A particular feature of these problems is that they are the result of decisions by individuals (the polluters) who do not bear the full consequences of their actions. [16] For economists, these problems constitute « externalities » (Pigou, 1920), i.e. situations in which individuals produce by their actions external effects that affect the well-being of other individuals, without any counterpart. Externalities thus constitute a particular form of market failure, in the sense that in their presence economic *laissez-faire* leads to an inefficient allocation of resources, and in particular to excessively high levels of pollution.

Since the externalities result from a coordination problem between polluters and polluted parties that cannot be solved by giving free rein to the market, their existence justifies public intervention. The objective of environmental economists is to determine the exact nature of this intervention, in order to improving social welfare as much as possible. There are two main aspects to this objective : on the one hand, to determine targets for regulation — i.e. the levels of pollution that society must target in order to maximize its welfare — and on the other hand, to determine how to achieve them.

16. For example, passive smoking, exposure to particulate matters or noise pollution are all situations in which the victims of pollution (the polluted) do not have full control over the decision of the polluters.

Determining regulation targets

The choice of the pollution levels to be targeted is a tricky problem, as it involves comparing different types of costs and benefits. While the effects of pollution are harmful and therefore undesirable, the activities that cause it may themselves be beneficial. Thus, energy consumption induces various forms of pollution,[17] but it also allows us to heat and move around. The question that economists ask themselves when a regulatory policy is introduced is therefore what is the overall impact of this policy on social welfare. In the case of environmental policies, two elements must be taken into account : the gain in well-being associated with a given reduction in pollution, and the loss in well-being induced by the introduction of the new regulation.

The social cost of pollution

The first element is directly related to what is known as the social cost of pollution (SCP). In order to be able to compare the cost of pollution with other costs, it is translated into a monetary equivalent. This monetary equivalent is the maximum price that society is willing to pay to reduce pollution by a certain level. Thus, if the estimated SCP is x€ per unit of pollutant, then society should be willing to spend up to x€ to avoid the emission of an additional unit of that pollutant. In other words, a good costing 10€ to produce and creating pollution with an estimated social cost (SCP) of 5€ will cost society a total of 15€. Insofar as this additional cost of 5€ is not taken into account by the producer or consumer, this good will be produced and consumed in too large a quantity. In order to remedy this problem, the so-called « pigouvian » approach to externalities therefore consists in making the polluter pay this additional price directly—i.e. the monetary value of the externality—by, for example, introducing a tax of this amount.[18]

In practice, the Pigouvian approach can only be relevant if it is possible to estimate the SCP fairly accurately. This implies not only being able to identify all the consequences of the emission of an additional unit of a pollutant, but also to assign a monetary value to each of these consequences. As already noted in Baumol & Oates (1971), for most pollutants this exercise is similar to a « Herculean » task as the numbers of consequences and possible victims are so large

17. If the use of different energy sources obviously does not imply the same damage, no source is perfectly clean and the transformation of any primary energy into final energy necessarily induces one form or another of pollution.

18. In the previous example, the people affected by pollution should be prepared to pay together up to 5€ to avoid the production of this good. By transferring this cost to the polluter (producer or consumer), the polluter will *internalize*—i.e. take into account in his or her decision—the negative effect he or she produces on the polluted. This mechanism therefore makes it possible to remedy the market failure.

and difficult to observe. In the case of greenhouse gases (GHGs) responsible for climate change, as the impacts are both diffuse in time and space, most of the consequences are still unknown and/or non-measurable. By extrapolating from observed climatic or meteorological variations, studies have been able to highlight consequences as varied as the increase in damage linked to natural disasters (Hsiang et al., 2017), a negative impact on the growth and development of poor countries (Dell et al., 2012), an increase in armed conflicts (Burke et al., 2009), a negative effect on health and human capital (Graff Zivin et al., 2018), or an increase in mortality (Deschênes & Greenstone, 2011). No list, however, can be exhaustive, and as suggested by Weitzman (2009) and Pindyck (2013), the degree of ambition of climate policies should depend mainly not on the known consequences of the phenomenon, but on the possibility of major disasters that would largely alter our lifestyles. Moreover, even if all the consequences were known, calculating their monetary equivalent—supposedly to make trade-offs possible and guide political decision-making—is an additional difficulty, *a fortiori* when this makes it necessary to compare costs and benefits on a very long time scale. [19]

While stressing the practical limitations of the Pigouvian approach, Baumol & Oates (1971) suggest that the study of the main consequences of pollutants makes it possible to define pollution targets which, although not optimal, induce an increase in aggregate well-being. In particular, the authors take the example of the effect of air pollution on health, for which it is in some cases possible to obtain a first approximation of the damage, and thus to set an environmental target (admittedly non-optimal) that makes it possible to limit the main air pollutants and improve collective well-being. In the case of climate change, a similar idea is that of the « carbon budget » : rather than trying to determine the social cost of carbon based on very uncertain and uninformative models (Pindyck, 2013), economic models can take as a given a target to be reached (for example, a level of CO_2 concentration in the atmosphere consistent with a warming of +2°C) and determine the policies allowing to satisfy this constraint at the lowest cost (Chakravorty et al., 2006). The preference for this second approach over the Pigouvian strategy depends in particular on the sensitivity to environmental risk, since it generally induces higher than optimal abatement efforts, but is consistent with a certain precautionary principle

19. The problem of climate change has generated an abundant literature aimed at determining the weight to be given to future generations *vis-à-vis* present generations. These discussions have seen two opposing approaches : the proponents of the « descriptive approach » who defend—from an arbitrage argument—the idea that the social discount rate should be consistent with the interest rate observed in the financial markets, and the proponents of the « prescriptive approach » who argue that the discount rate should be set based on ethical criteria, in particular by not giving any preference *a priori* for present generations (*cf.* Gollier, 2013). The controversy between Stern and Nordhaus (Stern, 2007; Nordhaus, 2007) on this subject illustrates both the divergences with regard to methodological choices, and the implications of these choices on recommendations for climate action.

with regard to environmental risks that cannot be perfectly measured. [20].

The indirect effects of regulation

The choice of the level of pollution to be targeted does not only depend on the estimated value of the externality. In order to determine the level of pollution that maximizes social welfare, one must also take into account the indirect effects of public intervention, such as its impact on innovation, employment, or inequalities. This second aspect depends on the specific choice of the regulatory instrument used, and has thus given rise to a large body of literature comparing the relative merits of different approaches to environmental regulation.

The choice of regulatory instruments

The different types of instruments

In some situations, the level of pollution can be reduced to an efficient target level in the absence of a control policy. This is the case when institutions make it possible to negotiate between the polluter(s) and the polluted, by establishing property rights over the pollution (Coase, 1960). In this situation, the polluters and the polluted are able to agree on the level of pollution in exchange for compensation, thus repairing the market failure. [21] However, for the majority of environmental problems, the polluters and polluted are too numerous and/or too difficult to identify for negotiation to be possible. Decision-makers are therefore led to take specific measures for pollution control in order to achieve emission reduction targets.

Apart from measures to facilitate negotiation, there are two main types of pollution regulation instruments : regulatory « command-and-control » instruments and economic « market-based » instrument [22]. The first category includes instruments to reduce pollution through rules imposed on production methods (e.g. vehicle consumption standards), bans on certain products (e.g. banning the use of chlorofluorocarbons, CFCs), or regulation of their use (e.g. banning polluting vehicles in city centers). The second category includes instruments providing economic incentives to reduce pollution, such as taxes (e.g. carbon tax) and charges (e.g. for

20. For a presentation in French of these two approaches and their implications for the carbon price, see Schubert (2008).

21. Thus, depending on who is the initial holder of the rights, the polluter may pay the polluted to accept a certain level of pollution, or the polluted may pay the polluter to agree to reduce it, to a level that is « efficient ». The initial allocation of rights to one or the other of these actors has in theory no implication on the efficiency of the resulting allocation, but it will obviously be critical from a redistributive point of view.

22. For a comprehensive presentation, see for example Perman et al. (2011), Chapter 6.

household waste collection), subsidies (e.g. environmental bonus on less polluting vehicles), or tradable emission allowances (e.g. EU Emissions Trading Scheme). While the first group of measures imposes the adoption of a certain behavior, the second group aims to induce this behaviour by providing the appropriate incentives.

The relative merits of different instruments

When the decision-maker chooses to take action to reduce pollution, he or she can adjust the level of regulatory constraint or the size of the economic incentives put in place to achieve the target level he or she has set. To the extent that more than one instrument can be used to meet a single environmental objective (albeit with varying degrees of precision), the choice of instruments to be preferred depends critically on all their other costs and benefits. The dual objective of decision-makers is therefore to determine which instrument(s) can achieve an environmental objective at least cost (efficiency objective), also considering how the instruments lead to the distribution of this cost among agents (equity objective).

One externality in a stylized model

In a simplified scenario in which the environmental externality would be the only market failure in the economy, market-based instruments provide the most effective response to the problem caused by pollution. By imposing a uniform price on the externality, i.e. on each unit of pollution emitted, these instruments encourage all actors to reduce their pollution as long as this effort « costs » them less than the imposed price. If the price of a unit of pollutant is x€, the agents (households and companies) will prefer to give up their pollution if it brings them a profit of less than x€, but will continue with activities that bring them more profit. The equalization of the marginal costs of abatement therefore makes it possible to achieve a given environmental objective (which may be more or less ambitious depending on the level of the price) at the lowest cost (these instruments are called « cost-effective ») since the emission reductions undertaken will be all those—and only those—requiring an effort lower than the price of the externality (Baumol & Oates, 1971). For the same to be true of regulatory instruments, it is necessary to set specific standards for each polluter according to his or her abatement costs. When polluters are numerous and heterogeneous, and even more so when there are information asymmetries between polluters and the regulator regarding these costs, such a policy is not feasible. The costs of pollution abatement may thus be too high for those who have the greatest difficulty in changing their behavior (e.g. a person living in the countryside who would be prohibited from driving more than 5,000 km per year), and too low for others who could have reduced their pollution further (e.g. a person living in a large city who would be subject to the same constraint). From a *dynamic* point of view, equalising marginal abatement costs also implies a better efficiency of market instruments through innovation. While regulatory instruments impose a binary framework (whether clean technology is adopted or not), market instruments make in theory any reduction in emissions profitable, and thus provide incentives for the development of ever cleaner technologies. [23]

In redistributive terms, the effect of market instruments such as taxes depends on how pollution is initially distributed in the population. When the taxed pollution is related to energy consumption (as is the case with the carbon tax), taxes are generally *regressive* because even though poorer households on average consume less energy (and therefore pollute less), this expenditure represents a larger share of their resources (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010). However, these redistributive effects can in theory be compensated for by means of lump-sum transfers. If these transfers are not conditional on variables that taxpayers can adjust, they will not induce a change in the incentives to reduce emissions. Thus, numerous studies have shown that when the income from a carbon tax is redistributed uniformly to all households, the policy becomes *progressive* : the amount of the transfer is on average higher than the taxes paid by the most modest households, and lower than that paid by the most affluent (e.g. West & Williams, 2004; Bento et al., 2009; Williams et al., 2015).

Multiple market failures

The previous stylized framework highlights the powerful mechanisms that flow from economic incentives. However, these arguments are based on a number of assumptions that are in practice never fully satisfied. When other market failures come into play, the comparative advantages of market-based instruments need to be reconsidered. In this so-called *second-best* situation, « a combination of policies is likely to be more dynamically efficient and attractive than a single policy » (Stern & Stiglitz, 2017). Thus, imperfect information may lead to a misallocation of abatement efforts induced by a single tax. This is particularly the case when the diffusion of clean technologies is slowed down by frictions. In this situation, regulatory ins-

23. From an empirical point of view, many studies point to the lower effectiveness of regulatory instruments vis-à-vis market instruments when the latter operate under the ideal conditions of the stylized model described here. Tietenberg (2006) lists 14 studies and shows that, for 12 of them, the use of market instruments would lead to costs that are 40% to 95% lower than with regulatory instruments.

truments can have the advantage of producing information on the best available technologies. Where the changes in behavior targeted by market instruments require the development of new infrastructure (e.g. to facilitate the development of cycling or electric cars), public investment can also be a useful complement to environmental taxation. Also, where consumer decisions are not determined by purely rational reasoning, other instruments such as standards or labels can be effective substitutes for or complements to market instruments. Finally, as shown in the first chapter of this thesis, when redistributive effects concern a large number of individuals heterogeneous on multiple dimensions, lump-sum transfers offer only an imperfect response to redistributive problems since the government cannot precisely target households to compensate them according to their needs. In the absence of adequate compensation, the mitigation of redistributive effects—partly due to past investments that can only be changed by costly new investments—can only be achieved by facilitating the transition to less polluting consumption patterns, e.g. through support for the conversion of polluting capital (e.g., vehicles, oil-fired boilers).

The relative merits of the instruments therefore depend on the environmental problem under consideration, and other issues that may interact with these measures. In general, market-based instruments can be considered necessary (although not sufficient) in the face of global problems with diffuse sources such as climate change, while regulatory instruments are all the more relevant when dealing with pollution whose sources are specific and well-known. Also, the more ambitious the objective is (i.e. close to 100% abatement), the smaller the difference in effectiveness between the different approaches is likely to be (Goulder et al., 1999). Indeed, banning the use of a pollutant is equivalent to a tax high enough to ensure that no one produces and consumes it any more. In these situations where differences in efficiency are small, other criteria are also likely to be decisive, such as the costs of implementing and managing the measure in question (e.g. the cost of monitoring compliance with standards, or of collecting taxes). Finally, where regulatory measures are significant, their effects on the economy are likely to lead to changes in the economic system beyond the level of pollution. For example, by regulating the pollution of firms, environmental policies can force them to reduce their activity, thus affecting employment and wages. On this point, it is again difficult to conclude unequivocally on the benefits of each instrument. However, a substantial literature has highlighted the value of taxes whose revenue can be used to finance new public expenditure—such as green investments or compensation to the most negatively impacted taxpayers—or, on the contrary, to lower existing taxes (Tullock, 1967; Terkla, 1984). Thus, by making it possible to replace taxes on goods that society wishes to favour (for example, employment) by taxes on goods that it wishes to reduce (here pollution), environmental taxes make it possible in certain cases to obtain a « double dividend », i.e. not only to reduce pollution, but also to favor the economy (Pearce, 1991).[24] This strategy to minimize the aggregate costs of environmental reform is not, however, neutral from a redistributive point of view (Williams et al., 2015). While several environmental tax reforms are possible, they imply an important trade-off between reducing aggregate costs and ensuring their equitable distribution (Goulder & Parry, 2008).

Environmental policies in practice

Successes and failures of environmental policies

The preceding sections provide an overview of the basic framework provided by economic theory for addressing environmental issues. The application of these theories has in the past led to a number of successes in environmental protection. Where polluting products could most easily be substituted by cleaner alternatives, the use of standards has proved effective, as illustrated by the examples of the ban on CFCs or leaded fuels. Standards are also frequently used—sometimes in combination with market instruments—to control water pollution (Shortle & Horan, 2013) and air pollution (Kuklinska et al., 2015). The use of market-based instruments is more frequent for more diffuse problems, or when behavioral changes involve a significant cost. Thus, before their complete ban, the introduction of permit markets led to a gradual reduction in the use of CFCs and leaded fuels (Hammitt, 2000; Kerr & Newell, 2003). These policies have also proved their worth in the management of certain natural resources such as fisheries (Hilborn et al., 2005), or in the regulation of pollutants from energy consumption. Unilateral actions by some countries to reduce their consumption of fossil fuels through CO_2 taxation have,

24. When the efficiency gains induced by reductions in old taxes exceed the efficiency losses induced by these new regulations, we speak of a strong double-dividend, as opposed to a weak double-dividend when the induced efficiency gains do not compensate for the new distortions created. While the literature largely confirms the existence of a weak double-dividend, the evidence is more mixed as to its strong version, and depends heavily on the pre-existing inefficiencies taken into account (*cf.* Freire-González, 2018, for a recent meta-analysis of the empirical literature). The canonical models of Bovenberg & de Mooij (1994a,b) rejected the hypothesis of a strong double-dividend by highlighting the importance of efficiency losses due to the interaction between environmental taxes and the rest of the tax system. Subsequent work has qualified these results, highlighting in particular the role of fixed factors of production (Bovenberg & van der Ploeg, 1996; Bento & Jacobsen, 2007) reducing new distortions and implying possible positive effects of a green tax reform on the economy and employment (for a review of the theoretical literature in French, see Chiroleu-Assouline, 2001). In any case, even if recycling tax revenue would not make an environmental reform a *free lunch*, it does constitute a comparative advantage of taxes compared to other non-revenue generating environmental policies.

for example, proved effective, as shown by the Swedish example (Andersson, 2019) and the British example (Leroutier, 2019; Abrell et al., 2019). In France, the increase in taxation on diesel has induced a significant change in the car fleet, while the ecological *bonus-malus* policy has accelerated the transition to less emitting vehicles at a higher rate than the initial projections (d'Haultfoeuille et al., 2011).

However, for many major environmental problems, starting with climate change, the policies implemented remain largely unsatisfactory, as they are insufficient and often inappropriate. While economists agree on the need for a carbon tax to limit climate change,[25] in 2018 55% of the emissions of OECD and G20 countries were not subject to any price (OCDE, 2018). Thus, even in these relatively developed countries the effective levels of regulation remained very low, well below the most conservative recommendations in the literature. Beyond their low level, climate change policies are also striking in their diversity, sometimes at the price of effectiveness. As mentioned above, in a *second-best* environment, the use of multiple instruments is justified for both efficiency and equity reasons (Stern & Stiglitz, 2017; Stiglitz, 2019). However, the fragmentation of sectoral policies with numerous exemptions generates important differences in abatement costs between countries and between sectors, leaving room for significant opportunities to reduce emissions or their abatement costs.[26]

A difficult inter- and intra-generational coordination

The free-rider problem

Undoubtedly, the main explanation for the low ambition of policies in the face of environmental threats is to be attributed to a lack of coordination between polluters and polluted. While everyone benefits from the reduction of pollution by others, no one has an interest in supporting the clean-up efforts themselves. This situation thus creates a so-called « free-rider problem », where individuals have a private interest in not contributing enough to a public good. In the case of climate change, this problem is accentuated by two factors specific to the characteristics of this environmental problem : its diffusion in time and space. Because each unit of GHG emitted in a given place on earth will have consequences on the entire globe for several centuries,

25. The recent call by more than 5,000 European and Americans economists to rapidly develop carbon taxation illustrates the existence of clear recommendations addressed to decision-makers in the fight against climate change.

26. In a recent study, Parry (2020) estimates the efficiency gains that could be obtained by substituting the current mix of instruments used by European Union countries to reduce their CO_2 emissions with market policies. He concludes that such a reform would make it possible to halve the cost of these policies for the same environmental result.

the fight against this pollutant requires the cooperation of all citizens, all countries, all generations. Thus, in the absence of a regulator with authority over all the citizens of the world and representing their common interest—*a fortiori* that of future generations—the coordination of efforts to combat climate change remains extremely difficult.

Voluntary contributions

In the case of the fight against climate change, the difficulties in coordinating the action of States have led decision-makers to abandon at least temporarily the search for a common agreement setting out binding measures (such as the Tokyo agreement in 1997), in favor of decentralized decisions in the form of voluntary contributions (the form adopted at the COP 21 in Paris in 2015) (Harstad, 2020). Despite strong incentives for *free-riding*, many countries have committed themselves to ambitious climate action. In the absence of perfect altruism on the part of all actors, these voluntary contributions are necessarily sub-optimal, and the pledges made at the time of the Paris agreement remain insufficient to meet the announced objective of containing global warming to a maximum of +2°C (Rogelj et al., 2016). These commitments, however, suggest the possibility of developing relatively ambitious environmental and climate policies, motivated by ambitions as varied as the search for economic or environmental co-benefits, the desire to gain a technological lead, diplomatic leadership, altruism or a sense of historical duty (Keohane & Victor, 2016). These promises of the States also echo demand from citizens in many countries, as illustrated by the emergence of climate movements in civil society,[27] or the ambitious policy proposals made by French citizens at the Citizen's Convention for the Climate[28].

Agreement on ends, disagreement on means

In spite of these wishes, the environmental policy agenda—and more particularly climate policy—is struggling to move forward. While a majority of citizens in many countries appear concerned about climate change and say they are ready to act (*cf.* chapter 3 of this thesis), disagreements over the means persist. The Yellow Vest movement, which strongly opposed the deployment of a carbon tax in France at the end of 2018, illustrated the gap between the plans

27. Examples include the international student climate strike movement « *Fridays for Future* », or legal actions by citizens against States inaction on climate change, such as « L'affaire du siècle » in France

28. The Citizen's Convention for the Climate is an assembly composed of 150 French citizens drawn by lot. Starting in October 2019 and lasting several months, its members took part in conferences and debates with the aim of drawing up proposals that would enable France to reduce its greenhouse gas emissions by at least 40% by 2030 (compared to 1990 levels) in a spirit of social justice. Its proposals were submitted to the President of the Republic on June 29, 2020.

of many decision-makers and the expectations of citizens in the fight against climate change. These oppositions, which are not specific to France (*cf.* Carattini et al., 2018), reflect a certain skepticism as to the true effectiveness of economic instruments, as well as a deep disagreement on the distribution of the decarbonation effort (documented in Chapters 2 and 3), leading many citizens to see the carbon tax only as an additional tax reducing their purchasing power.

The subject of this thesis

The objective of the research conducted in this thesis is to better understand citizens' attitudes towards environmental policies. The work presented shows that citizens care about the environment and the climate and support the implementation of ambitious climate policies (chapter 3), but that they are opposed to the implementation of carbon taxation (chapters 2 and 3). In order to better understand the reasons for this opposition, this thesis explores both objective dimensions, such as the redistributive effects of carbon taxation (chapter 1), and subjective dimensions by considering the perceptions that citizens have of this policy (chapter 2). The link between preferences —particularly with regard to risk— and environmental policies is also studied from a more theoretical perspective, in a model in which the economy faces rare environmental disasters (chapter 4).

Contributions

The first chapter examines the redistributive effects associated with the latest changes in energy taxation (and in particular its carbon component) in France, i.e. the last increases before the emergence of the Yellow Vests protests. This study adds to a well-established literature on the redistributive effects of energy taxes, but it offers a novel perspective on the subject in two ways. First, while the literature has largely focused on the redistributive effects between income groups (so-called « vertical effects »), this chapter shows that the incidence of energy taxation is more heterogeneous between households with the same income (« horizontal effects »). This result echoes the concerns raised by the Yellow Vests about the disproportionate impact of the carbon tax on certain categories of households, such as rural and peri-urban households, but not necessarily all low-income households. Second, the use of micro-simulation allows me to simulate the impact of energy taxes at the household level, allowing accurate characterization of the tax impact along many dimensions. On the basis of this analysis, this chapter shows that it is much more difficult to deal with horizontal redistributive effects than vertical ones, because the heterogeneity of the tax incidence is poorly explained by observable household characteristics (whether geographical or socio-demographic), and it is more difficult for the government to target compensation on the basis of variables other than income.

The second chapter also looks at carbon taxation in France, and more specifically at how households perceive it. In this chapter, co-authored with Adrien Fabre, we analyse these perceptions, try to understand how they are formed, and how they translate in terms of positioning vis-à-vis the carbon tax. To do so, we created and administered a survey of 3,002 people representative of the French population. The respondents were presented with a carbon tax and dividend policy, i.e. a carbon tax whose income is transferred uniformly and entirely to all households. While this policy is widely defended by economists with a view to reconciling carbon taxation and social justice, we show that it is largely rejected by the French people. [29] This rejection goes hand in hand with pessimistic perceptions about the effects of the policy : the French overestimate its negative impact on their own purchasing power, think it is regressive and ineffective in reducing pollution and fighting climate change. We also find that rejection is strongly correlated with pessimism, and show that the causality between rejection and pessimism goes in both directions. When respondents are provided with new information about the policy, they tend to reject the positive information but to deal correctly with the negative. This phenomenon is stronger for those who are more opposed (including controlling for their initial beliefs), especially for those with higher education. This finding suggests that pessimistic beliefs may be formed in part by a motivated reasoning in which respondents justify their opposition by the effects they attribute to the policy. On the other hand, the original design of our survey allows us to show that beliefs causally determine support for the policy. We find that if people were convinced of the true attributes of the policy, the policy would be endorsed by a large majority. This result confirms that the rejection of a carbon tax and dividend is not motivated by people's intrinsic preferences regarding the effects of the measure, but rather by self-sustaining pessimistic beliefs that reinforce their mistrust, further increasing their pessimism, and so on.

The third chapter of this thesis is based on the same survey as the previous study. Although more descriptive, this work makes two useful contributions to the literature. First, through the analysis of more open questions, it highlights what may have fostered the initial opposition of the French to carbon taxation, leading to the excessive pessimism described above. Second, it highlights the link between citizens' knowledge and perception of climate change and their at-

29. The call signed by 3,354 American economists in The Wall Street Journal defended this strategy « To maximize the fairness and political viability of a growing carbon tax ».

titudes towards climate policies, with a particular emphasis on the heterogeneity of attitudes along many dimensions (socio-demographic, political and territorial). This study therefore offers a fairly comprehensive overview of French attitudes towards the problems and solutions to climate change, as well as a number of avenues for decarbonation supported by a majority.

The fourth chapter of this thesis also addresses the issue of the link between environmental preferences and policies. This more theoretical study develops an endogenous growth model in which the economy is punctually hit by environmental disasters that are themselves endogenous. The particularity of the study with respect to the literature it extends is to model the utility of individuals in a more flexible way, via the unexpected utility of the Epstein-Zin-Weil (EZW) type. This contribution is relevant for the study of environmental disasters, since a large literature in finance has shown that EZW utility better captures individuals' risk preferences. The aim of this study is to propose a very parsimonious stylized model which, despite the integrated complexities mentioned above, can be fully resolved with closed form solutions. Analysis of the model's solutions shows that the EZW utility offers a richer characterization of the relationship between disasters, growth, and welfare. Calibration of the model on U.S. data also shows its great flexibility. This calibration is useful not only because it quantifies the mechanisms found analytically, but also because it highlights the limitations of traditional utility functions in the study of disasters such as environmental disasters. The results presented in this chapter therefore suggest extending the use of recursive preferences to the modeling of disasters, particularly environmental disasters and climate change.

As the first three chapters are directly related to current political events and citizen debate, I felt it was important to present their conclusions in a more concise and less technical manner than in the corresponding articles. A note of the Institute of Public Policies (IPP) presents the main findings of the first chapter (Douenne, 2018), and a Cepremap note those of chapters 2 and 3 (Douenne & Fabre, 2019a).

Methodological approaches

The research conducted for this thesis reflects the variety of approaches used in economics. It draws on a wide range of empirical and theoretical methods to better understand people's beliefs and preferences, their attitudes towards environmental policies, and the impact of these policies on their budgets and behaviour.

In order to study the redistributive effects of energy taxation, the first chapter uses the micro-simulation model TAXIPP » of the IPP, fed by INSEE household surveys. The work carried out in this study has made it possible to develop the « indirect taxation » part of TAXIPP, in order to simulate precisely the impact of indirect tax reforms on household budgets. This module was also used for other IPP work, such as the evaluation of the effect of the 2019 Finance Act on the household budget (Ben Jelloul et al., 2019). For greater realism, the simulations carried out in this chapter take into account the behavioural reactions of households, i.e. the change in their consumption after the tax increase. The estimation of these behavioural effects from a demand model applied to INSEE surveys is thus one of the contributions of this study. [30] Extensive data work has also been necessary in order to be able to accurately measure the redistributive effects of energy taxation. Although the survey « Family Budget » has many advantages for studying household consumption, the information it contains leads to overestimating the heterogeneity of fuel consumption. To overcome this problem, a statistical matching with « The National Transport and Travel Survey » has been carried out. This new matched base was then also used for the second chapter of this thesis — where it allows to measure the objective effects of the proposed policy — as well as for new simulations of energy tax reforms conducted by the Conseil d'Analyse Économique (Bureau et al., 2019).

Faced with the massive rejection of the carbon tax expressed by the French in November 2018, it seemed useful to me to analyse not only the objective properties of this policy, but also the perception that citizens have of it. The second and third chapters of this thesis therefore employ methods and draw on literature closer to political and behavioural sciences. The realization of this project required the creation and dissemination of a survey on a large representative sample of the French population. The original design of this survey, in which we use various treatments, allows us to identify biases in beliefs, to highlight certain mechanisms explaining the formation of these erroneous beliefs, and to obtain the causal effect of the beliefs on support for the policy under study. This last aspect is based on the estimation of regressions with instrumental variables, and regressions on fuzzy discontinuities (*fuzzy regression discontinuity design*). The treatments used as instruments in these regressions themselves make use of original techniques, since in addition to random and general information (on the progressiveness of the policy or its environmental effectiveness) we provided respondents with personalised information, such as the information that their household would have a 5 out of 6 chance of gaining/losing purchasing power as a result of the proposed policy. This personalised estimate

30. The model used is the « *Quadratic Almost Ideal Demand System* » (Banks et al., 1997).

was itself based on the characteristics of the respondents, allowing them to be compared (via various methods such as regressions, statistical matching, or a decision tree) to households in INSEE surveys.

The fourth chapter is primarily a theoretical contribution. This chapter is in line with the literature on the risk of major macroeconomic disasters (*rare disasters*, see for example Barro, 2006). The resolution of the proposed growth model is based on stochastic optimal control theory. The main difficulty of this exercise was to propose a model parsimonious enough to obtain closed-form solutions, but rich enough to obtain original intuitions with respect to the existing literature. The empirical part of this chapter presents a calibration of the model using data from the United States. The parameters used are selected and discussed based on the literature, and several scenarios are analyzed to judge the sensitivity of the results to the choice of parameters.

Chapitre 1

The Vertical and Horizontal Distributive Effects of Energy Taxes : A Case Study of a French Policy [1]

1. Acknowledgments : I want to thank Fanny Henriet and Katheline Schubert for their precious comments. I am also very grateful to Mahdi Ben Jelloul, Antoine Bozio, Stéphane Gauthier, participants at several seminars and conferences, as well as anonymous referees and an editor of *The Energy Journal*.

Abstract :

This chapter proposes a micro-simulation assessment of the distributional impacts of the French carbon tax. It shows that the policy is regressive, but could be made progressive by redistributing the revenue through flat-recycling. However, it would still generate large horizontal distributive effects and harm a significant share of low-income households. The determinants of the tax incidence are characterized precisely, and alternative targeted transfers are simulated on this basis. The chapter shows that given the importance of unobserved heterogeneity in the determinants of energy consumption, horizontal distributive effects are much more difficult to tackle than vertical ones.

1.1 Introduction

It is paradoxical that while environmental taxes are considered by economists as one of the most efficient instruments to deal with environmental problems, public support for carbon pricing remains low, as showcased by the recent protests against the carbon tax rise in France. Initiated in 2014 at 7€/tCO_2, the French carbon tax was planned to gradually increase in order to reach 86.2€/tCO_2 in 2022, and even higher levels in a near future. In November 2018, in a context of high oil prices, the protests of the Yellow Vests against the tax led to the abandonment of the increases initially scheduled. Since, the tax has remained at its 2018 level, 44.6€/tCO_2. Similarly, the additional increases initially planned for the diesel tax have been abandoned. As of today, the future of the French carbon tax remains deeply uncertain. The negative impact of the tax on households' purchasing power was certainly what contributed the most to public discontent. In particular, Yellow Vests appeared concerned with the disproportionate burden that taxes on energies could impose on low income households, and more specifically on those most dependent on fossil fuels such as rural and peri-urban households.

The objective of this chapter is to precisely characterize and quantify the distributive effects of French energy taxes. The chapter focuses on the monetary distributive effects. Although the heterogeneity in behavioral responses to prices is also studied and discussed, a comprehensive assessment of welfare effects would require strong assumptions over the distribution of environmental valuation across agents. Based on TAXIPP, a micro-simulation model of taxation for French households (see Appendix 1.B for a description of the model), I evaluate French fiscal policy on energies between 2016 and 2018, i.e. the last evolution before the emergence of the protests. The policy essentially involved an increase in the carbon price on all energies except electricity — which was already subject to the European Union Emissions Trading Scheme. While numerous studies have already assessed the *vertical* distributive effects of energy taxes — i.e. distributive effects between households along the income dimension — this chapter contributes to the literature by investigating their *horizontal* distributive effects — i.e. between households with similar incomes. In particular, it shows that while low-income households may on average financially gain from an environmental tax after revenue-recycling, some of them could suffer large losses. This result echoes concerns raised by the Yellow Vests that carbon taxation may have a disproportionate impact on certain categories of households, such as rural and peri-urban households, but not necessarily all poor people. Understanding and quantifying these phenomena is key to a better design for these policies, and thus to improve both the fairness and support for ambitious environmental policies.

Several papers have investigated the distributive effects of energy taxes in France (e.g. Ruiz & Trannoy, 2008; Bureau, 2011; Berry, 2019). Yet, partly due to the lack of a comprehensive database, few works have jointly covered housing and transport, and existing studies all focus on vertical equity. To investigate these issues together, I created a novel dataset by matching the French transport survey (ENTD) and the consumer expenditures survey ("Budget de Famille", BdF). Using this new dataset, I micro-simulate fiscal policy on energies between 2016 and 2018. Given the relatively small scale of the tax, the use of micro-simulation is relevant as general equilibrium effects should play a limited role. As argued by Bourguignon & Spadaro (2006), these models are the best fit for a precise investigation of the distributive effects of policy changes, as they fully take into account households' heterogeneity. The model accounts for behavioral responses through heterogeneous price and income elasticities estimated using a *Quadratic almost ideal demand system* (QUAIDS, see Banks et al., 1997). I find that the median household reacts significantly to transport fuel prices with an uncompensated price elasticity around -0.45, and to a lesser extent to housing energy prices with an elasticity of -0.2. I also find that reactions are expected to be stronger for lower-income and less urban households.

Elasticities are then translated into changes in quantities and greenhouse gas emissions. For a given technology, the short-run response to prices appears to have a limited impact on aggregate emissions. With respect to monetary effects, I compute effort rates and analyze how the tax burden is spread across income groups, before and after revenue recycling. The results confirm the findings of the literature, whereby energy taxes are regressive when effort rates are computed as a function of disposable income (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010), but are almost not when total expenditures are instead used to measure standards of living (see Poterba, 1989; Metcalf, 1999; Flues & Thomas, 2015). Also, I find that the compensation mechanism proposed by the government and targeted towards low-income households does not solve regressivity. However, recycling the revenue left after this mechanism through homogeneous lump-sum transfers — a mechanism known as flat-recycling (e.g. West & Williams, 2004; Bento et al., 2009; Bureau, 2011; Williams et al., 2015) — would make the policy progressive.

From the above conclusions, it might seem straightforward to improve the acceptability of energy taxes. However, in the recent literature authors have emphasized the importance of the horizontal distributive effects of these taxes, which could be a major deterrent against their implementation (Rausch et al., 2011; Pizer & Sexton, 2019; Cronin et al., 2019; Sallee, 2019). In this chapter, I analyze the distribution of monetary gains and losses within income groups. In particular, I show that after flat-recycling, over a third of low-income households are expected to financially lose out due to the policy. Additionally, 25% of households in the bottom income decile are expected to lose more than the median household in the top income decile. This result confirms that monetary distributive effects are expected to be much larger in magnitude within income groups than across income groups, and could dampen the policy's acceptability.

Important progress has recently been made by general equilibrium models to incorporate more heterogeneity in households' characteristics (e.g. Rausch et al., 2011; Rausch & Schwarz, 2016). Yet, it is still unclear what the drivers are of the heterogeneous incidence of energy taxes (Pizer & Sexton, 2019). The literature has mostly focused on geographical criteria, looking at the differentiated impact across regions, and has emphasized the role of income composition. Thanks to micro-simulation, I adopt a more agnostic approach to characterize the determinants of the tax incidence at the household level. I show that — among many drivers — the energy used and to a lesser extent the urban density of the household residence account for a significant share of horizontal distributive effects, but even taking into account many determinants unexplained heterogeneity remains large. I illustrate this point by testing alternative scenarios for revenue-recycling using targeted transfers based on these characteristics. I find that, in addition to the bad incentives they provide, these transfers are ineffective to reduce horizontal distributive effects : indexing compensations on the urban density has no effect, while indexing them on the type of energy used for heating only slightly softens horizontal equity issues.

This chapter contributes to several strands of the literature. First, it uses statistical matching to build the most comprehensive existing database to study energy taxation in France. Using these data, it also offers an extensive evaluation of the most recent environmental fiscal policy. Second, this chapter adds new evidence on the incidence of energy taxes with respect to both vertical and horizontal heterogeneity. In particular, it sheds new light on the importance of the latter and its implications for the acceptability of environmental taxes. It also goes further than previous studies by using micro-simulation to identify the determinants of this heterogeneity at a more precise level. Given the urgent need to implement ambitious environmental policies and in particular carbon pricing, it is crucial to better understand the concerns associated with these instruments. Only then will we be able to bring effective solutions to improve their acceptability.

The chapter is organized as follows. Section 2 presents the data, and section 3 the estimation of households' elasticities with respect to their energy consumption. Section 4 evaluates the expected environmental effects of the policy and distributive effects between income groups. Section 5 discusses distributive effects within income groups and highlights the determinants of the tax incidence in order to propose alternative revenue-recycling mechanisms. Section 6 concludes. Technical elements are reported in the appendix, and an online appendix adds supplementary material to describe the matching of household surveys.

1.2 Data

1.2.1 The French household surveys

A comprehensive study of the incidence of energy taxes on households must include both housing and transport energies. In France, energy consumption from the transport and residential sectors represents respectively 27% and 12% of total emissions. Yet, most studies on French data have ignored one of these sectors. Bureau (2011) studies the distributional impacts of a carbon tax followed by lump-sum transfers, but focuses on transport fuels only. Using "Budget de Famille" (BdF) survey data, Nichèle & Robin (1995) cover both issues but they do not estimate elasticities specifically for energies, nor do they precisely detail the distributive effects of the tax. Closer to the present work, Berry (2019) investigates a previous increase in the carbon price on energies using the "Phebus" database. However, the smaller sample size and the limited quantity of information in this survey do not enable further exploration of the determinants of horizontal distributive effects.

In this chapter, I use the latest version of the "Budget de Famille" (BdF, 2011) consumer survey. Because of its very large set of variables describing households, and because it gathers accurate information on all their expenditures,[2] BdF is the best database to study indirect taxation, and in particular energy taxes. It is also the only database through which a demand system can be estimated for French households. Consumption of housing energies is taken from households' bills, and for most other goods they answer questionnaires to report their expenditures. To avoid seasonality effects, several waves of surveys are carried out all year long. For the computation of the demand system, households are matched with monthly price indices from Insee (the French national statistical institute). More details on the data and the imputation of price indices are given in the model estimation appendix (section 1.C).

2. The survey covers the consumption of all goods following the international nomenclature COICOP.

1.2.2 Data to simulate the policy

Although very convenient to estimate a demand system, BdF presents one limitation when studying horizontal distributive effects. As transport fuel consumption is reported over a short period of time, the heterogeneity in consumption between households is over-estimated. This excessive variability disappears when average expenditures for household groups are studied, but is problematic when the distribution *within these groups* is addressed. To overcome this problem, I therefore use statistical matching to match each household in BdF to a household from the last transport survey, "Enquête Nationale Transports et Déplacement", (ENTD) [3] where annual distances travelled are reported. This enables me to recover the distribution of expenditures without over-estimating its dispersion. A high-quality matching is possible because BdF and ENTD are both quite large, both come from the French statistical institute (Insee), both study the same population, and they share a large number of common variables with identical definitions. More details on the matching procedure can be found in Appendix 1.E. [4] The final dataset contains 10,342 observations. [5] Because the last BdF was conducted in 2011, I use national accounts to homogeneously inflate households' energy expenditures and incomes in order to make the data representative of 2016, the date from which the policy changes are studied. Table 1.A.1 in the appendix gives descriptive statistics for several variables and ten household groups corresponding to income deciles, and figures 1.A.1, 1.A.2, and 1.A.3 provide information over the distribution of energy expenditures for different household groups. [6]

1.3 Estimating households' responses to prices

1.3.1 The Quadratic almost ideal demand system

In order not to over-estimate the tax burden and the extent of regressivity of indirect taxation policies, one needs to take into account behavioral responses, that is, the effect of taxes on consumption choices (see West & Williams, 2004). I therefore estimate price and income elasticities on energy goods. These estimates will then be used to compute the reduction in

3. This survey was conducted in 2008 on 20,178 households.

4. Matching is performed using the non-parametric NND hotdeck method. The procedure applied closely follows standard guidelines as can be found in two recent Eurostat reports (2013 and 2017) and in a series of contributions by D'Orazio and coauthors (2006 and 2014).

5. Households from overseas departments and territories (DOM-TOM) are excluded since indirect taxes are set differently.

6. The income deciles used throughout the chapter are constructed on the basis of disposable income per consumption unit. Consumption units follow the equivalence scale of the OECD, i.e. it is equal to 1 for the first adult in the household, plus 0.5 for each other person aged 14 years or older, and 0.3 for each person under 14 years old.

consumption following the policy.

Since all household expenditures are reported in the BdF survey, this dataset can be used to evaluate elasticities through a demand system. The advantage over reduced-form equations is that demand systems build on an underlying model of household consumption behavior across all goods, which also serves to estimate a system of joint equations instead of separate regressions. I estimate the *Quadratic Almost Ideal Demand System* (QUAIDS) introduced by Banks et al. (1997). This model extends the *Almost Ideal Demand System* (AIDS) proposed by Deaton & Muellbauer (1980b) by allowing for non-linear Engel curves. It is preferred to other demand systems because it gathers many of their respective properties without making strong assumptions on preferences which could create a specification bias in the estimation. The QUAIDS considers the consumption by individuals of k different categories of goods and the share in their total expenditures they each represent. The full model — and the procedure used for its estimation — is presented in appendix 1.C, and leads to an estimation of the following equations :

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left\{ \frac{m}{a(\mathbf{p})} \right\} + \frac{\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2, \quad i = 1, \dots, k \tag{1.1}$$

where i and j represent bundles of goods and w_i the share of bundle i in total expenditures m, p_i its price index, and $a(\mathbf{p})$ and $b(\mathbf{p})$ two distinct price aggregators. These equations can be generalized to account for heterogeneity in preferences through the inclusion of demographic variables. I estimate the model on three categories of goods (i.e. $k = 3$). The first is transport fuels which include diesel and gasoline. The second group gathers housing energies, including electricity, natural gas and domestic fuel.[7] The third group is the remainder of non-durable products. Given that the survey is cross-sectional and expenditures are reported over a short period, the data do not enable the inclusion of durable products in a meaningful way. As a result, I cannot account for the effect of energy prices on the purchase of newer vehicles or cleaner heating technologies. The effect of the tax on labor supply is also ignored as it would require more information than available in the data to precisely estimate the cross-price elasticity of energy and leisure, as done in West & Williams (2004).[8] The elasticities should therefore be understood as short-run responses to price variations.

7. Wood and coal are marginal in French household energy consumption.

8. Using the U.S. Consumer Expenditure Survey, West & Williams (2004) estimate cross-price elasticities from an Almost Ideal Demand System. For one-adult households and females within two-adult households, they do not find significant effects of gasoline prices on labor supply. For males within two-adult households, they find a positive and statistically significant cross-price elasticity, but the magnitude (0.013) remains very small.

1.3.2 Results

Table 1.C.1 in appendix 1.C reports income and uncompensated price elasticities for four specifications, with the 95% confidence intervals for these estimates. Specifications (1) and (2) use Stone-Lewbel (SL) price indices (see appendix) that can be used to obtain household-specific prices. Specifications (1) and (3) use an IV for total expenditures that would otherwise be endogenous in equation 1.1 (see appendix). The results appear similar in all four specifications, although the confidence intervals are larger without SL price indices.

I find budget elasticities around 0.5 for both transport and housing energies and close to 1 for other non-durable products. Uncompensated price elasticities are around -0.45 for transport fuels, -0.2 for housing energies, and -1.0 for the remainder of non-durable goods, while uncompensated cross-price elasticities between energies are not significantly different from zero. These results are in accordance with common estimates in the literature. [9] On French data, Combet et al. (2009) found transport and housing energy elasticities of respectively -0.5 and -0.11 on time series data. Using BdF 2006, Clerc & Marcus (2009) found a higher elasticity of -0.7 for transport fuels, but did not find any reliable results for housing energies. On panel data, Bureau (2011) finds a more conservative estimate of a short-term elasticity of -0.22 for transport fuels. From BdF 2001, Ruiz & Trannoy (2008) found uncompensated price elasticities of -0.55 and -0.38 for transport and housing expenditures, although they did not focus on energy only. Finally, on BdF 2011 and through the computation of Engel curves, Berry (2019) found -0.19 for transport and -0.36 for housing energies. I believe the data and techniques employed in the present work offer accurate results. They bring new evidence that households react to energy prices in the short run, although the adjustment in consumption is somewhat limited for housing energies.

To examine the heterogeneity in responses to taxes, I also compute elasticities conditional on certain characteristics (see Table 1.C.2 in appendix 1.C). For both types of energies, elasticities are (in absolute value) decreasing with income, size of the urban unit, and number of children. [10] Owners, older households, and households with less individuals in the labor force appear to be more price elastic with respect to housing energy, but we see no significant difference with respect to transport energies. On the income dimension, the results are consistent with the findings of Reaños & Wölfing (2018) who analyze price elasticities for electricity in Germany. With respect to city size, they are consistent with the results obtained by Labandeira

9. For a meta-analysis of common estimates in the literature, see Espey (1996) for transport and Espey & Espey (2004) for electricity.

10. The urban units considered are all of similar sizes and correspond to rural towns, small cities, medium cities, large cities and the Parisian agglomeration.

et al. (2006) on Spanish data for transport but not for housing, for which these authors found more elastic demand for urban households. The intuition behind the present results is that, for lower-income and less urban households, energy represents a higher budget share, hence a stronger response to price increases in order to soften their budget constraint. Similarly, as older people and people out of the labor force tend to spend more time at home, they consume more energy for their housing and are therefore more sensitive to changes in prices.

In order to integrate heterogeneous elasticities to the model, I then group households by categories for which I can compute an average elasticity. In particular, I define fifty categories based on income (10 income deciles) and size of the urban unit (5 categories). Uncompensated price elasticities for transport and housing energies are given for all these groups in Table 1.C.3 in appendix 1.C. As shown by Table 1.A.1 in appendix, these groups are all of similar size. Although more dimensions could have been accounted for, I only keep these two to avoid having too many small groups for which the estimation of the average elasticity would not be precise.

From the previous results follow an important implication : by reacting more strongly to prices, some households — in particular low-income and less urban households — will soften the monetary impact of the policy through a higher adjustment in consumption. As a result, the welfare cost of the policy for these households will also come from higher privation in energy consumption. If some of them are already at the edge of their basic energy needs, their decrease in consumption could have critical welfare implications that will not be captured by the monetary effects. This should be kept in mind, as restricting attention to monetary effects will lead to an understatement of the welfare impact on those who reacted more strongly to prices.

1.4 Environmental and distributive effects of energy taxes

This section and the following one are the core of this article. Taking 2016 as the reference year, I study the effects of the switch to the 2018 legislation. This includes a higher price on carbon for all energies (44.6€/tCO_2 against 22€ in 2016) except electricity, and an additional increase for diesel (0.026€ per liter) with the aim of progressively catching up with the higher rate currently imposed on gasoline. [11] I first consider the environmental effects and then turn to distributive issues.

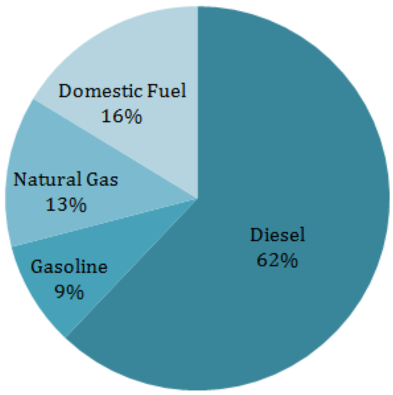
11. To give an idea, the carbon tax should increase the price on domestic fuel from 0.706€ to 0.779€ per liter, excluding the indirect effect on VAT. For diesel, together with the additional adjustment tax, the price is expected to increase from 1.11€ to 1.19€.

1.4.1 The effects on greenhouse gas emissions

The primary objective of the policy is to reduce the negative environmental impacts of energy consumption. I therefore start by evaluating the extent to which it could contribute to reducing greenhouse gas (GhG) emissions. For each energy, I apply the elasticities obtained with the QUAIDS to determine how quantities are expected to change after the policy, and infer the short-run impact on emissions. Figure 1.4.1 summarizes the effect by energy.

FIGURE 1.4.1 – Annual reduction in GhG emissions by energy, in thousands of tons of CO_2e.

Energy	CO_2e emissions
Diesel	1,893
Gasoline	270
Natural Gas	389
Domestic fuel	497
Total transports	2,164
Total housing	886
Total energies	3,049



EXAMPLE : following the policy and holding technology constant, annual GhG emissions from diesel are expected to decrease by 1,893 thousand tons of CO_2e. This corresponds to 62% of the reductions expected from all energies.

The policy is expected to reduce GhG emissions by more than 3 million tons of CO_2 equivalent (CO_2e), that is, slightly less than 0.7% of French total annual emissions, and around 1.5% of emissions due to the transport and residential sectors. [12] By way of comparison, between 1990 and 2013 total French emissions decreased by about 0.5% per year but increased at this same rate for transport and housing. Abstracting from efficiency gains due to higher incentives to invest in low-consumption technologies, the expected environmental impact of the policy is therefore rather limited. Interestingly, despite the larger budget share of housing energies compared to transport fuels, only 29% of the emissions saved are expected to come from this sector. This result reflects not only their lower average carbon content, but also their lower price elasticity. It raises the concern that the price-signal could be insufficient to significantly reduce emissions in this sector. Whether other mechanisms such as fiscal incentives to improve homes' energy efficiency would be more cost-effective is uncertain. As housing energy prices are not very salient to consumers, their effect may simply be delayed and more effective in the long run.

12. 451 Mt equivalent CO_2 in 2016. Source : Citepa, SECTEN report.

1.4.2 Monetary effects between income groups

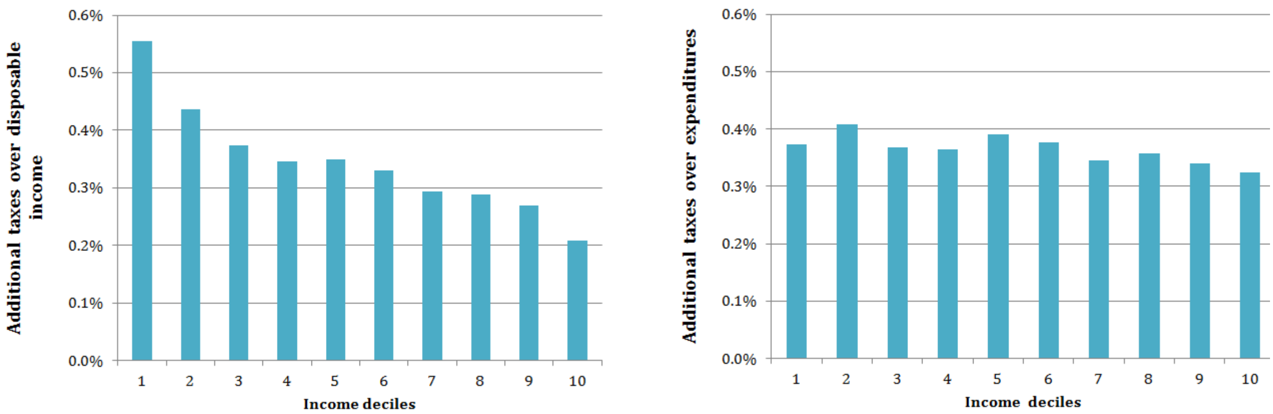
Besides the welfare costs due to reduced consumption, energy taxes will also affect welfare through monetary effects. In this respect, the most common fear — largely discussed in the literature — is that energy taxes are regressive (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010). This regressivity could be detrimental to the acceptability of such schemes and a major deterrent for policies aimed at curbing polluting emissions. Thus, when designing fiscal policies, this needs to be taken into account by policymakers.

In the case of the French policy, with regard to effort rates on the new tax prior to revenue-recycling, we do indeed observe a decreasing pattern, as illustrated by Figure 1.4.2. However, this holds only when disposable income is considered as the denominator (left). When using total expenditures instead (right), the pattern is rather flat. These results confirm the general finding that energy taxes are regressive with respect to income, but almost not when total expenditures are used as a measure of lifetime income. Which of these two measures is most relevant is subject to debate. The trade-off between these methods was originally discussed by Poterba (1989) and Metcalf (1999) who argued, following the permanent income hypothesis, that lifetime income is better reflected by the expenditures approach. A recent OECD paper (Flues & Thomas, 2015) discusses the trade-off for carbon taxes in 21 OECD countries. It also argues in favor of the expenditures approach since for students, the self-employed and retired people in particular, borrowings and savings create a large discrepancy between their income and their standards of living. Overall, one can consider these two approaches as complementary. While these figures point towards the regressivity of the carbon tax, the magnitude of the phenomenon appears smaller than is often assumed.

To compensate for the regressivity of energy taxes, the French government used to grant social tariffs on energies to allow for a discount on energy bills for low-income consumers. In 2018, these tariffs were replaced by energy vouchers (called "Chèque énergie") directed towards low-income households on the basis of their size and fiscal income. These vouchers can only be used to pay energy bills or for renovation works to improve the dwelling's energy efficiency. The distributive effects of this new compensation mechanism will critically depend on the evolution of the take-up rate, as yet unknown. However, assuming an identical take-up rate for both mechanisms, I find that energy vouchers simply compensate for the loss of social tariffs.

The energy vouchers are meant to be a compensation mechanism for low-income house-

Figure 1.4.2 – Average effort rate on the policy, by income decile.

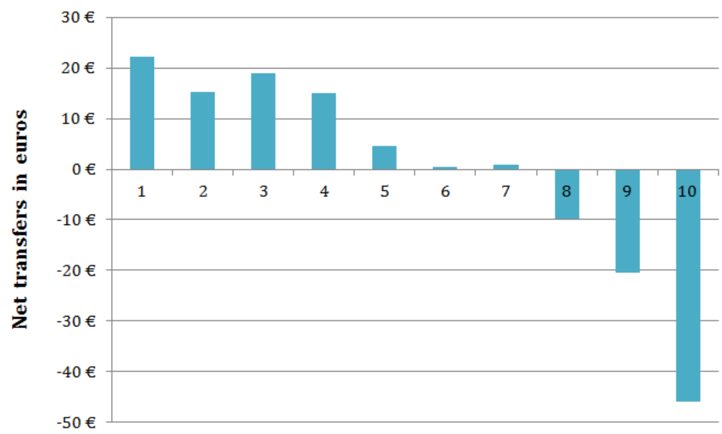


Example : for households belonging to the first income decile, the increase in energy taxes following the policy will represent 0.55% of their disposable income, against 0.21% for those in the last income decile. As a share of their total expenditures, it represents respectively around 0.37% and 0.32%.

holds. However, they currently represent a very low share of the tax revenue. [13] Given that the policy generates a large excess revenue, it leaves room for additional revenue-recycling mechanisms. As many studies have shown, recycling the revenue of the tax through lump-sum transfers directed towards consumers can turn regressive taxes into progressive fiscal policies (e.g. West & Williams, 2004; Bento et al., 2009; Williams et al., 2015). In the rest of the article, I simulate a budget-neutral policy where the excess revenue — i.e. what remains after the official compensation scheme — is equally transferred to households as a proportion of their number of consumption units. In this situation — referred to as “flat-recycling” — we obtain a progressive policy as illustrated by Figure 1.4.3. The net transfers following the policy are then positive for the first five income deciles, around zero for the sixth and seventh, and negative for the last three. This is in line with previous studies and confirms that regressivity is not an issue as long as the revenue can be returned to households. Beyond this general finding and looking specifically at the French policy, one should keep in mind that this result holds under the assumption of an equal split of the revenue. As shown by several studies (e.g. Dinan, 2012; Williams et al., 2015), if the government seeks a double dividend and uses this revenue to lower labor or capital taxes instead, the pattern could be different.

13. From the model, I find an annual revenue for the increase in tax of 4,101 million euros. Energy vouchers should cost 354 million euros for the same period, that is, 8.6% of the total.

FIGURE 1.4.3 – Average net transfers per consumption unit after flat-recycling, by income decile.



EXAMPLE : on average, households belonging to the first income decile will receive an annual net transfer of 22€ after flat-recycling, against -46€ for those in the last income decile.

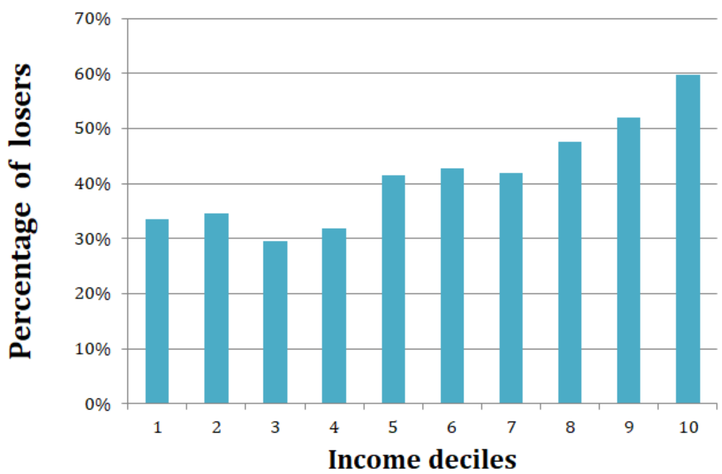
1.5 Horizontal distributive effects

1.5.1 Monetary effects within income groups

While there is an extensive literature on vertical equity issues related to environmental taxes, the literature looking at horizontal distributive effects — i.e. distributive effects between individuals with equivalent incomes — is still scarce, although growing. (Poterba, 1991) first highlighted the disparities in gasoline consumption among households with similar incomes. More recent contributions such as Rausch et al. (2011), Pizer & Sexton (2019), Sallee (2019), and Cronin et al. (2019) have shown that horizontal distributive effects could in fact be of higher magnitude than vertical ones. Although there is a debate about the normative implications of horizontal equity (see Musgrave, 1990; Kaplow, 2000), one must still recognize that these effects are perceived as negative by society and could dampen the acceptability of environmental taxes. More formally, if we assume that the pre-existing distribution of resources is optimal given the available fiscal instruments, policymakers should seek to minimize distributive effects, including between households with similar incomes.

To investigate horizontal distributive effects, I first look at the share of households that are financially losing from the policy within income groups, after flat-recycling. Although the policy is progressive in this case, Figure 1.5.1 shows that within the three first income deciles we can expect around a third of households to receive negative net transfers. This proportion tends to increase with income, but not sharply. Almost half of the households in the ninth decile are expected to receive positive net transfers, and for the top decile the figure is still 40%. This is confirmed by the analysis of the within-income group distribution of net transfers. We can see in Figure 1.5.2 that within the first income group, if 25% of households are expected to earn more than 87€ per consumption unit annually from the policy, 25% are also expected to lose more than 32€. The gap between the first and third quartiles of net transfers within this income group is therefore much higher than the gap in average net transfers between the first and last income deciles. In the first income decile, 25% of households lose more than the median household in the top income group. Finally, considering the bottom of the distribution in net transfers for all income groups, and in particular the 10th percentile, the decreasing trend is no longer clear and expected losses among the lowest income groups are as large as for any other group except the two last income deciles.

FIGURE 1.5.1 – Share of households financially losing from the reform, by income decile.

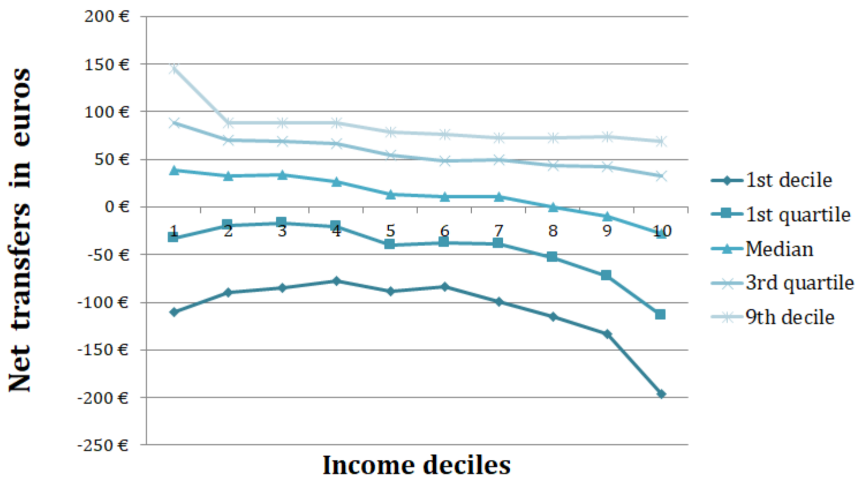


EXAMPLE : after flat-recycling, 34% of households belonging to the first income decile are expected to receive negative net transfers from the policy.

1.5.2 The determinants of within-income group distributive effects

From the preceding analysis, one may wonder whether it is possible to identify specific determinants that would explain the heterogeneity of the tax incidence, and that could then be accounted for in the policy design. Cronin et al. (2019) stress the importance of the income composition but do not have information on other relevant household characteristics. Bento et al. (2009) and Rausch et al. (2011) both point towards the heterogeneous impacts of a carbon

Figure 1.5.2 – Distribution of net transfers per consumption unit, by income decile.



Example : after flat-recycling 25% of households belonging to the first income decile are expected to lose more than 32€ per consumption unit.

tax across regions, as well as differences across racial and ethnic groups. However, they do not explain the determinants of these differences. As pointed out by Pizer & Sexton (2019), other important drivers including housing and commute characteristics could play a major role, and are not considered in these papers.

In order to identify the determinants of the horizontal heterogeneity of the tax incidence, I regress the net transfers per consumption unit (c.u.) received by households after revenue-recycling on many characteristics. This approach is similar to the one recently employed by Sallee (2019) for the gasoline tax in the U.S. It is very agnostic as it enables me, without any *a priori*, to identify the role played by all these dimensions holding the others constant. Because one can expect these results to depend critically on elasticities, I estimate different regressions where the dependent variable is computed assuming (1-2) no elasticities, (3) homogeneous elasticities across groups, and (4) the heterogeneous elasticities used above. A fifth specification (5) estimates the net transfers for a hypothetical reform where electricity would be subject to the same increase in the carbon tax as other energies. The results are reported in Table 1.5.1 below. Overall, they are all similar, although accounting for elasticities smooths distributive effects since households adjust their consumption downward when prices increase.

Holding everything else constant, we see that on average a higher income implies lower net transfers. The relationship is slightly convex but the quadratic term is of low magnitude, so that for most of the income distribution the effect is close to being linear. With respect to house-

Table 1.5.1 – Regression of net transfers per consumption unit after revenue recycling on several household characteristics.

	(1)	(2)	(3)	(4)	(5)
R^2	0.051	0.382	0.371	0.373	0.363
N	10,342	10,342	10,342	10,342	10,342
Elasticities used for dep. var.	None	None	Homogeneous	Heterogeneous	Heterogeneous
Electricity taxed	No	No	No	No	Yes
Intercept	15.64	27.16**	22.09**	25.18***	25.50***
	(2.65)	*(8.41)*	*(7.42)*	*(7.51)*	*(6.85)*
Disposable income	-6.43e-04***	-2.42e-04***	-1.94e-04***	-2.97e-04***	-2.94e-04***
	(3.56e-05)	*(3.92e-05)*	*(3.47e-05)*	*(3.51e-05)*	*(3.20e-05)*
Disposable inc. sqr.	3.13e-10***	1.15e-10***	9.31e-11***	1.42e-10***	1.22e-10***
	(3.00e-11)	*(2.74e-11)*	*(2.42e-11)*	*(2.45e-11)*	*(2.23e-11)*
Domestic fuel		−76.42***	−71.20***	−69.92***	−55.99***
		(2.37)	*(2.09)*	*(2.11)*	*(1.93)*
Natural gas		−79.66***	−75.57***	−76.24***	−61.54***
		(1.83)	*(1.62)*	*(1.64)*	*(1.49)*
Transport fuels		−39.93***	30.08***	−30.50***	−28.16***
		(3.13)	*(2.76)*	*(2.79)*	*(2.55)*
Diesel		−60.38***	−44.24***	−45.00***	−39.37***
		(2.05)	*(1.81)*	*(1.83)*	*(1.67)*
Rural	−8.58**	−8.11**	−5.49*	−3.28	−4.96*
	(2.96)	*(2.69)*	*(2.38)*	*(2.40)*	*(2.19)*
Small cities	4.15	2.92	2.25	3.33	2.27
	(3.38)	*(2.80)*	*(2.47)*	*(2.50)*	*(2.28)*
Large cities	13.13***	2.45	2.04	-0.41	−0.70
	(2.99)	*(2.44)*	*(2.16)*	*(2.18)*	*(1.99)*
Paris	43.55***	9.07**	7.25**	2.58	2.48
	(3.48)	*(3.04)*	*(2.70)*	*(2.72)*	*(2.48)*
West/south		4.88**	4.95**	4.44**	4.27**
		(1.76)	*(1.56)*	*(1.58)*	*(1.44)*
Building before 1949		−6.31**	−6.59***	−6.66***	−3.92*
		(2.02)	*(1.79)*	*(1.81)*	*(1.65)*
Building 1949/74		−2.56	−3.04	−3.03	−0.36
		(2.04)	*(1.80)*	*(1.82)*	*(1.66)*
Individual housing		−8.89***	−8.78***	−9.47***	−11.75***
		(2.34)	*(2.07)*	*(2.09)*	*(1.90)*
Owner		−2.64	−1.61	−1.32	−1.79
		(2.15)	*(1.90)*	*(1.92)*	*(1.75)*
Living area (m^2)		−0.28***	−0.26***	−0.26***	−0.27***
		(0.02)	*(0.02)*	*(0.02)*	*(0.02)*
Nb. consumption units		58.29***	47.96***	50.80***	49.27***
		(2.04)	*(1.80)*	*(1.82)*	*(1.66)*
Nb. in labor force		−2.72	−1.39	−1.54	−0.73
		(1.40)	*(1.24)*	*(1.25)*	*(1.14)*
Student		44.85***	41.68***	41.58***	49.27***
		(6.66)	*(5.88)*	*(5.94)*	*(5.42)*
Age		0.93**	0.94***	0.91**	0.57*
		(0.31)	*(0.27)*	*(0.28)*	*(0.25)*
Age sqr.		−0.01*	−0.01**	−0.01**	0.00
		(0.00)	*(0.00)*	*(0.00)*	*(0.00)*
Vehicle age		0.68***	0.52***	0.55***	0.48***
		(0.14)	*(0.13)*	*(0.13)*	*(0.12)*
Share distance to work		0.35*	0.28	0.28	0.24
		(0.17)	*(0.15)*	*(0.15)*	*(0.14)*

* 0.05 ** 0.01 *** 0.001

holds' residential location, we see from regression (1) that living in rural areas or smaller cities has a negative impact, while living in Paris largely increases expected transfers, with an expected gain of 52€ per c.u. relative to rural households. This is in accordance with Glaeser & Kahn (2010), who show the negative link between urban density and household CO_2 emissions from transports and housing in the U.S. Indeed, one may expect rural households to differ in many respects, such as distance to their workplace. However, as shown by the other specifications, once other characteristics are controlled for, the urban density variables appear to be far less significant, suggesting that this effect is actually largely driven by covariates not directly related to location. In particular, the type of energy used appears to be the major determinant as it is strongly significant both economically and statistically. Households using natural gas or domestic fuel are expected to lose more than 70€ per c.u. relative to other households. Interestingly, given the low carbon content of electricity in France, the result is robust to the inclusion of this energy in the policy : in that situation, the effect only goes down to around 60€. The burden on these households is therefore not explained by the exclusion of electricity from the policy. [14] With respect to transport, accounting for elasticities, households using private vehicles lose on average an additional 30€ per c.u. from the policy, the effect being far stronger for diesel users who lose an additional 45€ per c.u. As the share of diesel and domestic fuel users is higher among rural and suburban households, [15] these results largely explain the higher magnitude of the urban density dummies in the first regression. Still, the high correlation between urban density and carbon tax incidence is in line with Yellow Vests' concerns regarding the high burden borne by rural and peri-urban households.

Looking at climatic regions, we also see that all else being equal, households living in the south or west of France are expected to gain slightly (+4€ in regression (4)). Yet, contrary to what might have been expected given the spatial heterogeneity of temperatures during winters, the impact is relatively small. The distributive effects of energy taxation between regions with different climates therefore seems limited and should not have significant political implications. Other interesting effects of note are the very large gains for students (more than 40€ on average), and the expected losses for people living in individual (-9€) and larger dwellings (-0.3 € per square meter). With respect to energy efficiency, one can note the negative and significant effect of living in an older building. [16]. Family composition also matters a lot : having a larger household has a strong positive effect (+51€ per c.u.) which might be explained by the sharing of many energy expenditures such as heating, in particular once we control for dwelling size. Interestingly, controlling for a number of characteristics, the number of household members in the labor force and the share of commutes in private vehicles to the workplace are not statistically

14. Note that the effect on households using domestic fuel is softened by the switch from social tariffs — which did not apply to fuel — to energy vouchers, which are not conditional on the energy used.

15. 76% of rural households in the sample have at least one diesel vehicle, against 36% of Parisians. For the use of domestic fuel, they are respectively 34% and 5%.

16. The two dummies have been chosen to capture years with major changes in insulation standards.

significant. While working further from home has an obvious negative effect on transfers, this effect disappears when it is taken as a share of the total distance travelled : having on average more travel constraints does not create a higher exposure to energy taxes. Lastly, it can be noted that although many characteristics are identified as significant drivers of the tax incidence, unobserved heterogeneity still plays a major role. In all specifications, the R-square is around 0.38, leaving a large part of unexplained variations. This result suggests that designing policies to solve horizontal distributive effects could be a difficult task.

1.5.3 Alternative revenue-recycling strategies

To test this last hypothesis, I evaluate three alternative revenue-recycling mechanisms. The details of these schemes are given in appendix 1.D, but they basically correspond to 1) an additional transfer based on the urban density of the household's residence, 2) an additional transfer to households heating with domestic fuel or natural gas, and 3) both additional transfers. In each of these scenarios the official energy vouchers are lowered such that total transfers to low-income households (i.e. those eligible under the official compensation scheme) stay the same. The excess revenue and the flat-transfers that follow are therefore unchanged. I restrict my attention to these dimensions because they are among the most important determinants identified in the data, are very prominent in the public debate, and are supposed to be observable by the State, although this observation might be costly.[17] Table 1.5.2 shows for each scenario the net transfers per consumption unit for the households losing the most within the first three income deciles. Relative to the official revenue-recycling mechanism, we see that vouchers differentiated by residential area do not lead to significant improvements. Because the urban density of the residential location is a poor proxy for the tax incidence, it follows that targeted transfers based on this criterion do not improve horizontal equity. If these vouchers enhance the situation of rural and suburban households, it is at the expense of other, highly exposed households. When targeted according to the heating mode, these vouchers outperform the official ones for the first income group but do not make big differences for the second and third. We thus see that these mechanisms have the potential to slightly soften horizontal distributive issues, but their effect remains limited.

By indexing these vouchers on many other dimensions, one may hope to target more preci-

17. One could also raise concerns over the constitutionality of locally differentiated transfers, given the principle of equality before taxation. The exact criteria on which these transfers could be based would be critical for their implementation to be feasible.

TABLE 1.5.2 – Net transfers per consumption unit for the 25th percentile (left) and 10th percentile (right) of households losing the most within income deciles, for alternative recycling.

	1st decile	2nd decile	3rd decile
Official	-32.8€ / -110.4€	-19.5€ / -89.2€	-16.9€ / -84.3€
By area	-30.6€ / -109.6€	-18.8€ / -89.2€	-16.8€ / -83.9€
By energy	-22.0€ / -87.8€	-18.0€ / -77.9€	-16.0€ / -80.0€
By area and energy	-19.1€ / -96.4€	-15.8€ / -77.6€	-14.4€ / -79.4€

EXAMPLE : when revenue-recycling is differentiated by residential area, 25% of households in the first income decile lose at least 30.6€ from the policy after flat-recycling, and 10% lose at least 109.6€.

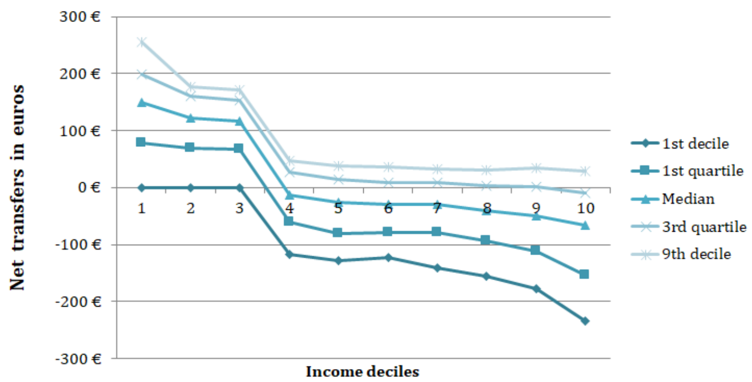
sely the most vulnerable households and thus reduce the policy's distributive effects. However, because households' heterogeneity is largely unobservable by the State, this strategy offers little promise. As shown by the third alternative (by area and energy), combining targeted transfers does not necessarily improve the results. This result is consistent with the findings of Sallee (2019) for the U.S., who shows that the difficulty to precisely target households may prevent Kaldor-Hicks improving policies to be Pareto improving. Also, even though it has the potential to somewhat reduce distributive effects, the benefits of this mechanism should be weighted against its costs. As these transfers would introduce incentives not to switch technologies for households that pollute more, this strategy would reduce the environmental benefits of the policy. This problem could be partly alleviated by phasing out these specific transfers over time — assuming people are only constrained in their heating technology in the medium run. Nonetheless, one should also consider that distributing vouchers specifically to households that use more carbon-intensive energies could be perceived as unfair. As mentioned earlier, the normative aspects of horizontal equity are ambiguous. Whether people are more concerned about the equity of the policy outcome or that of the policy itself is not straightforward.

An alternative to the previous transfers could be to subsidize energy-efficiency improvements. The French government already finances subsidies for clean vehicles as well as tax credits for less carbon-intensive heating technologies and insulation improvements. [18] Such policies could potentially reduce both pollution and distributive issues in the medium run. Unfortunately, they can hardly be evaluated from cross-sectional data. Further work would be needed to assess their cost-effectiveness and actual distributive impact. Indeed, the take-up of these policies could be low among the poorest households, which are more credit constrained, resulting in a windfall for higher-income households and raising non-additionality concerns. Given the dif-

18. The two mechanisms are respectively called "Prime à la conversion" and "Crédit d'Impôt pour la Transition Énergétique (CITE)".

ficulty of precisely targeting households on criteria other than their income, another possibility in the short run would therefore be to offer more generous compensations to all low-income households. Figure 1.5.3 depicts a mechanism defined such that no more than 10% of households lose in the first three income deciles. As we can see, such transfers would imply a larger distortion between income groups with, in particular, substantial losses borne by medium-income households.

FIGURE 1.5.3 – Distribution of net transfers per consumption unit after additional transfers to low-income households, by income decile.



EXAMPLE : when additional transfers are targeted towards low-income households to ensure no more than 10% of losers, 25% of households in the fourth income decile are expected to lose more than 60€ in net transfers per consumption unit due to the policy.

Overall, this evidence suggests that when accounting for horizontal heterogeneity, the policy solutions to the distributional impacts of environmental taxes are far less clear-cut. If not everybody can financially gain from these policies, it is ultimately a matter of political choice to decide how to split the burden between different household groups.

1.6 Conclusions

Through the *ex ante* micro-simulation of the latest reform of energy taxes in France, I have shown that these taxes were regressive with respect to disposable income, and almost flat with respect to total expenditures. The small-scale compensation mechanism proposed by the French government does not change this picture. However, returning the revenue left over through homogeneous lump-sum transfers would make the policy progressive. Yet, even in this situation the policy's acceptability could be dampened by horizontal distributive effects that are much greater in magnitude than the vertical ones. I investigated the determinants of the tax incidence and simulated alternative transfers targeted towards the policy's losers. While such mechanisms could soften distributive issues somewhat, their effect is likely to be limited and should be weighted against their costs.

The French government initially committed to an ambitious trajectory for the carbon price that was supposed to reach 86.2€ by 2022, and keep growing to even higher rates after that date. Following the recent protests by the Yellow Vests against the impact of these taxes on household purchasing power, the trajectory has been abandoned. Given the urgent need to take action against climate change and other environmental issues, it is necessary to find a way to increase the support for environmental policies by dealing with their distributive effects. As shown in this chapter, recycling the entire revenue of the tax through lump-sum transfers would make the majority of poor households net winners, and potentially increase acceptability. Dealing with horizontal heterogeneity seems more difficult in the short run, however. In the long run, energy efficiency improvements seem necessary to reduce both emissions and distributive effects.

1.A Descriptive statistics

TABLE 1.A.1 – Descriptive statistics for matched data, average per income decile.

	1	2	3	4	5	6	7	8	9	10
Annual Disp. income	16,371€	25,829€	31,039€	36,709€	40,509€	46,585€	53,498€	60,286€	71,199€	113,557€
Annual expenditures transport energies	700€	846€	894€	1,037€	1,215€	1,343€	1,400€	1,500€	1,588€	1,534€
Annual expenditures housing energies	1,272€	1,542€	1,572€	1,635€	1,720€	1,783€	1,875€	1,903€	2,046€	2,520€
Annual total expenditures	23,142€	24,430€	27,728€	30,571€	31,895€	36,104€	39,880€	42,699€	49,467€	62,426€
% rural	16.8%	22.3%	24.0%	23.6%	25.2%	23.1%	25.6%	22.9%	22.1%	17.4%
% small cities	14.0%	18.5%	19.6%	16.5%	18.3%	17.4%	16.5%	17.0%	17.1%	11.2%
% medium cities	19.6%	21.6%	19.6%	21.8%	19.4%	22.1%	17.0%	17.7%	16.8%	15.0%
% large cities	33.3%	24.7%	26.3%	24.6%	24.3%	24.1%	24.2%	24.8%	22.1%	23.4%
% Paris	16.3%	12.9%	10.6%	13.4%	12.8%	13.3%	16.7%	17.6%	21.9%	33.0%
% natural gas	37.9%	40.1%	40.3%	40.3%	40.9%	42.0%	40.1%	41.9%	42.7%	51.5%
% domestic fuel	11.0%	14.9%	17.1%	14.6%	17.8%	15.0%	12.7%	14.1%	14.8%	13.9%
% transport fuels users	58.7%	66.4%	70.3%	77.9%	82.6%	86.9%	89.8%	89.7%	89.9%	90.6%
% diesel users	36.6%	42.4%	45.5%	49.9%	54.1%	60.7%	65.8%	65.3%	61.5%	62.3%
% gasoline users	24.5%	29.1%	30.0%	37.6%	39.1%	38.8%	35.8%	39.9%	44.5%	48.1%
Weekly home-work distance (km)	13.8	24.9	25.6	47.3	48.6	60.2	60.5	63.2	81.4	66.8
Age vehicle (years)	6.8	7.6	7.9	8.1	8.4	8.2	7.7	7.3	7.3	6.3
% building before 1949	28.2%	29.8%	25.8%	26.4%	22.9%	23.0%	21.6%	22.1%	24.1%	25.4%
% individual housing	31.6%	47.2%	50.9%	52.1%	59.3%	60.6%	59.9%	61.9%	63.3%	57.8%
Living area (m^2)	71	79	81	83	88	91	94	99	105	118
# consumpt. units	1.46	1.54	1.51	1.55	1.52	1.56	1.59	1.56	1.55	1.51
# in labor force	0.69	0.77	0.78	0.92	0.97	1.11	1.21	1.24	1.24	1.23
Age representative	44.2	53.0	54.8	54.7	54.0	51.8	49.7	50.8	51.7	53.2

NOTE : Income deciles are constructed on the basis of disposable income per consumption unit.

1.B The microsimulation model TAXIPP

The microsimulation of the policy's impact on households is performed using the model TAXIPP. The model is managed by the Institut des Politiques Publiques (IPP) at the Paris School of Economics (PSE). [19] For the study of indirect taxation, the model uses consumer survey data as described in Section 2 of this chapter. For each household in the dataset and for each good it consumes the model computes — from the expenditures reported in the data — the amount paid for various taxes. These computations simply replicate the legislation. For instance, if one

19. For more information on the model, see https://www.ipp.eu/en/tools/taxipp-micro-simulation/.

Figure 1.A.1 – Households' annual expenditures in energy per c.u. before the reform, by income decile

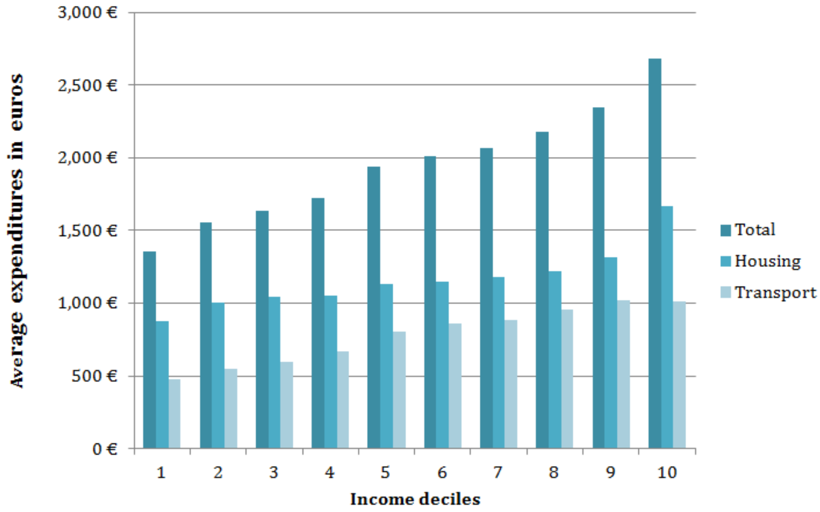


Figure 1.A.2 – Households' annual expenditures in energy per c.u. before the reform, by urban unit

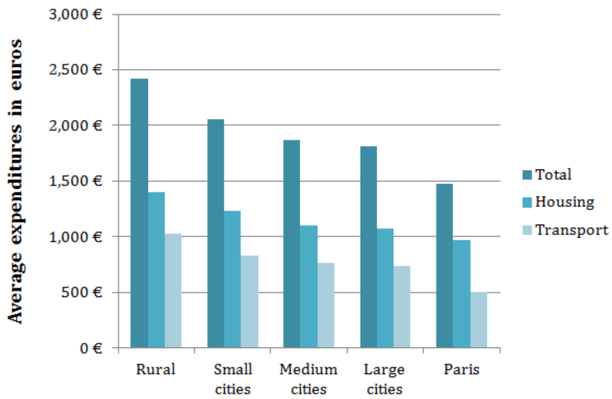
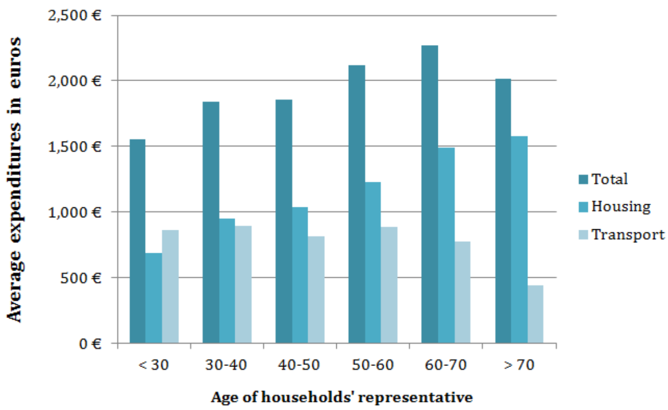


Figure 1.A.3 – Households' annual expenditures in energy per c.u. before the reform, by age group



is interested to know what is the contribution of an household to taxes on energies, the model uses the following formula to decompose expenditures (E) :

$$E = qQ = (1+t)(p+a)Q \tag{1.2}$$

with Q the quantity of energy consumed, q the final price, p the price without taxes, t the VAT rate and a the excise (e.g. carbon) tax. From this we can compute the household spending in VAT ($E_{VAT} = t(p+a)Q$) and in excise tax (aQ). From the expenditures provided in consumers survey, one can easily recover quantities of energies consumed since $Q = E/q$. The only exception is for gas as it is subject to contracts with both a fixed and a marginal cost. For this energy, the formula thus becomes $Q = (E-F)/q$ with F the fixed cost of the contract. As various contracts are available to French consumers, the model takes the regulated prices proposed by the historical company "Engie" (ex "GDF-Suez") and computes from households' gas expenditures the quantity they would have consumed if they had subscribe to each of these contracts. Assuming households are rational and can approximately forecast their future consumption, the model matches each household to the contract that would provide the largest quantity (i.e. the optimal contract given its observed expenditures). Thus, households with the largest consumption are matched to the contract with the most expensive fee but the lower variable price, and vice-versa.

Beyond the computation of taxes currently paid by households, the model also allows to assess the impact of policies, such as the increase in the carbon tax studied in this chapter. In order to simulate the impact of a change in the carbon tax (i.e. an increase in a), one simply needs to compute the impact of such a change on the final price and the effect on quantities consumed. In this chapter, we assume the change in prices equals the increase in excise taxes. This is akin to suppose that the tax burden falls by 83% on consumers. [20] From this increase in prices, one can then apply the elasticities estimated in this chapter to compute the new expenditures E' for each household. If we denote e the price elasticity of the good, by log-differentiation of $E = qQ$ we have :

$$\frac{dE}{E} = \frac{dq}{q} + \frac{dq}{q}\frac{dQ}{dq}\frac{q}{Q} = \frac{dq}{q}(1+e) \tag{1.3}$$

20. If we denote i the tax incidence on consumers, dq the change in prices and da the change in the excise tax, then for marginal changes we have $dq = i \times da \times (1+t)$, so that we can approximate $dq = da$ assuming $i = 1/(1+t) \simeq 0.83$. On U.S. data Marion & Muehlegger (2011) find that gasoline taxes are in general fully-passed onto consumers. Carbonnier (2007) analyses shifts in the French VAT and finds that part of the burden is born by producers, in particular in highly concentrated sectors. Considering the little competitiveness of the French energy sector, it seems relevant to assume that the tax burden will be born not entirely although in the largest part by consumers.

hence :

$$E' = E + dE = E\left(1 + (1+e)\frac{dq}{q}\right) \tag{1.4}$$

from which one can use the methodology previously described to compute the new contribution to taxes.

1.C The Quadratic Almost Ideal Demand System

1.C.1 The model

The QUAIDS starts from a quite general specification on the form of the indirect utility function :

$$\ln V(\mathbf{p}, m) = \left[\left\{\frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})}\right\}^{-1} + \lambda(\mathbf{p})\right]^{-1} \tag{1.5}$$

where $\ln a(\mathbf{p})$ is the transcendental logarithm function that can be written

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2}\sum_{i=1}^{k}\sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k \tag{1.6}$$

with p_i the price of the bundle of goods i. $b(\mathbf{p})$ is a Cobb-Douglas price aggregator that takes the form :

$$b(\mathbf{p}) = \prod_{i=1}^{k} p_i^{\beta_i}$$

and :

$$\lambda(\mathbf{p}) = \sum_{i=1}^{k} \lambda_i \ln p_i, \qquad \text{where} \quad \sum_{i=1}^{k} \lambda_i = 0$$

All the parameters of the model can be estimated except for α_0 in the translog price index. This parameter must therefore be set arbitrarily. I follow Deaton & Muelbauer (1980b) who recommend taking the value of the minimal standards of living in the sample. Finally, economic theory requires a certain number of constraints to hold on the value of the parameters : the following restrictions are implied for the first two by adding-up (to make sure $\sum_i w_i \equiv 1$), the third by homogeneity, and the last by Slutsky symmetry :

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{j=1}^{k} \gamma_{ij} = 0, \quad \text{and} \quad \gamma_{ij} = \gamma_{ji}$$

Now, if we take q_i the quantity of good i consumed, $p_i q_i$ is the expenditure for good i, then $w_i = (p_i q_i)/m$ is the share of the total expenditure associated with the consumption of good i. Then, using Roy's identity we can derive :

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln\left\{\frac{m}{a(\mathbf{p})}\right\} + \frac{\lambda_i}{b(\mathbf{p})}\left[\ln\left\{\frac{m}{a(\mathbf{p})}\right\}\right]^2, \quad i = 1, \ldots, k \tag{1.7}$$

The aim of the QUAIDS is to estimate this equation for all goods i.

1.C.2 Elasticities

The estimates obtained for the parameters serve to compute the income and price elasticities with respect to each bundle of goods. Indeed, if we differentiate the share equations with respect to the logarithm of expenditures, we get :

$$\mu_i \equiv \frac{\partial w_i}{\partial \ln m} = \frac{\partial w_i}{\partial m} m = -w_i + w_i \frac{m}{q_i}\frac{\partial q_i}{\partial m} = \beta_i + \frac{2\lambda_i}{b(\mathbf{p})}\left[\ln\left\{\frac{m}{a(\mathbf{p})}\right\}\right] \tag{1.8}$$

from which we can identify the budget elasticity of good i :

$$e_i = \frac{\partial q_i}{\partial m}\frac{m}{q_i} = 1 + \frac{\mu_i}{w_i} \tag{1.9}$$

Similarly, if we differentiate the share equations with respect to the price of the same good, we get :

$$\mu_{ii} \equiv \frac{\partial w_i}{\partial \ln p_i} = w_i(1 + e^u_{ii}) = \gamma_{ii} - \mu_i\left(\alpha_i + \sum_k \gamma_{ik} \ln p_k\right) - \frac{\lambda_i \beta_i}{b(\mathbf{p})}\left[\ln\left\{\frac{m}{a(\mathbf{p})}\right\}\right]^2 \tag{1.10}$$

since $\partial \ln a(\mathbf{p})/\partial \ln p_i = \alpha_i + \sum_k \gamma_{ik} \ln p_k$ and $\partial b(\mathbf{p})/\partial \ln p_i = \beta_i b(\mathbf{p})$. Thus the uncompensated price elasticity of good i is :

$$e^u_{ii} = \frac{\mu_{ii}}{w_i} - 1 \tag{1.11}$$

Estimation is performed using the Stata package *aidsills* introduced by Lecocq & Robin (2015). It uses iterated linear least-squares (ILLS) and provides elasticities at the mean of each variable, together with their standard errors.

1.C.3 Households' heterogeneity

The command *aidsills* serves to introduce heterogeneity in households' preferences through the inclusion of demographic variables. The procedure makes use of the translating approach of Pollak & Wales (1981). If $\mathbf{s^h}$ represents the set of demographic variables, the intercept in the share equation becomes household-specific and is written :

$$\alpha^{\mathbf{h}} = \mathbf{A}\mathbf{s}^{\mathbf{h}}, \qquad \mathbf{A} = (\alpha'_{\mathbf{i}})$$

which then translates into households' specific elasticities. We can thus estimate heterogeneous responses for different groups of households by conditioning on some of their characteristics — such as income or city size — without having to estimate elasticities on sub-samples.

1.C.4 Specification and estimation

The main difficulty in estimating demand systems with survey data stems from the lack of variability in prices. For each household, and for each good it consumes, I match the prevailing monthly price index [21] of the French statistical institute (Insee) according to the period of the survey. Like Nichèle & Robin (1995), I take the last three surveys — 2001, 2006 and 2011 — for a total of 20 periods, [22] hence 20 different prices for each good. For transport fuels, more variations can be introduced by making use of the quantities reported in the notebook filled out by households, from which we can deduce the exact price they faced. For housing energies and many other non-durable goods, this strategy cannot be used. To overcome the low variability in prices, I compute Stone-Lewbel price indices (see Lewbel, 1989) that use households' consumption mix to derive personalized prices. For a bundle i consumed by household h, the price index is written :

$$\ln(p_{ih}) = \sum_{l=1}^{N_i} \frac{w_{lh}}{w_{ih}} \ln(p_{lh}) \tag{1.12}$$

where w_{lh} is the consumption share of good l belonging to the bundle i for household h, w_{ih} the consumption share of bundle i in total consumption for this household, and p_{lh}, p_{ih} their respective price index. Without any additional assumption on the form of the *between bundles* utility function, this method is used to construct price indices that rely on heterogeneity of consumer preferences *within each bundle*. This heterogeneity serves to introduce more variations in prices. It has been widely used in the literature that has computed demand systems, and to my knowledge is the only efficient strategy to construct price indices with high enough variability from cross-sectional data. In an assessment of this method, Hoderlein & Mihaleva (2008) have shown that it produces better empirical results than standard aggregate price indices.

However, one should still be careful about the potential endogeneity introduced by this procedure. When *within-bundle* utility functions are Cobb-Douglas, the weights used in the price index correspond to households' exogenous preference parameters. But if this assumption is not met, since expenditures are used in the construction of prices, there is a risk of biasing

21. These price indices are national. The information regarding households' geographical location are not precise enough to match households with local price indices.
22. There were 8 waves in 2001, 6 in 2006 and 2011. For each survey I exclude overseas departments and restrict the sample to households with positive consumption on all bundles, for a total of 18,090 households.

identification. In order to check the robustness of the results, I therefore estimate an alternative specification where I do not use personalized Stone-Lewbel price indices. Instead, I group households in preference categories based on their size and location (city size and region of France) and compute an average price index for each category. While the variability in prices is reduced, the threat of endogeneity in the price index is also significantly lowered.

To further reduce any chance of endogeneity, I add controls to account for diversity in households' preferences such as their composition, age, heating mode, the urban density of their residential location and other characteristics that could explain the composition of households' bundles. I also use time fixed effects to account for seasonality in consumption. Finally, because expenditures are endogenous in demand systems, I use households' disposable income as an instrument (see Lecocq & Robin, 2015).

1.C.5 Results

Tables 1.C.1, 1.C.2, and 1.C.3 below report the elasticities estimated from the QUAIDS, at the sample mean, and at the sample mean of given categories.

TABLE 1.C.1 – Elasticities from the QUAIDS.

	(1)	(2)	(3)	(4)
SL price index	yes	yes	no	no
Instrument expenditures	yes	no	yes	no
elas. unc. transport	−0.47	−0.49	−0.44	−0.47
	[-0.51;-0.42]	[-0.62;-0.36]	[-0.57;-0.31]	[-0.60;-0.35]
elas. unc. housing	−0.21	−0.21	−0.15	−0.18
	[-0.27;-0.16]	[-0.26;-0.15]	[-0.25;-0.04]	[-0.28;-0.08]
elas. unc. other	−1.03	−1.03	−0.97	−0.97
	[-1.04;-1.01]	[-1.04;-1.01]	[-1.02;-0.92]	[-1.01;-0.92]
elas. exp. transport	0.48	0.54	0.45	0.52
	[0.44;0.53]	[0.52;0.56]	[0.41;0.50]	[0.50;0.54]
elas. exp. housing	0.58	0.47	0.56	0.47
	[0.53;0.63]	[0.45;0.49]	[0.51;0.61]	[0.44;0.49]
elas. exp. other	1.07	1.07	1.07	1.07
	[1.06;1.07]	[1.07;1.07]	[1.07;1.07]	[1.07;1.07]
N	18,090	18,090	18,090	18,090
R^2 eq. transport	0.291	0.291	0.289	0.288
R^2 eq. housing	0.309	0.309	0.277	0.277
R^2 eq. other	0.368	0.368	0.349	0.349

Note : the 95% confidence intervals are given in brackets. Elasticities are calculated at the sample mean of each variable.

Table 1.C.2 – Uncompensated price elasticities for energies by group

	Transport	Housing
Income decile : 1	-0.548	-0.343
	(*0.055*)	(*0.024*)
Income decile : 2	-0.539	-0.334
	(*0.056*)	(*0.024*)
Income decile : 3	-0.524	-0.309
	(*0.058*)	(*0.025*)
Income decile : 4	-0.507	-0.279
	(*0.061*)	(*0.026*)
Income decile : 5	-0.495	-0.259
	(*0.062*)	(*0.027*)
Income decile : 6	-0.482	-0.227
	(*0.064*)	(*0.028*)
Income decile : 7	-0.460	-0.185
	(*0.067*)	(*0.030*)
Income decile : 8	-0.431	-0.148
	(*0.071*)	(*0.031*)
Income decile : 9	-0.399	-0.101
	(*0.075*)	(*0.034*)
Income decile : 10	-0.310	-0.052
	(*0.087*)	(*0.037*)
Rural	-0.490	-0.337
	(*0.063*)	(*0.024*)
<20k	-0.481	-0.287
	(*0.064*)	(*0.026*)
20-100k	-0.501	-0.259
	(*0.061*)	(*0.028*)
>100k	-0.450	-0.064
	(*0.068*)	(*0.035*)
Paris	-0.334	0.219
	(*0.084*)	(*0.052*)
Owner : Yes	-0.464	-0.306
	(*0.069*)	(*0.025*)
Owner : No	-0.506	-0.139
	(*0.063*)	(*0.031*)
Age : $\leq$ 40	-0.523	-0.058
	(*0.061*)	(*0.035*)
Age : 40–65	-0.477	-0.191
	(*0.067*)	(*0.029*)
Age : $\geq$ 65	-0.476	-0.409
	(*0.067*)	(*0.021*)
# in labor force : 0	-0.494	-0.389
	(*0.065*)	(*0.022*)
# in labor force : 1	-0.503	-0.199
	(*0.064*)	(*0.029*)
# in labor force : 2	-0.480	-0.073
	(*0.067*)	(*0.034*)
# in labor force : >2	-0.487	-0.095
	(*0.066*)	(*0.035*)
# children : 0	-0.514	-0.278
	(*0.062*)	(*0.026*)
# children : 1	-0.498	-0.170
	(*0.064*)	(*0.030*)
# children : 2	-0.460	-0.103
	(*0.069*)	(*0.033*)
# children : >2	-0.406	-0.091
	(*0.077*)	(*0.034*)

Note : Standard errors are reported in brackets.

TABLE 1.C.3 – Transport and housing energy uncompensated price elasticities by group.

	Rural	Small cities	Medium cities	Large cities	Paris
1st decile	(-0.54/-0.43)	(-0.55/-0.39)	(-0.58/-0.37)	(-0.55/-0.21)	(-0.49/-0.01)
2nd decile	(-0.54/-0.43)	(-0.54/-0.37)	(-0.56/-0.34)	(-0.54/-0.21)	(-0.45/-0.01)
3rd decile	(-0.52/-0.39)	(-0.53/-0.35)	(-0.56/-0.32)	(-0.51/-0.16)	(-0.47/0.07)
4th decile	(-0.52/-0.37)	(-0.51/-0.34)	(-0.53/-0.29)	(-0.50/-0.13)	(-0.44/0.04)
5th decile	(-0.51/-0.35)	(-0.50/-0.33)	(-0.54/-0.28)	(-0.47/-0.10)	(-0.42/0.06)
6th decile	(-0.49/-0.32)	(-0.50/-0.29)	(-0.51/-0.26)	(-0.47/-0.08)	(-0.36/0.14)
7th decile	(-0.48/-0.29)	(-0.46/-0.25)	(-0.48/-0.23)	(-0.44/-0.04)	(-0.41/0.14)
8th decile	(-0.45/-0.27)	(-0.44/-0.22)	(-0.46/-0.23)	(-0.42/-0.02)	(-0.34/0.22)
9th decile	(-0.45/-0.26)	(-0.42/-0.20)	(-0.44/-0.19)	(-0.36/0.05)	(-0.29/0.32)
10th decile	(-0.38/-0.28)	(-0.37/-0.20)	(-0.37/-0.19)	(-0.30/0.08)	(-0.17/0.38)

EXAMPLE : households belonging to the first income decile and living in a rural area have transport and housing energy price elasticities of respectively -0.54 and -0.43.

NOTE : Due to the imprecision of the estimation for small categories, the housing energy price elasticity is expected to be positive for ten groups. For the sake of consistency of the micro-simulation analysis I impose an *ex post* zero upper-bound. This constraint does not introduce large effects in the results. If anything, it will give more conservative results by lowering the heterogeneity in gains and losses.

1.D Policies simulated

1.D.1 The official policy

In this chapter I study the effects of switching to the 2018 legislation for energy taxes, compared to the reference situation of 2016. The policy studied therefore implies the following evolution : 1) An increase in the price of CO_2 that goes from 22€ to 44.6€ per ton. 2) An additional 0.026€ per liter increase in the diesel tax to gradually catch up with the gasoline tax. 3) Energy vouchers transferred towards low-income households, based on their fiscal income and their size. These vouchers replace the previous social tariffs on electricity and gas. All the previously mentioned changes are taken into account in the model. In addition, the policy enlarged the "Crédit d'impôt pour la transition énergétique" (Cite) whose aim is to help people finance energy efficiency improvements in their dwelling, and a scrapping premium to improve the energy efficiency of the vehicle fleet. These last changes are not modelled in TAXIPP.

1.D.2 Targeted transfers design

The chapter also evaluates the potential of targeted transfers to reduce the burden borne by some of the poorest households. From the output of regression (1) in Table 1.5.1, I design a mechanism called transfers "by area" which gives rural households *already eligible for the official energy voucher* an additional 52€ per consumption unit. Following the regression results, the transfers amount to 39€ for small cities, 43€ for medium cities, 30€ for large ones and zero for Paris. From the output of the four other specifications, I also design a mechanism called "by energy" in which households heating with fuel or gas receive an additional 70€ voucher per consumption unit. In the third scenario "by area and energy", both additional transfers are included. For all these alternatives, the initial energy vouchers based on income and household size are decreased such that the total cost of the policy stays the same.

Online Appendix

1.E Matching

This section corresponds to the online appendix of the paper titled "The vertical and horizontal distributive effects of energy taxes : a case study of a French policy" to detail the matching of the two households surveys used in this chapter. The first part presents the surveys and the objective of the matching. The procedure is discussed in the second part. In the third one, various tests are displayed in order to highlight the quality of the matching.

1.E.1 Why it is necessary to match BdF and ENTD

1.E.1.1 The surveys

The microsimulation model TAXIPP used in the chapter is fed by a novel database that comes from the matching of two French households surveys : the consumer survey "Budget de Famille" and the transport survey "Enquête Nationale Transports et Déplacements". Both surveys come from the French national statistical institute (Insee).

Budget de Famille (BdF) The objective of Budget de Famille (BdF) is to describe households accounting. It provides information over all their revenues and expenditures, as well as some socio-demographic characteristics. The survey was conducted in several waves from October 2010 to September 2011. 10,342 households were surveyed in metropolitan France. Their expenditures in non-durable products were reported over a period of seven days, and then annualized.

Enquête Nationale Transports et Déplacements (ENTD) The objective of Enquête Nationale Transports et Déplacements (ENTD) is to describe all households trips, whatever the mode. It provides information on households' vehicle fleet, their use over a week, and additional information such as annual distances travelled with their vehicles and various socio-demographic characteristics. The survey was conducted in several waves from April 2007 to April 2008 over a sample of 20,178 households in metropolitan France.

1.E.1.2 Objective of the imputation

As explained in Section 2 of the chapter, because the timing of the survey is too short, BdF data tend to over-estimate the heterogeneity in transport fuel consumption. Considering average expenditures for given households groups, this is not an issue as the noise averages out. However, if one wants to consider the heterogeneity in consumption behavior *within* these groups, the use of BdF data will lead to an overestimation. To avoid this problem, I therefore match households in BdF with households in ENTD where annual distances travelled are recorded. From these distances, it is then possible to recover long run expenditures that should not over-estimate households heterogeneity because of short-run fluctuations in their consumption. Such a matching is unnecessary for expenditures in housing energies as these are already taken from households bills in BdF and represent consumption over long periods.

The objective is therefore to impute to each household in BdF (called the *recipient* database) an annual distance travelled from ENTD (the *donor* database). This is done both for the distance travelled with gasoline, and with diesel vehicles [23]. This distance is then converted in expenditures in the following way : households are gathered in small groups based on income and geographical area. Their imputed distances are then multiplied by the ratio of average expenditures from BdF over average distances within that group. This procedure enables to conserve average expenditures by groups from BdF - that average out the noise from household level expenditures - but to restore the distribution within groups. The underlying assumption is that within groups, consumption per kilometer and prices are the same. As shown by the distribution of distances plotted in the last part of this document - see figures 1.E.2 and 1.E.3 - these differences are of second order relative to differences in driving behaviors. If anything, this will lead to more conservative results with respect to horizontal heterogeneity.

1.E.2 The matching procedure

1.E.2.1 Homogeneity between surveys

Before proceeding to the matching, several steps need to be done in order to make sure households are comparable across surveys. A clear exposition of the procedure is given in D'Orazio et al. (2006b) [24]. I first exclude from BdF households living in overseas department since these

23. In addition, I also impute some characteristics linked to the vehicle use such as the age of the vehicle, or the home to work distance.
24. For a recent application to the Eurostat Household Budget Survey, see Serafino & Tonkin (2017).

are not covered by ENTD[25]. When necessary, variables common to the two surveys are re-coded so that they share the exact same definition. We should then expect their distribution to be the same across datasets. To make sure this is the case, we use two types of homogeneity criteria :

— **The Hellinger distance :** this distance is used to reduce the comparison between two distributions to a unique scalar in $[0;1]$. It gives a simple criterion common to all variables. In the case of two discrete distributions it is defined as :

$$d(X,Y) = \frac{1}{\sqrt{2}} \left[\sum_i \left(\sqrt{Pr(X=i)} - \sqrt{Pr(Y=i)} \right)^2 \right]^{1/2}$$

A rule of thumb is to consider two distributions as similar if their distance is lower than 5% (see Leulescu & Agafitei, 2013).

— **Visual tests :** when distributions differ, we also need a less synthetic approach to understand how. We therefore use visual representations to compare different quantiles of the distribution. We also consider the variables' distribution specifically for some households groups.

Table 1.E.1 gives the Hellinger distance for several variables common to BdF and ENTD. Most of them appear to have a very comparable distribution across surveys. Two exceptions are income per consumption unit (c.u.) and the number of diesel vehicles per household. The latter can be explained by the change in the vehicle fleet towards more diesel between 2008 and 2011. This composition effect will be accounted for in the matching. As shown by figure 1.E.1, differences in incomes per c.u. can also be explained by an upward trend in incomes between the two surveys. As this variable will just be used to split households by groups in the matching (see part 2.2.2), only households rank matters and there is no need to re-scale the distributions.

1.E.2.2 The method : NND hotdeck

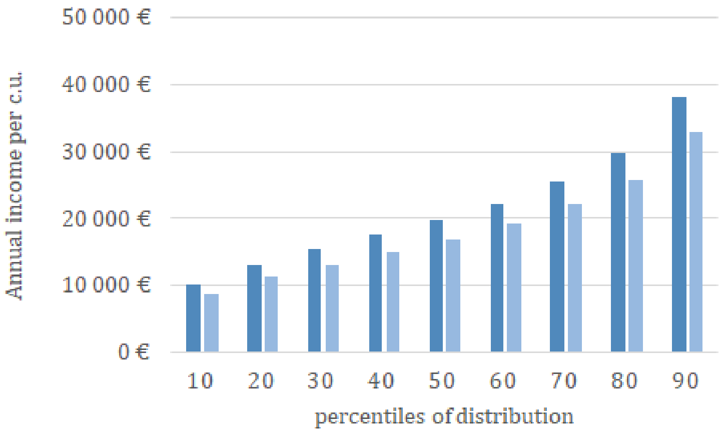
Households' statistical matching is performed using a non-parametric method : the *neirest neighbor distance* (NND) hotdeck. The different steps of the procedure are described below. The general idea of the NND hotdeck is to compute for each household of the *recipient* database, the statistical distance with households from the *donor* database, and match them with the one having the shortest distance.

25. Also, the taxation of energetic products being different, we do not want to include these department in the study.

TABLE 1.E.1 – Hellinger distances ENTD/BdF

Variable	Hellinger distance
Rural	0.3%
Paris	1.2%
Number people	2.5%
Number in labor force	1.8%
Number children	1.8%
Number vehicles	1.2%
Number diesel	7.7%
Age representative	6.4%
Housing benefits	1.5%
Income per c.u.	15.7%

FIGURE 1.E.1 – Distribution of annual income per consumption unit, in ENTD (dark blue) vs. in BdF (light blue)



The distance The distance is a measure of households similarity. It is evaluated from a set of characteristics observable in both the *recipient* and the *donor* database. Several definitions of the distance can be used in the computations. The most commons are the Euclidean, the Manhattan (or city-block), the Mahalanobis and the Gower distance. After having tested these different options, the Gower distance has been chosen. It calculates separately the distance between two households on each dimension (i.e. for each explanatory variable) and normalizes it so that it is included in $[0;1]$. For two households x and y on a dimension k, the distance writes :

$$d_k(\mathbf{x},\mathbf{y}) = \frac{|\, x_k - y_k \,|}{R_k}$$

with R_k the maximal distance observed. The Gower distance is then computed as the average :

$$d(\mathbf{x},\mathbf{y}) = \frac{1}{p}\sum_{k=1}^{p} d_k(\mathbf{x},\mathbf{y})$$

The main advantage of this method is to be able to compare variables of different types without giving too much weight to large scale dimensions. This is key in particular when using both continuous and binary variables as explanatory ones.

Donation classes The previous method suggests that for each household of BdF, we need to compute the distance with each household of ENTD. The use of donation classes enables to shorten these long computations. In the two datasets, I group households in categories. I have chosen income deciles [26] so that each dataset is divided in ten groups. Then, for each household in the n^{th} group in BdF, I compute the distance only with households in the n^{th} group in ENTD. The advantage of this method is not only to shorten calculations, but also to make sure that households are truly similar on some of the most important dimensions. Since an important part of this chapter relies on comparisons between and within income deciles, it seemed crucial to make sure all households imputed distances were coming from households of the same income decile.

One could be tempted to condition matching on more variables. However, as groups become more numerous they also become smaller. This leaves then less flexibility to the matching. Using income deciles, each household in BdF may still be matched with more than 2,000 households in ENTD.

Variables selection The choice of the matching variables is a crucial step as it will later enable to judge whether the *Conditional Independence Assumption* (CIA, see part 3) is likely to be satisfied, and whether the results presented will be robust or not. To determine the variables to include, I use a *stepwise regression*, and more specifically the *forward selection approach*. The idea is to estimate a series of regressions by adding at each step the independent variable that increases the adjusted R^2 the most. Taking as dependent variables the distance with diesel, gasoline, and both, I obtain adjusted R^2 of respectively 0.48, 0.45 and 0.33.

From the set of variables pre-selected, I then keep a sub-set for the matching with the objective to be parsimonious, to correctly reproduce the marginal and conditional distributions of ENTD in the matched dataset, and to satisfy as much as possible the CIA. The results are described in the next part, but this procedure led to include the following variables to compute distance : the household's number of vehicles, its number of diesel vehicles, the age of the household representative, the number of person in the household, the number of persons in the

26. As in the chapter, groups are constructed on the basis of disposable income per consumption unit

labor force, whether the household lives in a rural area, and whether he lives in the Parisian agglomeration.

Imputation procedure Once the distance is computed, several methods can be used to match households. The *NND* hotdeck implemented here matches households in BdF with the one having the shortest distance in its donation class in ENTD. A popular alternative method is the *random* hotdeck that selects a sub-sample of close households and randomly picks one. In the present case, the standard NND has been preferred to the *random* hotdeck as the two methods provided very similar results, and the former avoids having a different match each time the procedure is performed.

1.E.3 *Ex post* validation

1.E.3.1 *Ex post* tests

In order to chose the best specification, and to assess the quality of the matching, I examine the degree of similarity between the distributions of imputed variables in ENTD and in the matched dataset. As an example, figure 1.E.2 shows the distribution of annual distances travelled within each income group, in ENTD and in the matched dataset. Figure 1.E.3 displays the same distributions within geographical categories. It appears from these figures that the matching correctly reproduces the distribution from the original dataset. Figure 1.E.4 and 1.E.5 show that this also holds when looking specifically at distances per type of fuel [27]. One can replicate this exercise by considering other groups than those presented. All the results confirm that marginal and conditional distributions are correctly replicated in the matched data-set.

1.E.3.2 The underlying hypothesis : the CIA

The last criterion to judge the matching quality is the credibility of the *Conditional Independence Assumption* (CIA) on which the matching strategy relies. If one starts with a dataset containing a set of variables Y and X that he wants to match with another dataset containing Z and X, using X as explanatory variables, the CIA implies that all common variations of Y and Z are explained by X. The CIA is a necessary condition to the validity of the matching. However, in the absence of exogenous information on the joint distribution of X, Y and Z, there is no empirical

27. The slight downward shift of distances for gasoline is driven by the fact that households own on average less gasoline vehicles in BdF than in ENTD due to the evolution of the overall vehicle fleet toward diesel between 2008 and 2011.

Figure 1.E.2 – Distribution of annual distances travelled per household, within the ten income deciles, in ENTD (dark blue) vs. in the matched dataset (light blue)

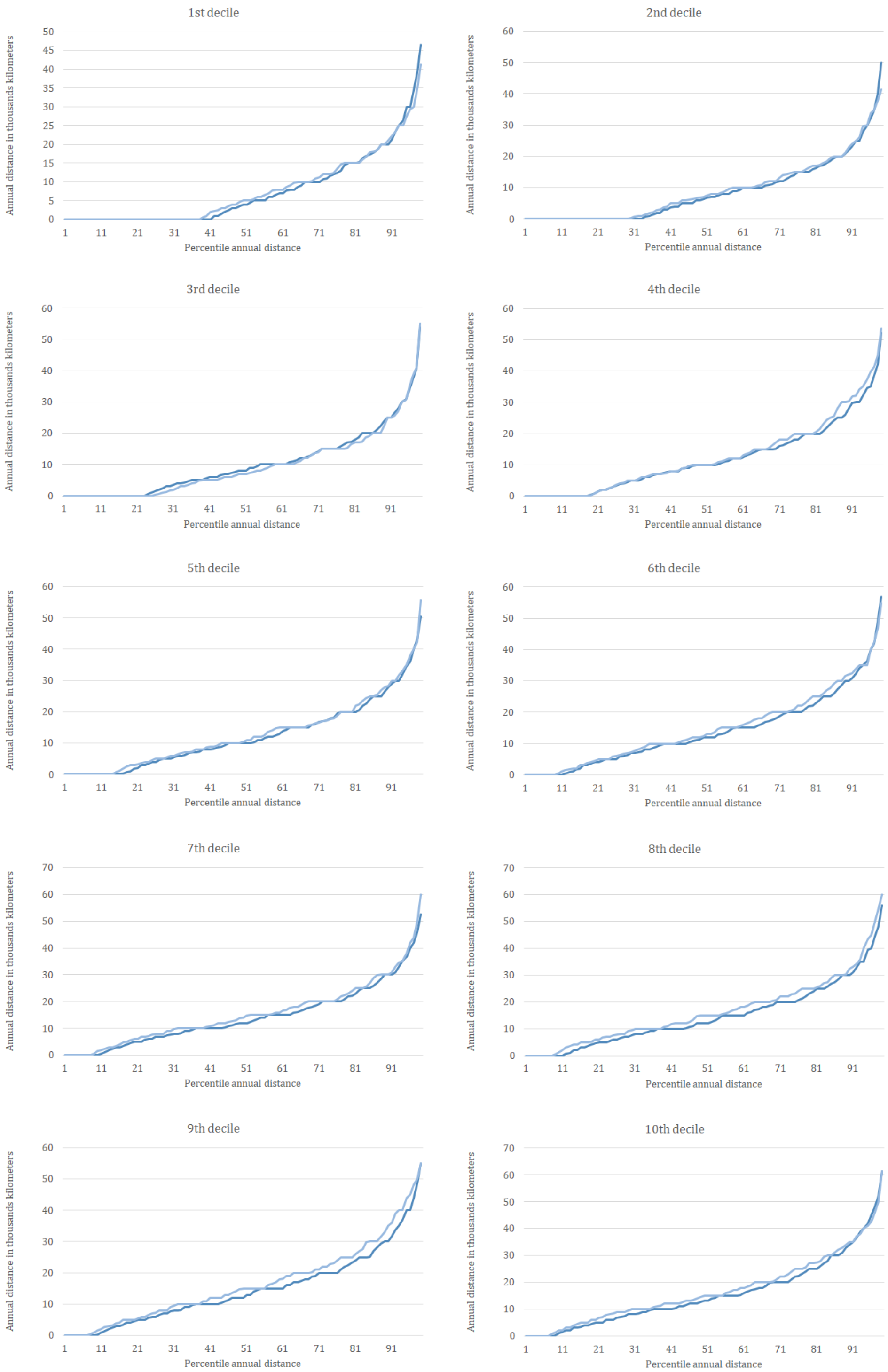


Figure 1.E.3 – Distribution of annual distances travelled per household, within the five geographical areas, in ENTD (dark blue) vs. in the matched dataset (light blue)

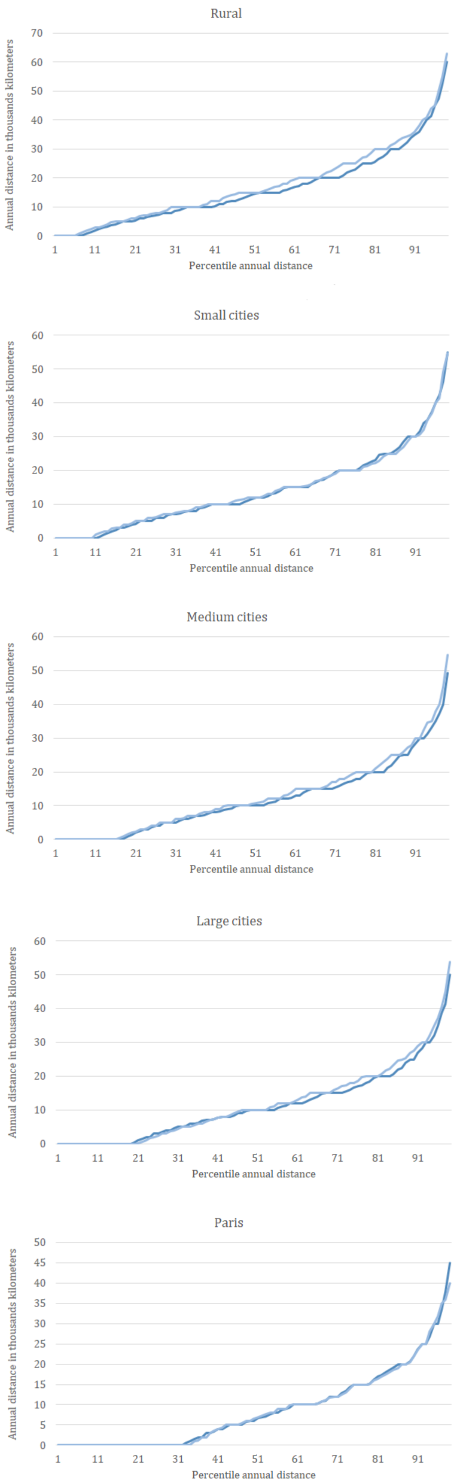


Figure 1.E.4 – Distribution of annual distances travelled with diesel vehicles per household among diesel users, within the ten income deciles, in ENTD (dark blue) vs. in the matched dataset (light blue)

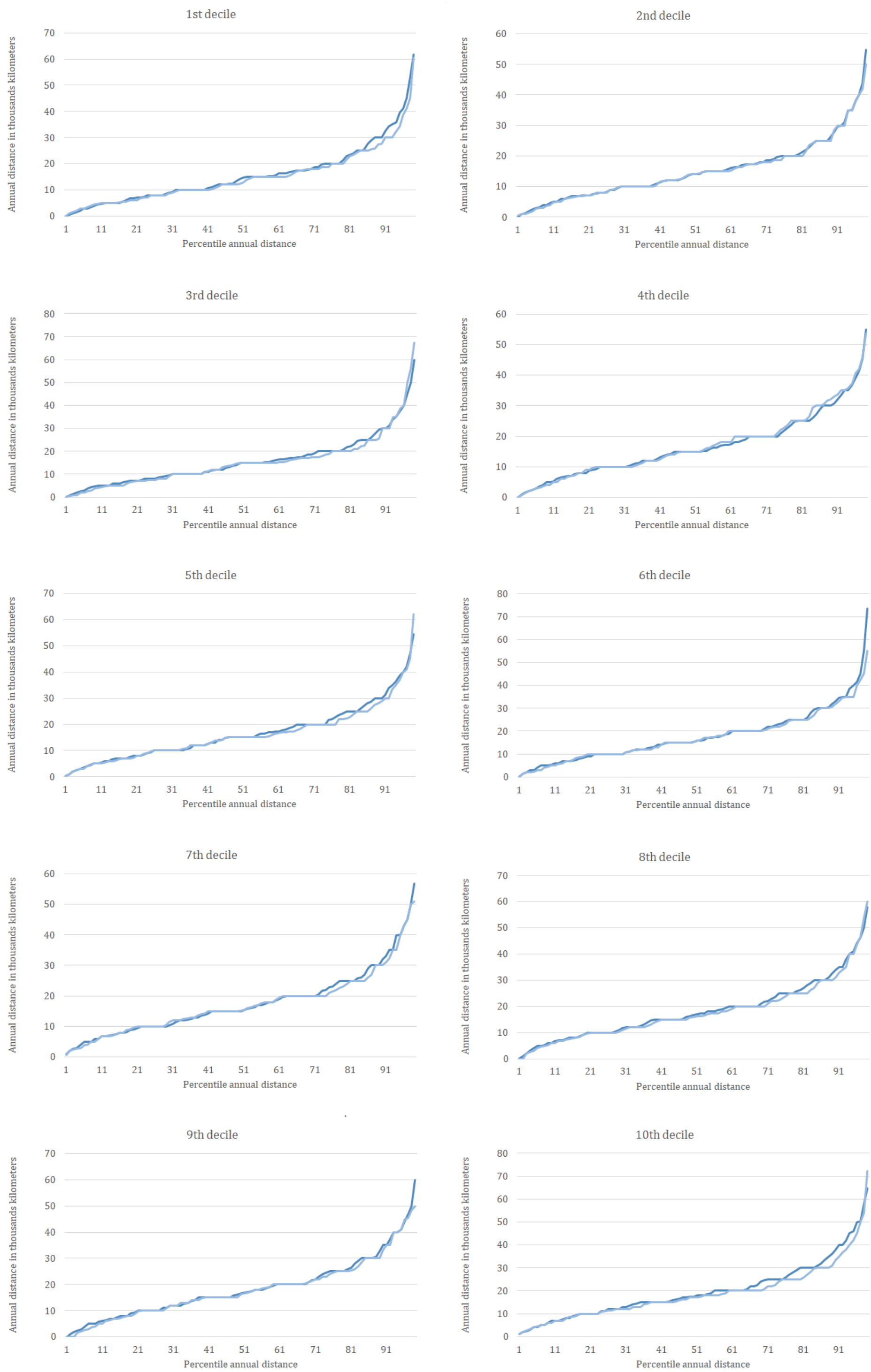
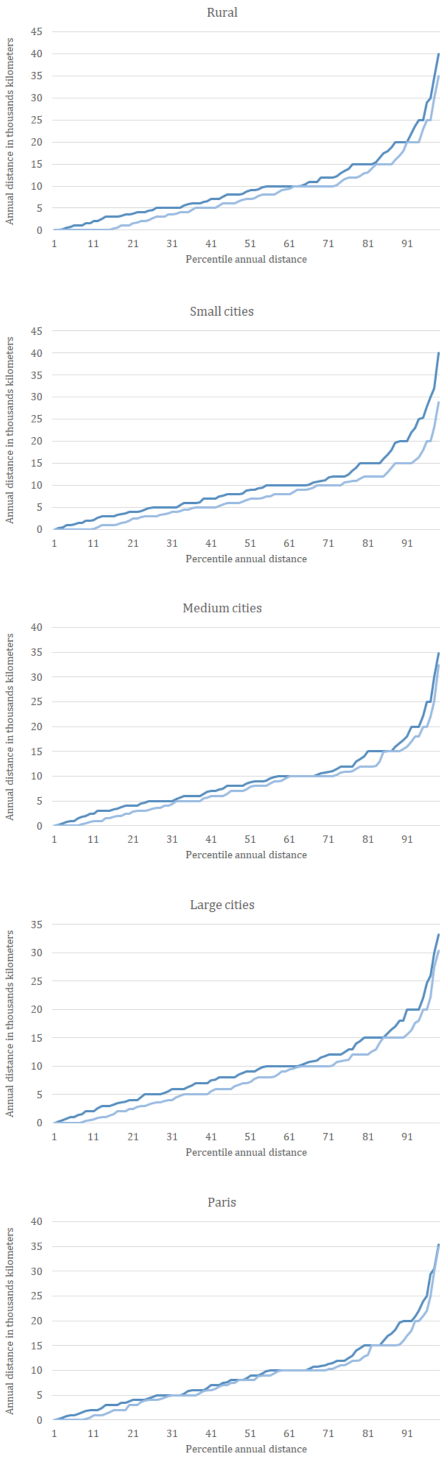


Figure 1.E.5 – Distribution of annual distances travelled with gasoline vehicles per household among gasoline users, within the five geographical areas, in ENTD (dark blue) vs. in the matched dataset (light blue)



test to check whether it is satisfied. In this case, we therefore want to know how the distances imputed from ENTD correlate to other variables in BdF that are not in ENTD.

Since the distances imputed are used to compute the tax incidence and how it differs across and within income groups, we want to be sure that the imputation does not lead to mis-estimate their distribution. As shown by the previous figures, since distributions are correctly replicated both across and within income groups, the results on the incidence of the tax on transports will be robust. The only remaining concern could be that the common variations of these distances and housing energy expenditures are mis-represented. By controlling for a large number of households characteristics strongly correlated to energy consumption, the correlation between transport and housing energy consumption should not be over-estimated and the results be robust.

Chapitre 2

Yellow Vests, Pessimistic Beliefs, and Carbon Tax Aversion [1]

1. Acknowledgments : This chapter is based on a joint work with Adrien Fabre. We are grateful to Mouez Fodha, Fanny Henriet and Katheline Schubert for their comments and their help to get funding. We also thank Stefano Carattini, Linus Mattauch, Joseph Stiglitz, Thierry Verdier, as well as seminar participants at the Paris School of Economics, Columbia University, University of Pennsylvenia, University of Amsterdam, University of Quebec at Montréal, KU Leuven, Erasmus University Rotterdam, Environmental Defense Fund, EIEE-CMCC (Milan), OECD, OFCE, and conference participants at FSR Climate Annual Conference (Florence), ADRES (Lyon), FAERE (Rennes). We are thankful to Christina Hobbs for the proof-reading. We are grateful to Erzo Luttmer and anonymous referees for their insightful comments and suggestions. We acknowledge financial support from the Cepremap, EUR PGSE (ANR-17-EURE-0001) ANR (ANR16-CE03-0011), and Université Paris 1 Panthéon-Sorbonne economics doctoral school (ED 465).

Abstract :

Using a representative survey, we find that after the Yellow Vests movement, French people would largely reject a Tax & Dividend policy, i.e. a carbon tax whose revenues are redistributed uniformly to each adult. However, they overestimate their net monetary loss, wrongly think the policy is regressive, and do not perceive it as environmentally effective. We show that changing people's beliefs about the tax incidence and effectiveness can largely increase support. Yet, beliefs change little following our informational treatments. Indeed, if overly pessimistic beliefs cause tax rejection, they also result from it through motivated reasoning, which manifests what we define as "tax aversion".

2.1 Introduction

The French government had initially committed to an ambitious trajectory for the price of carbon.[2] Initiated in 2014 at 7€/tCO_2, the French carbon tax reached 44.6€/tCO_2 in 2018 and was supposed to continue growing to hit 86.2€/tCO_2 by 2022. Yet, at the end of 2018, the same government that had accelerated the price trajectory decided to abandon it and froze the tax at its current level for an undetermined period. This turnaround in French climate policy is the direct consequence of the popular protest of the "Yellow Vests", which started against the carbon tax.[3] Among several factors, the negative impact of the tax on households' purchasing power has certainly been a key driver of public's discontent. The increasing revenues from the carbon tax were mostly used to fund the budget rather than redistributed to households, raising concerns over the distributive effects of the policy. In order to tackle the negative impact of carbon taxation on households' purchasing power, economists have proposed a scheme known as "Tax & Dividend", i.e. a carbon tax whose revenue is redistributed uniformly to each adult. This strategy has recently been supported by 3,354 American economists in The Wall Street Journal, "To maximize the fairness and political viability of a rising carbon tax". Implicitly, it is therefore assumed that with a design that ensures that the properties of the tax are aligned with people's *preferences* one should be able to generate support for it. But is it really sufficient ? In this chapter, we show that to understand the link between the properties of a policy and its support, one has to account for a critical ingredient : *beliefs*.

The objective of this chapter is to understand how beliefs about a policy form and then determine attitudes towards it. The recent events undoubtedly make the French carbon tax an interesting case study. In order to explain French attitudes towards carbon taxation, we conducted a survey on a representative sample of 3,002 French households. We focus on a "Tax & Dividend" carbon tax with uniform lump-sum compensation, which allows one to specify clearly the distributive effects of the policy, in contrast to the policy abandoned by the government. The reform is approved by only 10% of respondents and disapproved by 70% (the rest do not know or do not want to answer). We analyze the perceptions of three well-known determinants of acceptance of the carbon tax : the impact on one's purchasing power, the progressivity of the scheme, and its environmental effectiveness. We compare subjective beliefs regarding the impacts on one's

2. More precisely, the "Contribution Climat-Énergie" is a *sectoral* carbon tax specific to fossil fuels.

3. Following a massive petition against rising gasoline prices in November 2018, hundreds of thousands of people started protesting. They would wear their recognizable fluorescent clothing and gather on roundabouts and tolls every day, and demonstrate in Paris each Saturday. The Yellow Vests express a general concern for their purchasing power as well as discontent for French elites and institutions.

purchasing power to the objective distribution computed using official households' survey data. This comparison shows that people largely overestimate the tax incidence. For instance, while 70% of households are expected to win from this policy, only 14% think they would. Similarly, while the scheme proposed in our survey is progressive, a large majority of individuals perceive it as regressive. In addition, a majority of respondents do not believe that such a policy would reduce pollution and fight climate change. Using information reported over their energy equipment and usage, we are able to compute a respondent-specific estimation of the tax incidence on their purchasing power. This estimation enables us to look at the heterogeneity in what we call *biases* about the perceived tax incidence. We find that the people most opposed to the policy, and in particular those supportive of the Yellow Vests, are the most biased, i.e. the most inclined to over-estimate their losses. Thus, one may wonder whether pessimistic beliefs lead to policy rejection or if the causality goes in the other direction.

To disentangle the effect of initial beliefs on attitudes towards the policy from the reverse effect of attitudes on perceptions, we investigate the effect of providing new information to respondents through random treatments. Respondents randomly receive (or not) a piece of information about the progressivity and/or about the effectiveness of the policy, as well as the customized information — derived from our respondent-specific estimation — on whether their household is expected to win or lose from the policy. We also specify that this latter information is correct in five cases out of six, a probability that we carefully estimated out-of-sample. A first observation is that our treatments generally fail to change pessimistic beliefs. For example, among those advantaged by the reform who pessimistically believe they would lose, only 12% are convinced that they would gain when we disclose our estimation to them. Worse, respondents revise their beliefs in an asymmetric way, giving more weight to new information when it shows they would lose from the reform, i.e. when it provides them with arguments against the tax. We also find evidence strongly supportive of motivated reasoning [4] in the formation of beliefs, as those who already approved of the reform are more likely to correctly revise their belief, while those most opposed to it such as supporters of the Yellow Vests tend to discard new information unless it goes against the tax. Moreover, we find that this phenomenon is accentuated among highly educated people, suggesting that it stems from an adaptive advantage rather than a cognitive deficiency.

We use the random display of information as instruments to estimate the causal effect on

4. Motivated reasoning is the "tendency to find arguments in favor of conclusions we want to believe to be stronger than arguments for conclusions we do not want to believe" (Kunda, 1990).

the policy support of holding certain beliefs (measured as binary variables). In the case of self-interest (taken as one's beliefs about winning or losing purchasing power from the policy), we supplement these treatments by testing the support for a different policy, a Tax & *Targeted* Dividend whose compensation is targeted to people with incomes below a threshold that varies between respondents to create exogenous variations in eligibility. The method we use in this case is noteworthy, as it creates random variation in beliefs of winning around the eligibility thresholds and enables us to estimate the causal effect of this belief using a fuzzy regression discontinuity design (RDD). Our results indicate that convincing people about the actual incidence and effectiveness of the policy could lead to majority support. Indeed, we find that self-interest has a large effect on the support for the policy : the belief that one does not lose from it increases the acceptance rate by 50 p.p. Similarly, believing that the tax is environmentally effective increases the approval rate of the reform by above 40 p.p. We also provide non-causal evidence that believing in the progressivity of the scheme has a large effect on the support. Overall, these results suggest that rejection of carbon taxation does not commonly result from clashing principles, such as a disinterest in climate or a dislike of price instruments, but rather from overly pessimistic beliefs about the properties of the reform. To the extent beliefs are formed endogenously in a motivated way, people's biases gain inertia, so that new information might only push their attitude in one direction. [5]

The contribution of this chapter is three-fold. First, it contributes to a recent literature that has emerged to understand the political economy of climate policies, as this issue is becoming critical in the public debate. For a thorough review of this literature, we refer the reader to Carattini et al. (2018), and also suggest the more synthetic Klenert et al. (2018), as well as Millner & Ollivier (2016) for a review of the political obstacles to environmental policies. Stern et al. (1993) is an early work proposing and testing a model of attitudes for environmental quality aimed at disentangling egoistic from altruistic motives on the one hand, and beliefs from values on the other hand. Among all possible attitudes, they show that beliefs about consequences on self-interest are the only predictor of the willingness to pay Pigouvian taxes. Using a post-electoral survey in Switzerland, Thalmann (2004) also finds a correlation between carbon tax acceptance and self-interest, proxied by the number of cars owned. In surveys on British, Swe-

5. The "campaign effect" documented by Anderson et al. (2019) (in the case of referenda in the US state of Washington) is an example of how support for a carbon tax can decrease substantially after it enters the public debate. It may explain why acceptance of an increase in the carbon tax plummeted with the Yellow Vests movement, down from a level of 48% (ADEME, 2018) in the middle range of other countries' (Brechin, 2010). This effect confirms that the French carbon tax may be an insightful case study to understand what could happen in other countries when a controversial policy is publicly debated.

dish, and Swiss respondents respectively, Bristow et al. (2010), Brannlund & Persson (2012), and Carattini et al. (2017) document a higher approval rate when the reform addresses distributional issues. Baranzini & Carattini (2017) report that a majority of the people they interviewed in Geneva do not believe the tax would be effective, which confirms what Dresner et al. (2006b) find with focus groups in the UK. Surveying Norwegian people, Kallbekken & Sælen (2011) show that self-interest matters for acceptance, but less than concerns for environmental effectiveness or distributional effects. On US data, Anderson et al. (2019) argue that ideology explains most of the support for carbon taxation, and suggest that this effect would dominate that of self-interest.

In the present chapter, we also study how acceptance depends on these three motives (i.e. self-interest, perceived environmental effectiveness and progressivity). We contribute to the literature by providing robust evidence for causal effects where past studies essentially show correlations, often relying on proxies such as fuel consumption to proxy self-interest (e.g. Thalmann, 2004; Kallbekken & Sælen, 2011; Anderson et al., 2019). In contrast, we do not assume that people are fully rational nor have perfect information. Thus, our methodology offers a novel look at the political economy of climate policies, as it allows one to disentangle erroneous *beliefs* from pure effects of *preferences*.[6] The chapter also quantifies biases regarding the costs of the carbon tax. To our knowledge, it is the first study that compares subjective beliefs and objective data about the private costs that arise from carbon taxation. Given the intense public debate over the incidence of such a policy, identifying and measuring the discrepancy between actual impacts and their subjective perception is critical.

Second, our empirical results relate to a more theoretical literature in public finance that investigates the implications of behavioral biases on optimal taxation. In particular, Farhi & Gabaix (2020) show that the optimal tax to correct externalities deviates from the standard Pigouvian tax when agents mis-perceive commodity prices. When mis-perception is heterogeneous between agents, they also show that quantity regulations may be preferred to price instruments, and that the targeting principle does not necessarily hold anymore, i.e. it may be preferable to tax complements of the good responsible for externalities, or to subsidize its substitutes. Although our empirical strategy does not aim at estimating the formulas derived in their paper, our results show that the mechanisms they highlight are relevant in the assessment of optimal

6. We take preferences over policies as the mapping from beliefs (on facts) to attitudes (on policies), i.e. how attitudes are determined as a function of beliefs. Conversely, motivated reasoning represents the feedback loop from attitudes to beliefs.

climate policies.

Third, beyond the case of carbon pricing, this chapter contributes to the literature on the formation of political beliefs. Recent research has shown how beliefs on inequality and social mobility affect people's attitudes regarding distributive policies (e.g. Cruces et al., 2013; Kuziemko et al., 2015; Alesina et al., 2018). This chapter adds to this literature by investigating the relationship between beliefs and attitudes on climate policies. It also goes further than previous studies by identifying a bi-directional relationship as we show that not only do beliefs determine attitudes, but attitudes over policies in turn shape beliefs. Indeed, using a representative survey, our paper brings evidence consistent with theories of motivated reasoning (Kunda (1990), see Bénabou & Tirole (2016) for a recent review) that have so far been mostly tested in the lab (e.g. Redlawsk, 2002; Thaler, 2019). In particular, our results support the recent theory of Little (2019) who formalizes motivated reasoning as a way to reconcile an auxiliary belief (one's self-interest in the reform) to a core belief (here, the policy rejection). We believe our results apply beyond the case of carbon taxation, and illustrate more generally the determinants and consequences of tax aversion. Indeed, the few previous definitions of tax aversion (Sussman & Olivola, 2011) are hardly exploitable empirically, as they do not relate the concept to an observable phenomenon. This may contribute to the limited number of papers on this topic (Kallbekken et al., 2011; Kessler & Norton, 2016). Building upon our results, we can define *tax aversion* as a gut rejection of a tax (or taxation in general) that influences beliefs about the tax properties such as its effectiveness, fairness, or sameness with an equivalent measure labeled differently. Our work then shows that tax aversion can be identified through motivated reasoning, by observing that the initial tax rejection impacts how one integrates new information into one's beliefs.

The rest of the chapter is organized as follows. In Section 2.2, we describe our survey and other data sources. In Section 2.3, we compare subjective perceptions to objective data, and measure the bias regarding the impacts of carbon taxation. In Section 2.4, we study the formation of beliefs and propose several mechanisms to rationalize people's pessimism. In Section 2.5, we estimate the effects on acceptance of changing people's beliefs about the tax incidence and effectiveness. Section 2.6 concludes. Further results and methodological complements are reported in the Appendix and in an online Appendix.

2.2 Context, survey, and data

2.2.1 Context of the study

The Yellow Vests constitute a singular protest movement : although over-represented within the far left and right, they are supported by a large fraction of the French spanning from across the political spectrum.[7] Thousands of small-scale protests were organized autonomously on social networks, and the movement was remarkably independent from political parties and unions. Before the emergence of the movement, none of the major political parties was campaigning against the carbon tax, and this policy did not trigger specific opposition until the increase in oil prices brought it to the forefront of the debates.[8] The opposition then quickly gained ground, notably through Facebook where a petition against the tax and a call to protest on roundabouts were largely relayed. These protests initially occurred every day and did not phase-out until December 2018 when the government responded by a set of measures including the abandonment of the carbon tax increases initially scheduled as well as boosts to low wages and modest pensions. The fading movement came to an almost complete halt at the end of April 2019 when the government gave in on some of the demands for more purchasing power and direct democracy (Boyer et al., 2020).

A simple interpretation of these protests could be that French people are far more concerned by their purchasing power than by climate change. Yet, our companion paper documents that a large majority of French people are aware and concerned about climate change and supportive of various climate policies, such as a tax on air travel, green investments or stricter pollution norms (Douenne & Fabre, 2020),[9] and our survey suggests that willingness-to-pay for the carbon tax is similar to that of other countries (see online Appendix 2.K). Instead, French people may just not perceive the carbon as the appropriate policy to tackle climate change. Thus, the present chapter sheds light on people's beliefs about the carbon tax, how they form and how they affect the policy support.

7. Table 2.H.1 in online Appendix 2.H provides our respondents' position towards the Yellow Vests depending on their socio-demographics and left-right leaning. It shows that the support for the movement is widespread. People at the center of the political spectrum are the least supportive with still 46% warming the Yellow Vests, vs. 66% for the whole population.

8. Fuel prices peaked in October 2018. The movement gained momentum at that time, leading to the first massive protest on November 17th.

9. The levels of awareness and concern are similar to those of other countries (Stokes et al., 2015). For instance, 72% know that climate change is anthropogenic, as compared to 66% in the US (Gallup, 2019).

2.2.2 Our survey

2.2.2.1 Survey data collection

The survey was conducted in February and March 2019, three months after the government decided to abandon the planned increase of the carbon tax. The 3,002 responses were collected through the survey company Bilendi. This company maintains a panel of French respondents whom they can email with survey links. Respondents are paid 3€ if they fully complete the survey. The respondents who choose to respond are first channeled through some screening questions that ensure that the final sample is representative along six socio-demographic characteristics : gender, age (5 brackets), education (4), socio-professional category (8), size of town (5) and region (9). The quotas are relaxed by 5% to 10% relative to actual proportions for ease of the sampling process. Table 2.A.1 in Appendix 2.A shows that our sample is still extremely representative. Nonetheless, observations are weighted to correct for small differences between sample and population frequencies (e.g. in education). The median time for completion of the survey was 19 minutes. We made sure that all questions requiring some concentration were in the first half of the survey. We took several steps to ensure the best possible data quality. Our representative sample was obtained after excluding inattentive and quickest respondents. We confirm in online Appendix 2.L that this sampling restriction does not affect the main results.

2.2.2.2 The survey

The full survey in French can be seen online, [10] and the translated questionnaire is detailed in online Appendix 2.G. It contains several random branches and treatments that are independent of one another : Figure 2.2.1 presents in a diagram the sequence of information or treatments (represented by ellipses) and questions (boxes). This section presents in turn each part of the survey.

Priming on environmental issues The survey opens with a brief presentation : three short sentences to welcome the participant, introduce ourselves as "two researchers in social sciences", and say that it will last 15 to 20 minutes. Two blocks of information are then randomly displayed or not : one on climate change and the other on particulate matter (i.e. air pollution). This priming divides the sample into four groups, who receive either one block of information, the other, none, or both of them. The objective of these primings is to see whether providing

10. preferences-pol.fr/doc_q.php#_e

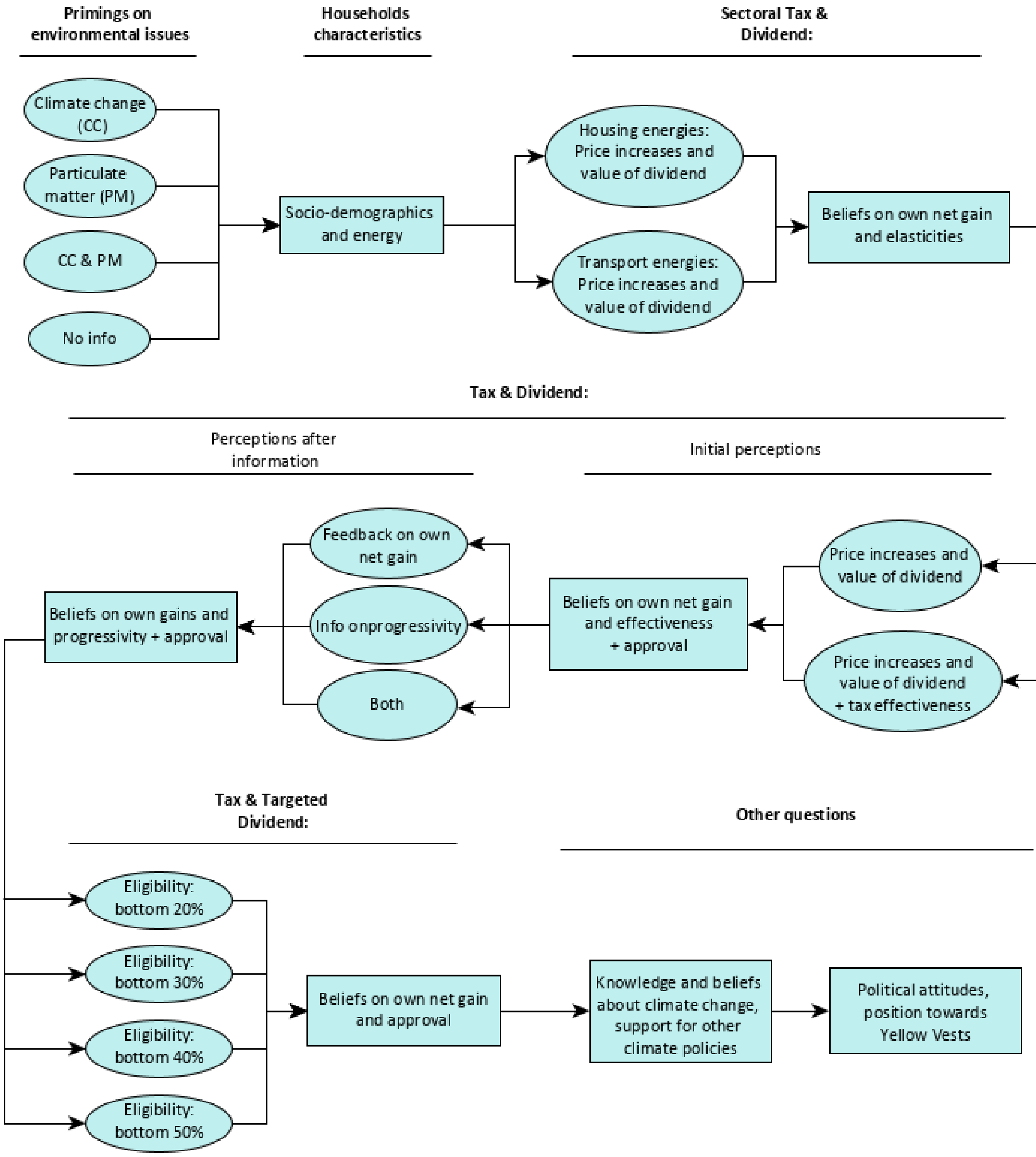


FIGURE 2.2.1 – Sequence of information or treatments (ellipses) and questions (boxes).

NOTE : The succession of informative treatments and of questions on beliefs and support for different Tax & Dividend policies informs about how beliefs are revised in view of new information, and allows to estimate the causal effects of these beliefs on the policy support.

salient information on the consequences of climate change or air pollution affects respondents' answers later in the survey. Climate change information includes temperature trends for the long-run future, concerning facts on current and expected impacts, and a claim that keeping global warming below 2 °C is technically feasible. Particulates information consists of the estimated impact on French mortality (48,000 deaths per year), life expectancy (reduced by 9 months on average in France), and the assertion that reducing fuel consumption would improve health. The time spent on each block is saved, and links to scientific references are displayed to support the information.

Household characteristics In addition to the six quotas strata, socio-demographic characteristics include zip code, household structure, income of the respondent and of their household. A block on energy characteristics contains questions that allow us to estimate the impact of a carbon tax increase on housing expenditures (energy source, size of accommodation) as well as on transport expenditures (number of vehicles, type(s) of fuel, distance travelled last year, and average fuel economy). The distributions of answers are much in-line with official statistics, as shown in Table 2.A.2 in Appendix 2.A.

Sectoral Tax & Dividend We first randomly allocate the respondent to one of the two sectors on which the French carbon tax applies : housing *or* transport. They are presented with a specific policy : a sectoral Tax & Dividend, i.e. an increase in housing *or* transport energies taxes that would finance a lump-sum transfer to all adults. [11] We detail the increases in prices that would follow and the value of the dividend they would receive : for the housing energy tax, +13% for gas and +15% for heating oil together with a yearly transfer of 50€ per adult ; for the transport energy tax, +0.11€ per liter of gasoline and +0.13€/L for diesel with a yearly transfer of 60€ per adult. These figures are equivalent to an increase in the carbon price on these energies by 50€/tCO_2, but we do not mention the name "carbon tax" at this stage as we do not want people to think that it also falls on the other sector. The value of the dividends were obtained such that the policy is budget neutral, and assuming typical price elasticities (see 2.2.3.1). We present the policy starting with "The government studies..." to capture the effect of distrust in government that could arise in the actual political process.

Then, we ask the respondent whether their household would win, lose, or be unaffected by

11. We chose to redistribute per adult instead of per consumption unit to make the scheme more understandable. We limited the number of beneficiaries to two per household to better align with current welfare benefits that depend on the number of consumption units.

the reform in terms of purchasing power (win/lose category thereafter). Depending on their answer, we further ask them to estimate their expected gain (or loss) among 5 (or 6) intervals. The interval thresholds are tailored to each respondent, as they are computed in proportion of the number of consumption units (c.u.) of their household (as defined by Eurostat).[12] Similarly, households' gains and losses are always expressed per consumption unit in the analysis. The questions were not incentivized by monetary rewards for accurate answers. Indeed, Sapienza & Zingales (2013) show that people think that economic experts are too optimistic regarding the carbon tax, so incentivizing the answers could have led respondents to misreport their true beliefs and shift them towards what they think the researchers expect. Finally, to see whether people think the incentive purpose of the tax operates, respondents are asked to estimate their own elasticity as well as that of French people. To this end, we borrow the phrasing of Baranzini & Carattini (2017), and ask for the expected decrease in consumption that would follow a 30% increase in the price of heating (or equivalently, an increase of 0.50€/L in fuel prices), among 5 brackets.

Tax & Dividend

Initial perceptions Our main reform of interest is an increase by 50€/tCO_2 of the French carbon tax, that concerns *both* housing and transport.[13] The revenues generated are again redistributed equally, so that each adult receives a yearly lump-sum compensation of 110€. We now explicitly present the reform as an increase in the carbon tax, although as before we do not give the implicit carbon price but rather the effect on energy prices (the same as before, but on both sectors) and the value of the dividend.[14] After describing the reform, a first block of questions elicits the respondent's perceptions. Their subjective net gain in purchasing power is asked in the same manner as for the sectoral tax, with adapted intervals. The priming that "scientists agree that a carbon tax would be effective in reducing pollution" is randomly displayed or not before asking whether the reform would be effective in reducing pollution and fighting climate change. Finally, we ask : "Would you approve of this reform ?" and let the respondent choose between "Yes", "No" and "PNR (I don't know, I don't want to answer)".[15] In the following, we say that a respondent *approves* a reform if they respond "Yes", and that they *accept* the reform if

12. For instance, for a single-member household (c.u.=1), the intervals of expected gain (in €/year) are (0, 10), (10, 20), etc. ; while for a childless couple (c.u.=1.5), these intervals are (0, 15), (15, 30), etc.
13. Electricity and industries are exempt from the French carbon tax as they are already covered by the EU-ETS.
14. For the exact phrasing, see question 35 in online Appendix 2.G.
15. In English, "PNR" stands for "Prefer Not to Respond".

they do *not* respond "No". Table 2.I.1 in the online Appendix 2.I describes the rates of support for the Tax & Dividend policies at different stages of the survey.

Perceptions *after information* To assess how beliefs are formed and measure the importance of self-interest and fairness motives in the acceptance of the reform, we then provide some information on the effect of the reform. To a random half of the sample, we explain that "this reform would increase the purchasing power of the poorest households and decrease that of the richest, who consume more energy". To two-thirds of the respondents (the remaining half plus one-third of the respondents with the previous priming on *progressivity*), we provide customized information explaining that : "In five cases out of six, a household with your characteristics would [win/lose] through the reform. (The characteristics taken into account are : heating using [energy source] for an accommodation of [surface] m^2 ; [distance] km travelled with an average consumption of [fuel economy] L for 100 km.)". In Section 2.2.3.2, that details how we compute each respondent's net gain, we show that our prediction that a household wins or loses is correct in 83% of cases, hence our "five cases out of six".

Then, we again ask for the win/lose category (i.e. if the respondent's household would win, lose or be unaffected by the reform) and for the approval of the reform. Respondents are also asked about the perceived advantages and disadvantages of the policy, including the effect on the poorest households. To the later half of the sample, we explicitly ask right after the treatment on progressivity whether they think the reform would benefit the poorest as most respondents appeared not to believe our information.

Tax & Targeted Dividend In order to disentangle the effect of self-interest from other acceptation motives in Section 2.5, we then submit to respondents an alternative reform where only some people are eligible. More specifically, we propose one of four alternative reforms where the payments, still equal among recipients, are targeted to adults whose income is below some threshold. The four possible thresholds correspond to the 20th, 30th, 40th, and 50th percentile of the income distribution. They are computed using inflated deciles of individual income from the *Enquête sur les Revenus Socio-Fiscaux* (ERFS 2014) produced by Insee (the French national statistics bureau).[16] Respondents whose income lies between two thresholds are allocated randomly to a reform defined with one of them. For example, a person at the 25th percentile of the income distribution has one in two chances to face a reform targeted to the bottom 30%,

16. Incomes entitled to the household rather to its members, such as certain welfare benefits, are divided equally among the two oldest adults of the household.

where they are eligible to the dividend, and one in two chances to face a reform targeted to the bottom 20%, where they are not. When the income is close to only one threshold (i.e. when its percentile in the distribution is below 20 or within [50; 70]), the allocated reform corresponds to that one. When the respondent's income is distant from all thresholds, i.e. when it is in the *top* 30% (above 2220€/month), the reform they face is determined by the income of the household's second adult. Finally, when both (or the only one) adults in the household are in the top 30%, their reform is allocated randomly between the four variants. Table 2.2.1 details the income thresholds and dividends of the four variants as well as the proportion of respondents allocated to each of them, along with the proportion one would expect from the *ERFS*. The two sets of figures match almost perfectly, indicating that our sample is representative along the income dimension.

We describe to each respondent the variant they face : the price increases, the income threshold and the value of the dividend ; we also specify how many persons would be eligible to the payment in their household. Finally, we ask again respondents for their anticipated win/lose category and their approval. The random variation in eligibility creates exogenous variation in the win/lose belief which is used to estimate its causal effect on acceptance in a fuzzy RDD.

TABLE 2.2.1 – Characteristic of the targeted reform by target of the payment.

Targeted percentiles	≤ 20	≤ 30	≤ 40	≤ 50
Income threshold (€/month)	780	1140	1430	1670
Payment to recipients (€/year)	550	360	270	220
Proportion of respondents	.356	.152	.163	.329
Expected proportion of respondents	*.349*	*.156*	*.156*	*.339*

NOTE : This table reads as follows : when targeted people are the ones below the 20th percentile (≤ 20), all adults with an income below 780€/month receive a dividend of 550€/year. 0.356 of our respondents are assigned to this policy (to which they may be eligible or not depending on their income), against 0.349 if our survey was *exactly* representative of the true income distribution of the French population.

Other questions We do not detail the other questions of the survey, because we devote a companion paper to their analysis, Douenne & Fabre (2020). In these questions, we examine opinions on environmental policies, including other ways to recycle the revenues of a carbon tax. We measure the knowledge and perceptions of climate change ; ask some specific questions on the influence of climate change on the choice to give birth, and one's willingness to change their lifestyle. We study the use, availability, and satisfaction with public transportation and active mobility. We also ask for political preferences, including position in relation to the Yellow Vests. Finally, we let the respondent express any comment in a text box.

Notations We adopt consistent notations throughout the chapter, defined in Appendix 2.B, and recalled throughout the text.

2.2.3 Official households surveys

In addition to our survey, the chapter makes use of three official households surveys produced by Insee : the consumer survey *Budget de Famille* (BdF 2011), the transport survey *Enquête Nationale Transports et Déplacements* (ENTD 2008) and the housing survey *Enquête Logement* (EL 2013). We use these additional datasets for two purposes. First, we use the first two surveys to estimate the distribution of additional fossil fuels expenditures. This in turn provides both an estimate of total revenues from the tax (and hence of the dividend) as well as an estimate of the *objective* distribution of net gains that allows for a comparison with the *subjective* distribution derived from our survey. Second, we use the housing survey to compute a respondent-specific estimate of the objective net gain. It allows us to measure respondents' bias regarding their net gain and provide them with a customized win/lose feedback. The precision of this estimate is assessed by testing it out-of-sample on the consumer survey. The different steps are explained below. [17]

2.2.3.1 Eliciting objective aggregates and distributions

Data For the first purpose, we use the database constructed by Douenne (forthcoming) whose objective was to estimate the distributive effects of a carbon tax on French households. It builds on the consumer survey (BdF 2011) that includes over 10,000 households for whom it provides information over all their revenues and expenditures — including their energy bills — together with many socio-demographic characteristics. This survey is matched to the transport survey (ENTD 2008) to correct for short run fluctuations in transport fuels consumption. Such matching is not necessary for housing energies as these already represent consumption over long periods in BdF. [18]

Computing tax incidence and revenues From this combined dataset, we are able to determine the increase in expenditures households would face and compute the total tax revenue to be redistributed lump-sum. We thereby obtain the distribution of households' *objective* net gains

17. Data from National Accounts is used to homogeneously inflate households' sectoral expenditures of each dataset we use in order to make them representative of the most recent trend and comparable across datasets.
18. For more information about these surveys, see Appendix 2.C.1.

in purchasing power implied by the policies proposed. Formally, the net gain γ_h of an household h can be expressed as :

$$\gamma_h = N_h^a \cdot D - \Delta E_h^{transport} - \Delta E_h^{housing} \tag{2.1}$$

where $D = 110€$ denotes the value of the dividend, N_h^a the number of adults receiving it in this household, and $\Delta E^{transport}$, $\Delta E^{\text{housing}}$ the increases in their energy expenditures. The formulas used to compute the three terms on the right hand side are given in Appendix 2.C.2. Our computations use typical elasticities found in the literature on French households : -0.4 for transport and -0.2 for housing, as well as an incidence borne at 80% by consumers. [19]

2.2.3.2 Computing households' expected net gains

Simulating expected net gains In order to measure each respondent's bias and to provide a customized feedback on their win/lose category, we need to estimate their net gain as expressed by equation (2.1). Since households are asked about yearly distance travelled and average fuel consumption of their private vehicles, we can directly compute the increase in their transport fuels expenditures $\Delta E^{transport}$. However, we lack their housing energies expenses to evaluate $\Delta E^{housing}$. We therefore need to estimate it based on their energy characteristics. To do so, we use the housing survey *Enquête Logement* (EL 2013) that again provides information on household expenditures in housing energies as well as many demographic and energy characteristics. It enables us to compute $\Delta E^{housing}$ and regress it on household characteristics. The coefficients obtained can then be used to compute $\widehat{\Delta E}^{housing}$ (and thus obtain $\widehat{\gamma}$) for any household. The specification we chose is as follows :

$$\Delta E_h^{housing} = \beta_0 + \beta_1 \chi_h^G + \beta_2 \chi_h^F + \beta_3 \sigma_h + \varepsilon_h \tag{2.2}$$

where χ_h^G (resp. χ_h^F) is a dummy variable equal to 1 if the household uses gas (res. heating oil) for heating, and σ the size of the household's accommodation in square meters. The results are provided in Appendix 2.C.3, where they are shown to be as accurate as the ones obtained from alternative prediction methods and specifications, with the advantage of more robustness to potential misreporting of size of accommodation.

19. These values correspond to the short run uncompensated price elasticities estimated by Douenne (forthcoming), and are in line with previous findings on French households (e.g. Clerc & Marcus, 2009; Bureau, 2011).

Assessing feedback's accuracy The previous estimation could have also been conducted with BdF data. Still, running this estimation on the housing survey is very useful : it enables us to test the accuracy of our prediction out-of-sample. Indeed, since for households in BdF data we observe both their energy characteristics and their actual energy bills, we can both calculate directly $\Delta E^{housing}$ and use our prediction to compute $\widehat{\Delta E}^{housing}$. Adding to this the additional costs arising from transport energies and the dividend, we can obtain both their true net gain γ and their estimated one $\widehat{\gamma}$. This allows us to estimate the likelihood of correctly predicting the win/lose category for these households. Because the prediction was made from a different survey than the one on which it was tested, we avoided the risk of over-fitting.

Figure 2.C.2 in Appendix 2.D.2 shows how the probability that our prediction is correct depends on objective gains. For five households out of six, we correctly predict whether their purchasing power would increase or decrease through the policy. We make this ratio symmetrical to balance the shares of overly optimistic and overly pessimistic feedbacks : among households in BdF predicted to win, 83.4% were actual winners, while among those predicted to lose, 83.4% were actual losers. Assuming that the characteristics reported by our respondents are correct, there is no reason to believe that the probability of error is higher or lower when simulations are applied to our survey respondents. [20]

2.3 Pessimistic beliefs

2.3.1 Self-interest

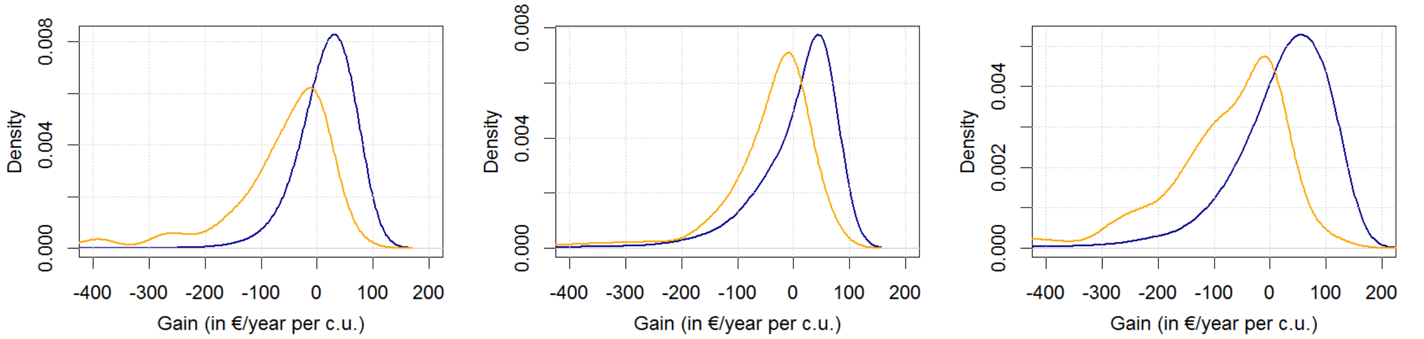
Over-estimation of policy costs While 70% of households should benefit (in monetary terms) from the compensated carbon tax, only 14% think they would (and 22% see themselves unaffected). [21] Figure 2.3.1 plots the kernel density of expected net gains for objective data from Insee, and subjective beliefs from our survey. Figure 2.3.2 compares the CDF of objective vs. subjective net gains. [22] It is evident from these figures that on average, respondents overestimate the cost of the policy, even in the extreme case of perfectly inelastic expenditures. This result holds

20. In particular, a critical assumption is that people correctly reported their distance travelled and the average fuel economy of their vehicles, so that the computation of $\Delta E^{transport}$ is correct. As shown in Table 2.A.1 in Appendix 2.A, the values reported by respondents follow a distribution very similar to the one found in official statistics.

21. For transport and housing energy taxes, the objective proportions of winners are very similar at respectively 74% and 67%, while the subjective shares are 16% and 17% (with 22% and 30% of unaffected).

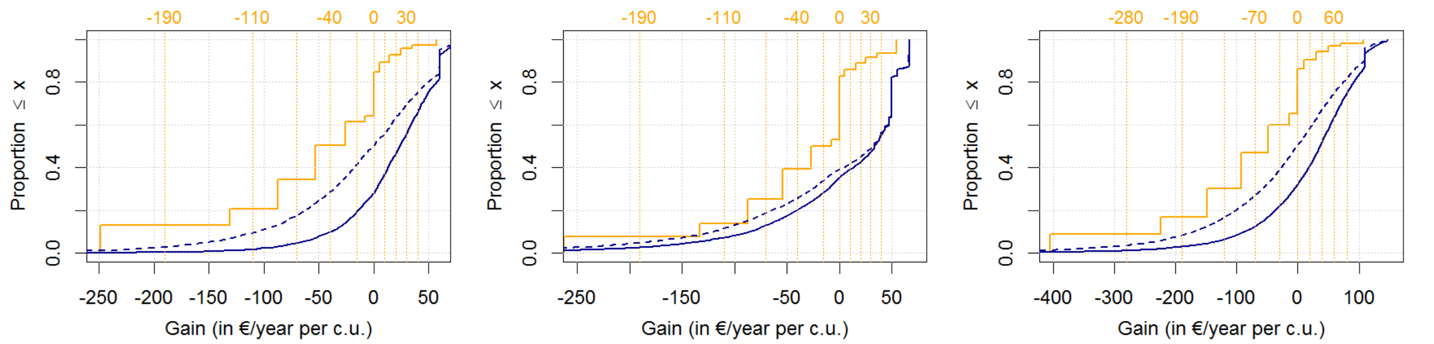
22. The subjective intervals are translated into numerical values, assuming that the distribution within each interval is the same as that of Insee data. Within each bin, we draw values that match the actual distribution for the PDF, while we simply take the actual average for the CDF. Among the several methods that we tried to assign numerical values, all realistic ones yield identical results, and we find an overestimation of policy costs even in the most conservative one (taking the maximal bounds of intervals).

both for the carbon tax and for partial carbon taxes on transport and housing energies. The average net gains from the carbon tax on transport, housing, and both, are respectively 18€ per consumption unit (c.u.), 6€ per c.u., and 24€ per c.u. from BdF data. Extrapolating from our survey, we instead find average subjective net gains of respectively −61€, −43€, and −89€. The median gap of 116€ between objective and subjective gains indicates a substantial bias towards loss from typical respondents. This bias is widespread, as we find that 89% of respondents underestimate their gain of purchasing power relative to our household-specific estimation. (The full distribution of respondents' bias is provided in Figure 2.C.3 in Appendix 2.C.3.) This proportion remains as high as 77% when assuming inelastic expenditures, which provides a lower bound on the share who underestimate their net gain in utility.



(a) Transport fuels (b) Housing energies (c) Both

Figure 2.3.1 – Distribution of objective (dark blue) vs. subjective (orange) net gains from our Tax & Dividend.



(a) Transport fuels (b) Housing energies (c) Both

Note : Dashed blue lines represent distributions of objective gains in the extreme case of totally inelastic expenditures. Vertical dotted orange lines show the limits of intervals answers of subjective gains.

Figure 2.3.2 – Cumulative Density Function of objective (dark blue) vs. subjective (orange) net gains from our Tax & Dividend.

Heterogeneity in bias In order to characterize profiles of individuals more likely to mis-perceive their gains, we regress mis-perception over many respondents' characteristics. Mis-perception

TABLE 2.3.1 – Determinants of bias in subjective gains.

	Large bias ($\|\hat{\gamma} - g\| > 110$)		
	OLS	*logistic*	*OLS*
Initial tax : PNR (I don't know)			−0.179
			(0.023)
Initial tax : Approves			−0.284
			(0.031)
Yellow Vests : PNR	0.039	0.035	0.024
	(0.036)	(0.035)	(0.036)
Yellow Vests : understands	0.081	0.062	0.041
	(0.025)	(0.024)	(0.025)
Yellow Vests : supports	0.108	0.103	0.051
	(0.026)	(0.025)	(0.026)
Yellow Vests : is part	0.202	0.193	0.147
	(0.048)	(0.040)	(0.047)
Ecologist	−0.064	−0.061	−0.025
	(0.026)	(0.026)	(0.026)
Left-right : Left	−0.066	−0.044	−0.045
	(0.063)	(0.065)	(0.061)
Left-right : Center	−0.062	−0.048	−0.046
	(0.065)	(0.068)	(0.064)
Left-right : Right	−0.024	−0.010	−0.026
	(0.064)	(0.066)	(0.063)
Left-right : Extreme-right	−0.076	−0.057	−0.088
	(0.066)	(0.069)	(0.065)
Left-right : Indeterminate	−0.009	0.017	−0.007
	(0.061)	(0.063)	(0.060)
Controls : Socio-demo, political leaning	✓	✓	✓
Observations	3,002	3,002	3,002
R^2	0.061		0.098

NOTE : Standard errors are reported in parentheses. For logit, average marginal effects are reported and not coefficients. Omitted variables are *Yellow Vests : opposes* ; *Left-right : Extreme-left*. The list of controls can be found in Appendix 2.F. A large bias is defined as a difference between subjective (g) and objectively estimated ($\hat{\gamma}$) net gain larger than 110€/year per c.u.

is defined as a gap between objectively estimated and subjective net gains beyond 110€ per c.u., because our estimation differs from true objective gain by more than 110€ in only 5% of cases. This definition ensures that the 55% of respondents with a mis-perception have in fact a large bias. Other definitions for the bias yield very similar results. The results given in Table 2.3.1 show that mis-perception is largely idiosyncratic : controlling for a large set of variables [23] (column 1), the R^2 remains small (0.06). Still, we identify several variables having a significant effect on mis-perception even when controlling the False discovery rate at 5%. [24]. Environmentalists are about 6 p.p. less likely to display a large bias. Interestingly, while the standard left/right political

23. The control variables used throughout the chapter are described in Appendix 2.F.

24. To conduct the multiple testing procedure (following Benjamini & Hochberg, 1995), instead of associating each dummy to a different null hypothesis we used F-tests of joint nullity for the dummies of each categorical variables as well as for two additional triplets of variables : those related to household composition and incomes.

leaning has no significant effect, the position towards the Yellow Vests appears to be the most critical determinant of mis-perception. Relative to respondents who declared to be opposed to the movement, those who declared to "understand", "support", or "be part" of it are more likely to mis-perceive their gains. This effect is increasing with the degree of adhesion, up to 20 p.p. for individuals who declared to be part of the movement. Column (3) additionally includes one's position towards the policy as a covariate : we see that people who approve the policy are 28 p.p. less likely to mis-perceive their gains relative to those who do not accept it, and 10 p.p. less likely relative to those who do not know. We can think that the degree of support of the policy is what determines most of the bias (explaining e.g. why *Environmentalist* loses its explanatory power when we control for the support), and that the Yellow Vests variables remain significant only because they capture different *degrees* of rejection of the tax (which our Yes/No question cannot do).

Overall, typical biases are large and closely related to one's convictions. However, the direction(s) of causality between beliefs and rejection is not resolved at this stage. Section 2.4 provides evidence that some people think they lose because they oppose the tax, while Section 2.5 shows that perceived outcomes causally influence support.

2.3.2 Environmental effectiveness

A well established result in the literature on the acceptability of climate policies is the perceived ineffectiveness of Pigouvian instruments (e.g. Dresner et al., 2006a; Kallbekken et al., 2011; Baranzini & Carattini, 2017). In particular, people do not see carbon taxes as effective to fight climate change. Our findings confirm this result : among our survey respondents, only 17% answered "Yes" when asked whether our Tax & Dividend would be effective in reducing pollution and fighting climate change, 66% answered "No", 18% that they did not know.

An explanation sometimes encountered to explain perceptions of ineffectiveness is that most people believe that energy consumption is quite inelastic (Kallbekken & Sælen, 2011; Carattini et al., 2018). To test this hypothesis, we regress a binary variable E equal to 0 if the respondent does not perceive the policy as environmentally effective and 1 otherwise, on their subjective price elasticity for French people. As respondents were randomly assigned to transport or housing, we run a separate regression for both types of energies. Table 2.D.1 in Appendix 2.D.3 reports results with and without control variables. They all consistently indicate that perceived elasticities are correlated with beliefs about the policy's effectiveness, as a respondent anticipating an elasticity of -1 is (on average) 6 p.p. more likely to perceive the policy as effective than one anticipating no elasticity. Although significant, the magnitude of the effect is modest, showing that the perceived ineffectiveness of tax instruments should not be reduced to small subjective elasticities. Indeed, among respondents who perceive the policy as environmentally ineffective, almost half anticipate responses to price changes larger than the literature.[25]

A more plausible explanation for perceived ineffectiveness is that people do not believe that the policy would be sufficient to *substantially* affect pollution and climate change. Taking respondents' average anticipated elasticities for transport and housing energies (that are fairly accurate[25]), the tax should reduce French greenhouse gas (GhG) emissions by 5.7 Mt of CO_2 equivalent (CO_2e) each year, according to the simulation from BdF data. This reduction corresponds to 0.8% of French annual emissions, 0.01% of global ones, and is only a small step towards the official objective of carbon neutrality in 2050.[26] Thus, although respondents do anticipate responses to price incentives, our results suggest that they do not perceive a 50€/tCO_2 national carbon tax as a proportionate reaction to climate change.

2.3.3 Progressivity

It is often argued that a critical barrier to accept carbon taxation is its perceived distributional impact, in particular the higher burden imposed on lower income households (Bristow et al., 2010; Brannlund & Persson, 2012; Gevrek & Uyduranoglu, 2015). A broad literature has shown that carbon taxation alone is regressive (Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010), meaning that it is more costly for poorer households as a share of their resources. However, it has also been shown that redistributing its revenue through uniform lump-sum transfers — i.e. a Tax & Dividend — can make the policy progressive (West & Williams, 2004; Bento et al., 2009; Williams et al., 2015), including for France (Bureau, 2011; Douenne, forthcoming). Figure 2.C.4 in Appendix 2.C.4 displays the average net gain by income decile for our Tax & Dividend. It clearly appears from this figure that lower income households would gain more than richer households, both in relative and in absolute terms. Yet, only 19% of respondents think the policy would benefit the poorest households, compared to 60% who declare it would not, and 21% who do not know.

25. Overall, average subjective elasticities are close to these estimates for transport (at -0.45) and somewhat overestimated for housing (-0.43). Among those who declared that the policy was not effective, 45% (resp. 43%) anticipated an aggregate elasticity at or below -0.5 for housing (resp. for transport), while elasticities obtained from the literature are around -0.2 for housing and -0.4 for transport.

26. The computations are based on households' carbon emissions. In 2014, French GhG consumption based emissions were equal to 712 MtCO_2e (CGDD, 2019). 2017 global emissions were 53.5 GtCO_2e (UNEP, 2018).

2.4 How attitudes shape beliefs

The previous section has shown that people's low acceptance of our Tax & Dividend correlates with pessimistic beliefs about the properties of the scheme. As knowledge about these properties has been shown to be decisive for acceptance (Carattini et al., 2018), it is important to assess how beliefs are formed. In the following, we test respondents' reactions to information about their gains, environmental effectiveness, and progressivity. If overly pessimistic views simply reflected a lack of knowledge, we would expect them to revise their beliefs after new information is provided, what we refer to as "update".

2.4.1 Self-interest

2.4.1.1 Pessimism in the revision of beliefs

Our respondent-specific estimation of net gains (see Section 2.2.3) enables us to tell respondents that given their characteristics, they have 5 out of 6 chances to "win" or "lose" from the policy. We can then examine how they update their beliefs about their win/lose category after receiving this information. The full transition matrices of people's beliefs are given in Tables 2.D.2 and 2.D.3 in Appendix 2.D.2. More concisely, Table 2.4.1 reports the share of respondents whose beliefs after being informed are aligned with our feedback, with the corresponding 95% binomial confidence intervals. It shows a very asymmetric response depending on the feedback received. On the one hand, for the 24% of individuals who receive a "lose" feedback ($\widehat{\Gamma} = 0$), the *ex post* belief is on average consistent with the fact that 83% of them are effectively losers. If anything, these people would rather tend to *agree too much* with our noisy signal, especially when excluding people who initially consider themselves as unaffected (i.e. focusing on $g^0 \neq 0$). On the other hand, the 76% who received a "win" feedback ($\widehat{\Gamma} = 1$) appear to be much more conservative in their revision since only 25% of them endorse the "win" feedback. Among the respondents who initially thought they would lose in this group, a mere 12% flip their answer from "lose" to "win". This is in sharp contrast with the respondents who initially thought they would win and receive a "lose" feedback, since 82% of them endorse our prediction. Thus, pessimistic beliefs are persistent to our treatment, but optimistic ones are not.

Table 2.D.4 in Appendix 2.D.2 conducts the same analysis for the 28% of respondents whose gain is largely positive or largely negative, i.e. above 110€ per c.u. in absolute terms. For such respondents, our out-of-sample prediction of the win/lose category is correct in 99% of cases, as

Table 2.4.1 – Share of respondents with new beliefs aligned with feedback.

	Aligned with feedback : $G^F = \widehat{\Gamma}$	
	Feedback :	
	win ($\widehat{\Gamma} = 1$) (75.8%)	lose ($\widehat{\Gamma} = 0$) (24.2%)
Initial belief winner ($g^0 > 0$) (14.0%)	78.8% [73.2%; 83.4%]	81.5% [65.0%; 91.3%]
Initial belief unaffected ($g^0 = 0$) (21.7%)	21.6% [17.6%; 26.2%]	44.9% [33.5%; 56.8%]
Initial belief loser ($g^0 < 0$) (64.3%)	12.2% [10.3%; 14.5%]	93.9% [90.9%; 96.0%]
Initial belief affected ($g^0 \neq 0$) (78.3%)	26.1% [23.7%; 28.7%]	92.9% [89.8%; 95.1%]
All (100%)	25.1% [23.0%; 27.3%]	85.7% [82.2%; 88.7%]

Note : The 95% confidence intervals for binomial probabilities are given in brackets. The Table reads as follows : among those who initially think they would win ($g^0 > 0$) but are told they are expected to lose ($\hat{\Gamma} = 0$), 81.5% agree that they would lose ($G^F = 0$). The feedback $\hat{\Gamma}$ is not a random draw, but a deterministic outcome of the characteristics reported by respondents in the survey.

can be seen in the Figure 2.C.2 in Appendix 2.D.2. The alignments with our feedback are similar between the whole sample and these respondents for whom we are sure to make a correct prediction. The similarity of alignments for different prediction accuracy rules out the possibility that a large fraction of respondents do not update because their private information would be *truly* more accurate than our prediction.

2.4.1.2 Mechanisms

There are several ways to rationalize the pessimistic beliefs and attitudes against the Tax & Dividend. We propose below four mechanisms : distrust, uncertainty, motivated reasoning, and intentional mis-reporting.

Distrust The first mechanism is that respondents distrust what we present to them. They may perceive our information as biased, think we wrongly estimate their likelihood to win and that we are too optimistic.[27] As a result, they may discount our new information relative to their prior, or assign relatively more weight to our information when it is pessimistic. This distrust may stem from an impression that experts understate the costs of a carbon tax, or that the go-

27. Another possibility is that respondents give too much value to their private information relative to the base rate one. That is to say, pessimistic winners might be over-confident in seeing themselves as specific so that they partly discard the new information, e.g. by thinking they are part of the one-sixth for whom our prediction is erroneous, perhaps because they believe they always lose more than others from new policies.

vernment will break its promise to pay the dividend. For instance, Sapienza & Zingales (2013) report that 51% of Americans are skeptical that their governments would deliver on using the proceeds of a carbon tax to reduce other taxes (see also Dresner et al., 2006a; Hsu et al., 2008). A similar level of skepticism regarding the dividend could explain much of the pessimism about net gains.

Uncertainty The second mechanism stems from people's uncertainty regarding their gain. That uncertainty would make them see their possible gain as a distribution (see Stiglitz, 2019). Then, instead of reporting the average of this distribution, people subject to loss-aversion would reason with conservative estimates for their gains. Also, the effect of uncertainty on updating is ambiguous : on the one hand uncertain people could be more likely to rely on our base rate information, but on the other hand their subjective probability to lose could remain high despite our information.

Motivated reasoning The third mechanism to explain the observed asymmetry in beliefs revision is that some people have a strong skeptical attitude towards the carbon tax, which affects the formation of their beliefs. They would engage in motivated reasoning, i.e. update their beliefs in a way that is consistent with their initial views (Druckman & McGrath, 2019; Little, 2019) rather than integrate information in a way that leads to accurate conclusions. Although linked to the distrust in that motivated reasoning also involves neglecting information, in the case of distrust information is discarded because its source is not trusted, while for motivated reasoning information is dismissed when its content goes against pre-existing views. Motivated reasoning entails a deviation from Bayesian updating — contrary to the first two mechanisms —, but it can still be *rationalized* as a psychological adaptation to preserve one's sense of identity (Kahan, 2013). We make a case for motivated reasoning in Section 2.4.1.4.

Intentional mis-reporting A fourth possibility is that some respondents intentionally report overly pessimistic beliefs compared to what they actually think. This could stem from a rejection of the tax and could follow from strategic thinking if they believe their survey answers might influence policy-makers. Such respondents could be aware that they would gain but still reject the tax for other motives, even more so if they are still uncertain about their gain. Their mis-reporting could also be due to a type of motivated reasoning that would not directly affect their beliefs, but rather induce them to mis-report what they think. This could help them justify their rejection of the policy, even more so that it could be costly for their ego to admit they were wrong to reject the policy.

2.4.1.3 Heterogeneity in pessimism

In order to know more about the determinants of the above pessimism, we investigate the heterogeneity in updating. To handle the notion of *correct updating*, we define a variable U which equals $+1$ if the respondent adopts a feedback that invalidates their initial belief, 0 if they do not update, or -1 if they initially felt *unaffected* but update against the feedback. Over the sub-sample of *invalidated* respondents who should have updated because their initial win/lose category is not aligned with our feedback ($g_i \cdot \widehat{\gamma}_i \leq 0$), we regress the *correct updating*, U, over the initial belief not to lose, G^0, and a vector of characteristics, $\mathbf{C}$:

$$U_i = \delta_0 + \beta_U G_i^0 + \beta_{\mathbf{C}} \mathbf{C} + \varepsilon_i \quad \text{for } i : \; g_i \cdot \widehat{\gamma}_i \leq 0, \tag{2.3}$$

The high values for β_U reported in columns (1-3) of Table 2.4.2 again prove that, among those who should have updated, those who initially think they would win (the optimistic losers) update significantly more correctly than those who do not think so (the pessimistic winners). Beyond this asymmetry, columns (2-5) show that some respondents' characteristics are correlated with correct updating. Relative to unemployed and inactive people, retired, active, and students update more correctly, the latter being 22 p.p. more likely to correctly revise their beliefs when invalidated than unemployed and inactive (column 2). The categories of respondents who initially displayed the largest bias also appear to update less correctly. Indeed, people who are part of the Yellow Vests movement are 14 p.p. less likely to correctly update than people who oppose it, even when controlling for disapproval of the policy which itself decreases the likelihood to correctly update by 18 p.p. The previous characteristics could be correlated to people's uncertainty. Alternatively, the Yellow Vests' higher distrust of the government (documented in Algan et al., 2019) could also apply to information provided by researchers regarding policies. Finally, these results also indicate that motivated reasoning may be at play.

2.4.1.4 Motivated reasoning

The previous results suggest that conservatism in beliefs' revision does not simply follow from people's cognitive difficulties when dealing with Bayes' rule. The higher likelihood to update correctly of those who support the reform is robust evidence that political views and iden-

Table 2.4.2 – Heterogeneity in updating.

	Correct updating (U)				
	(1)	(2)	(3)	(4)	(5)
Constant	0.120	−0.036	−0.011	−0.073	0.707
	(0.012)	(0.190)	(0.192)	(0.192)	(1.007)
Winner, before feedback ($\dot{G}$)	0.695	0.551	0.563		
	(0.078)	(0.083)	(0.083)		
Initial tax : PNR (I don't know)		0.179	0.186	0.199	0.113
		(0.032)	(0.067)	(0.033)	(0.155)
Initial tax : Approves		0.176	−0.031	0.216	−0.162
		(0.046)	(0.115)	(0.049)	(0.185)
Diploma × Initial tax : PNR			−0.003		
			(0.025)		
Diploma × Initial tax : Approves			0.072		
			(0.037)		
Subjective gain (g)		0.0004	0.0004	0.001	−0.001
		(0.0002)	(0.0002)	(0.0003)	(0.004)
Subjective gain : unaffected ($g = 0$)		−0.127	−0.126	−0.208	−0.331
		(0.033)	(0.033)	(0.033)	(0.219)
Bias about gain ($g - \hat{\gamma}$)		−0.00005	−0.0001	−0.001	−0.0003
		(0.0001)	(0.0001)	(0.0003)	(0.0002)
Diploma (1 to 4)		0.014	0.009	−0.001	0.148
		(0.013)	(0.014)	(0.013)	(0.078)
Retired		0.130	0.127	0.108	0.124
		(0.079)	(0.079)	(0.080)	(0.435)
Active		0.166	0.165	0.160	0.113
		(0.054)	(0.054)	(0.054)	(0.365)
Student		0.224	0.229	0.183	0.402
		(0.075)	(0.075)	(0.074)	(0.526)
Yellow Vests : PNR		−0.045	−0.047	−0.031	0.013
		(0.047)	(0.047)	(0.048)	(0.246)
Yellow Vests : understands		−0.065	−0.066	−0.059	0.141
		(0.034)	(0.034)	(0.034)	(0.170)
Yellow Vests : supports		−0.063	−0.063	−0.050	−0.156
		(0.036)	(0.036)	(0.036)	(0.206)
Yellow Vests : is part		−0.141	−0.142	−0.106	−0.985
		(0.061)	(0.061)	(0.063)	(0.367)
Includes "pessimistic winners"	✓	✓	✓	✓	
Includes "optimistic losers"	✓	✓	✓		✓
Controls : socio-demo, politics, estimated gains		✓	✓	✓	✓
Observations	1,365	1,365	1,365	1,265	100
R^2	0.055	0.144	0.146	0.115	0.696

Note : Omitted variables are *Unemployed/Inactive* and *Yellow Vests : opposes*. The list of controls can be found in Appendix 2.F.

tity shape beliefs' formation. Indeed, the more people oppose the tax, the less likely they are to correctly update, as shown in columns (2-5) of Table 2.4.2. From columns (4-5) we also see that this result is entirely driven by the "pessimistic winners" : the updating of people who wrongly think they win does not depend on their approval, another indication that the revision in beliefs is driven by a rejection of the tax. This is not to say that few people seek to reach accurate beliefs. It could still be the case that informing any respondent that they would win makes them revise their subjective gain by, say, 100€ upwards, leading only those with small subjective losses to discover that they would win. One can actually see from the positive and statistically significant effect of *subjective gain* (g) that such an accuracy motive is at play. However, this effect remains small relative to those indicative of policy support, pointing out the importance of motivated reasoning. Column (3) further shows that the effect of approving the policy on correct updating is even stronger for more educated people — as the interaction term between approval and diploma is positive and significant —, even capturing all the effect of initial tax approval.

The previous findings are comparable to empirical evidence from Kahan (2013) that political motivated reasoning about climate change is not a reasoning deficiency but rather a reasoning adaptation following the interest that individuals have in conveying "their membership in and loyalty to affinity groups central to their personal well-being". In our case, the position relative to the Yellow Vests proxies the groups that respondents identify with, and the differentiated updating along this spectrum can be interpreted as motivated reasoning. Besides, the hypothesis that motivated reasoning follows from a rational adaptation purpose can explain our finding that better educated people are *more* prone to motivated reasoning, as they are more able to formulate specious reasonings and reconcile antagonistic information and ideas. To our knowledge, this result is the first evidence of rational motivated reasoning in the context of climate policies, complementing the findings of Druckman & McGrath (2019) that this mechanism can explain polarization around beliefs on climate change. [28]

Building upon the cognitive and social mechanisms described by Kraft et al. (2015) and documented by e.g. Redlawsk (2002), we hypothesize the following narrative as one of the possible channels through which aversion for the carbon tax became entrenched. The Yellow Vests first gathered to defend their interest (above all their purchasing power), and a side effect of the daily interactions on roundabouts was to bring material and emotional support to the protesters (Challier, 2019). A group identity soon developed, which crystallized shared beliefs and affects such as a rejection of carbon taxation. This group identity gained support from a large majority of the population, notably through social networks. Now, due to the loyalty to the group as well as the affects that have entered their subconscious, Yellow Vests supporters oppose instinctively any carbon tax, and are prone to find excuses to cope with contradictory messages, e.g. by denying the reliability of these messages (Golman et al., 2016). Admittedly, such a narrative falls short of explaining the majority rejection among those who oppose the Yellow Vests (which may originate from pessimistic perceptions more than tax aversion), but it illustrates

28. This evidence provides empirical support for various models of endogenous belief formation. For example, Little (2019) formalizes the idea that directional motives may override accuracy motives and people update auxiliary beliefs (in our case, the win/lose category) in order to preserve their consistency with core beliefs (here, rejection of the tax). Admittedly, one might expect the importance of accuracy motives relative to directional motivated reasoning to increase in a higher stakes environment. However, this hypothesis cannot be tested in our set-up, and previous literature does not provide conclusive evidence on the matter (Kunda, 1990; Camerer & Hogarth, 1999).

how pessimistic beliefs can be so persistent among Yellow Vests supporters.

Overall, these results show that people's pessimistic beliefs about the incidence of a Tax & Dividend are very persistent. This pessimism is consistent with people forming their beliefs in a motivated way. Still, other mechanisms — such as a distrust of the government — may play a key role. Further research with a different design would be needed to conclude about the relative importance of these different mechanisms.

2.4.2 Environmental effectiveness

Table 2.D.5 in Appendix 2.D.3 reports the effect of displaying relevant information on the belief that our Tax & Dividend is environmentally effective. The effect of reporting a scientific consensus on environmental effectiveness (E) is positive and statistically significant, but its magnitude — around 5 p.p. — seems modest given that the question immediately follows the priming. The effects of information on climate change (CC) or particulates (PM) are smaller, and only CC is significant, which is understandable as they were displayed at the very beginning of the survey and do not mention any environmental policy. As suggested by Millner & Ollivier (2016), given the complexity of the mechanisms at play, drawing a causal link between causes and consequences of environmental problems requires considerable cognitive effort, making it difficult to convince one about the effectiveness of policies that decentralize efforts to tackle pollution. Finally, we observe that our primings have no significant effect on beliefs over causes and consequences of climate change. Overall, these primings appear insufficient to change most people's mind about climate change and carbon tax effectiveness.

2.4.3 Progressivity

Table 2.D.6 in Appendix 2.D.4 shows the absence of effect of explaining that our Tax & Dividend is progressive on perceived progressivity : the correlation between the two is close to 0 (at -0.006) and even has an unexpected negative sign. Column (2) of the same table clarifies why our treatment does not change the overall share of people who think the policy is regressive : those who have a large bias in their perception of gains are in fact *more* prone to perceive *regressivity* once provided the information, by 13 p.p. This result may be a manifestation of the boomerang effect with people inclined to motivated reasoning, which has already been documented for Republican attitudes over climate change in the US (Zhou, 2016). Indeed, Hovland et al. (1953) showed that when someone is pressured to make a certain choice, psychological

reactance (theorized by Brehm, 1966) can cause them to resist this pressure by adopting an opposite alternative. Although the effect on those without a large bias is not significant, providing them with information is associated with a lower perceived regressivity by 5 p.p. A possible explanation for the strong belief in regressivity is that people view the tax as regressive (relative to income) and the transfer as neutral (in absolute values), and mistakenly conclude that their combination is regressive. In any case, without a deep explanation of the underlying mechanisms, the progressivity of the policy remains unintuitive for most people, and we cannot convince them easily.

2.5 How beliefs determine attitudes

Our results clearly indicate that, as of today, a carbon tax is unlikely to be accepted in France. However, we have also shown that people display overly pessimistic perceptions about the true effects of the policy. Most of them overestimate the negative impact on their purchasing power, think that the policy is regressive, and do not see it as environmentally effective. In this section, we examine to what extent the low acceptance rate reflects intrinsic preferences or wrong perceptions. The question we address is whether convincing people about the actual incidence of the policy and its effectiveness would be sufficient to generate public support.

2.5.1 Self-interest

Identification challenge Among the three-quarters of the respondents expected to win from our Tax & Dividend, 62% both consider that they would not win and disapprove of the policy. We want to estimate to what extent knowing they would win would lead them to approve of the reform. Because respondents thinking they would win might differ in many respects from those thinking they would not, we cannot simply regress approval on perception of winning.

Main identification strategy In order to identify the effect *ceteris paribus* of self-interest on acceptance, we exploit exogenous variations in gains and losses. To do so, we consider a Tax & Targeted Dividend, where respondents are randomly assigned to a compensation scheme to which they are eligible or not depending on their income (see Section 2.2.2.2). Formally, we denote by $I_{i,1}$ the income percentile of respondent's i, and by $I_{i,2}$ that of the second adult of their household if there is one. We define eligibility of adult $j \in \{1;2\}$ as :[29]

$$T_{i,j} = \begin{cases} 0, & \text{if } I_{i,j} > t_i \\ 1, & \text{otherwise} \end{cases} \tag{2.4}$$

where $t_i \in \mathscr{T} = \{20;30;40;50\}$ is the eligibility threshold randomly allocated to household i (see Section 2.2.2.2). As eligibility increases the likelihood — but does not necessarily implies — to believe that one wins from the policy, our method leads to a fuzzy regression discontinuity design (RDD), where the eligibility corresponds to the intention to treat and the respondents who believe they win correspond to the treated. Formally, we denote by G_i^T a dummy variable equal to 0 if respondent i thinks they would lose from the Tax & Targeted Dividend, and 1 otherwise. Similarly, A_i^T is a dummy variable equal to 0 if respondent i disapproves of this policy and 1 otherwise. We can then write the model as a two-stage least square, with the following first stage equation :

$$G_i^T = \alpha_0 + \alpha_{T,1} T_{i,1} + \alpha_{T,2} T_{i,2} + \alpha_{T,3} \left(T_{i,1} \times T_{i,2} \right) + \sum_{k \in \mathscr{T}} \alpha_k \mathbb{1}_{t_i = k} + \alpha_S S_i + \alpha_{\mathbf{C}} \mathbf{C_i} + \alpha_{\mathbf{I}} \mathbf{I_i} + \eta_i \tag{2.5}$$

where $\mathbf{C_i}$ is a vector of respondents' characteristics, $\mathbf{I_i}$ a vector of income variables defined as $\left(I_{i,j}, \, (\min(I_{i,j} - k, \, 0))_{k=20,70} \right)'_{j=1,2}$ and S_i a dummy variable equal to 1 when there is a single adult in the household. $\mathbf{I_i}$ allows for a continuous piecewise linear relationship in incomes with slope changes at the 20th and 70th percentiles. Fixed effects for the policy assigned $\mathbb{1}_{t_i=k}$ ($k \in \mathscr{T}$) are also introduced to control for preferences regarding the specificities of the policy, i.e. the share of the population targeted by the policy and the value of the dividend. Finally, the second stage writes :

$$A_i^T = \beta_0 + \beta_1 \widehat{G}_i^T + \sum_{k \in \mathscr{T}} \beta_k \mathbb{1}_{t_i = k} + \beta_S S_i + \beta_{\mathbf{C}} \mathbf{C_i} + \beta_{\mathbf{I}} \mathbf{I_i} + \varepsilon_i \tag{2.6}$$

where $\widehat{G_i}^T$ denotes the fitted value of G_i^T from the first stage regression. As can be seen from first stage results in Appendix 2.E.1, eligibility of both respondents and households' second adults are positively correlated with beliefs of winning, so both instruments are relevant. The exclusion restriction states that conditional on income, being eligible affects approval solely through beliefs of winning. The RDD procedure employed in the first stage ensures that this is the case :

29. As explained in Section 2.2.2.2, we explicitly limit the number of beneficiaries to two per household.

conditional on income, eligibility is random, and controlling for the specific policy assigned ($\mathbb{1}_{t_i=k}$), it should affect acceptance only through self-interest.

Alternative specifications for robustness To get more precise estimates, we include control variables in all specifications. In particular, we control for initial acceptance of our Tax & Dividend as this should explain much of the variation in the dependent variable. In our main specification (1), we also exclude households where none of the adults has an income lying between the 10th and 60th percentiles, to keep only those close enough to the thresholds. In specification (2) we replicate the same estimation on the full sample. In (3), we also compare our results with a simple OLS regression on the full sample. Finally, in (4) we exploit a methodology similar to the main specification — i.e. a fuzzy RDD — but applied to the customized feedback. Indeed, we use our estimation of respondents' net gains $\widehat{\gamma}$ as the assignment variable, and the binary win/lose feedback $\widehat{\Gamma}$ as the intention to treat. As our feedback $\widehat{\Gamma}$ (which goes from 0 to 1 at the threshold of zero net gain) is predictive of the belief about the win/lose category after feedback, G^F, we can determine the effect of this belief on acceptance, A^F. This alternative fuzzy RDD leads to the following two-stage least square :

$$G_i^F = \alpha_0 + \alpha_1 \widehat{\Gamma}_i + \alpha_{\gamma,1}\widehat{\gamma}_i + \alpha_{\gamma,2}\widehat{\gamma}_i^2 + \alpha_{\mathbf{C}}\mathbf{C_i} + \alpha_{\mathbf{I}}\mathbf{I_i} + \eta_i \tag{2.7}$$

$$A_i^F = \beta_0 + \beta_1 \widehat{G}_i^F + \beta_{\gamma,1}\widehat{\gamma}_i + \beta_{\gamma,2}\widehat{\gamma}_i^2 + \beta_{\mathbf{C}}\mathbf{C_i} + \beta_{\mathbf{I}}\mathbf{I_i} + \varepsilon_i \tag{2.8}$$

where $\widehat{G}_i^F$ denotes the fitted value of G_i^F from the first stage regression. The identification assumption of this second IV states that conditional on estimated net gains ($\widehat{\gamma}$) — that we control for with a quadratic specification — receiving a win feedback ($\widehat{\Gamma} = 1$) affects approval solely through self-interest. We again restrict our analysis to respondents close enough to the threshold by keeping only those with net gains below 50€ per annum in absolute value ($|\widehat{\gamma}| < 50$).

Finally, we investigate alternative versions of the previous models in Appendix 2.E.2. We estimate the effect to "win" instead of "not to lose", and on "approval" instead of "acceptance" (Table 2.E.3). We estimate our main specification with the slope in incomes changing at an additional thresholds (30th, 40th, 50th or 60th percentile). Finally, we allow for heterogeneous effects along the income dimension (Table 2.E.4).

TABLE 2.5.1 – Effect of self-interest on acceptance

	Acceptance ("Yes" or "Don't know" to policy support)			
	Targeted Dividend (A^T)			After Feedback (A^F)
	IV : random target/eligibility		*OLS*	*IV : discontinuity in feedback*
	(1)	(2)	(3)	(4)
Believes does not lose (G)	0.534	0.476	0.438	0.644
	(0.132)	(0.106)	(0.014)	(0.170)
Initial tax Acceptance (A^0)	0.356	0.354	0.361	0.420
	(0.041)	(0.034)	(0.026)	(0.074)
Controls : Incomes (piecewise continuous) estimated gains, socio-demo, other motives	✓	✓	✓	✓
Controls : Policy assigned	✓	✓	✓	
Sub-sample	[p10 ; p60]			$\lvert\widehat{\gamma}\rvert < 50$
Effective F-Statistic	15.6	23.8		21.3
Observations	1,969	3,002	3,002	757
R^2	0.320	0.308	0.472	0.541

NOTE : Standard errors are reported in parentheses. The list of controls can be found in Appendix 2.F. The source of exogenous variation in the belief used in first-stages for the targeted dividend is the random assignment of the income threshold, which determines eligibility to the dividend. The first-stage for the non-targeted dividend exploits instead the discontinuity in the win/lose feedback when the net gain switches from negative to positive.

Results First stage regression results are given in Appendix 2.E.1. The effective F-Statistics (Olea & Pflueger, 2013) range from 15.6 to 23.8, indicating that both targeted transfers and feedback are strong instruments. Table 2.5.1 provides the second stage results for the six main specifications, and additional specifications can be found in Appendix 2.E.2. Overall, the estimated effects of self-interest indicate that believing not to lose increases acceptance by about 50 p.p. Both IV strategies yield consistent results, although they apply to different policies since the revenue-recycling is not designed in the same manner. The different results between the two local average treatment effects (LATE) (53 p.p. in column (1) vs. 64 p.p. in (4)) could also be due to the specificity of compliers in each setting. Since we have shown in Section 2.4.1 that respondents most likely to revise their beliefs after a "win" feedback are less opposed to the tax, they may also be more inclined to accept the policy once they are convinced that they win. Those most likely to comply in this setting could thus be more specific than those who comply when they are provided a (targeted) dividend that is large enough. The specificity of compliers could also explain why the average treatment effect estimated with the OLS is somewhat lower (44 p.p. in (3)), although the difference may also be due to a bias in the OLS that would remain despite our powerful controls. The result of the OLS is also very close to the one obtained from our main IV on the full sample (48 p.p. in (2)). The lower estimate found compared to (1) could again be due to heterogeneous preferences between respondents depending on their income — with people at the bottom and top of the income distribution less likely to revise their support when they learn that they win — or from a less accurate identification when we enlarge the window and compare less similar respondents. Column (1) of Table 2.E.4 in appendix confirms the existence of heterogeneous effects along the income distribution. Indeed, we find a larger effect for lower incomes, which may be due heterogeneous preferences or to the higher intensity of the treatment for low-income people (whose dividend represents a higher income share than average).

Overall, these results show that convincing citizens' of the true incidence of a Tax & Dividend could largely increase the support for such policy. Our results also qualify the findings of Anderson et al. (2019) who suggest that ideology better predicts carbon tax acceptance than self-interest. By distinguishing beliefs from preferences, we find that ideology plays an indirect role by shaping beliefs about one's self-interest, and that beliefs directly affect acceptance.

2.5.2 Environmental effectiveness

Main identification strategy One of the strongest barriers to carbon tax implementation is a widespread perception of its environmental ineffectiveness. Our objective is therefore to assess to what extent learning about the environmental benefits of the tax could increase support. To identify this effect, we estimate a two-stage least squares (2SLS) where the first stage uses random information to predict beliefs about environmental effectiveness, while the second stage regresses acceptance on the fitted exogenous variations in these beliefs. Because information on particulate matter (Z_{PM}) is poorly correlated with beliefs of effectiveness, we restrict the set of instruments to our primings on the scientific consensus (Z_E) and climate change (Z_{CC}). Even though these primings do not have a very large effect on people's beliefs (as discussed in Section 2.4.2), these instruments are significantly related to our endogenous variable. Denoting by $\dot{A}^0$ the dummy for an initial approval of the Tax & Dividend and $\dot{E}$ the dummy for the belief that the policy is environmentally effective, we can write a 2SLS model as follows :

$$\dot{E}_i = \alpha_0 + \alpha_1 Z_{E,i} + \alpha_2 Z_{CC,i} + \alpha_{\mathbf{C}} \mathbf{C_i} + \eta_i \tag{2.9}$$

$$\dot{A}_i^0 = \beta_0 + \beta_1 \widehat{\dot{E}_i} + \beta_{\mathbf{C}} \mathbf{C_i} + \varepsilon_i \tag{2.10}$$

where $\widehat{\dot{E}_i}$ denotes the fitted value of $\dot{E}_i$ from the first stage regression, and $\mathbf{C}$ a vector of characteristics.

Alternative specifications for robustness checks Acknowledging that our primings could affect acceptation motives other than effectiveness alone, we include other motives in our list of control variables to avoid a potential bias. In addition to the 2SLS (specification 1), we estimate an OLS (2) model to compare the LATE of our main specification with an ATE. For these two first specifications, we adopt strict definitions for our variables (i.e. answer "Yes", denoted by a dot, to the belief in effectiveness and approval). Indeed, our instruments appear more effective to switch answers from "PNR" to "Yes" than from "No" to "PNR", hence a larger statistical power with strict definitions. Specification (3) takes acceptance instead of approval as the dependent variable. In appendix, we also estimate a 2SLS with broad definitions only (i.e. effect of a *not "No"* belief at effectiveness on acceptance of the policy), as well as two OLS regression ("Yes" on acceptance and *not "No"* on acceptance). As a robustness check, we also report results of a limited information maximum likelihood (LIML) estimation of our main results in Appendix (Table 2.E.5).

TABLE 2.5.2 – Effect of believing in environmental effectiveness on approval

	Initial Tax & Dividend		
	Approval ($\dot{A}^0$)		Acceptance (A^0)
	IV	*OLS*	*IV*
	(1)	(2)	(3)
Believes in effectiveness ($\dot{E}$)	0.416 (0.168)	0.374 (0.013)	0.505 (0.242)
Instruments : info E.E. & C.C.	✓		✓
Controls : Socio-demo, other motives, incomes, estimated gains	✓	✓	✓
Effective F-Statistic	11.2		11.2
Observations	3,002	3,002	3,002
R^2	0.161	0.342	0.218

NOTE : Standard errors are reported in parentheses. The list of controls can be found in Appendix 2.F, and first stage results in Table 2.E.2 on page 125. The dependent variable corresponds to either initial approval (answer "Yes" to support of the policy) or acceptance (answer not "No"). The first stage exploits the information randomly displayed about climate change (C.C.) and the effectiveness of carbon taxation (E.E.) as exogenous instruments.

Results The first stage regressions results can be found in Appendix 2.E.1. Because of the relatively modest responses to our primings, the instruments are rather weak when broad definitions (i.e. *not "No"*) are taken in the first stage (effective F-statistic of 6), a problem that is alleviated in the case of strict definitions (11 in column 1 and 3). Given the exogeneity of our instruments, the only concern is a potential bias towards OLS, which — as suggested by the results of column (2) — would entail estimates that are too conservative in our case. Table 2.5.2 reports the results of the second stages. They all consistently indicate a strong positive and significant effect of beliefs about environmental effectiveness on support for the policy. All else equal, believing that the tax is effective increases the likelihood to accept it by 51 p.p. (3), and to approve it by 42 p.p. (1). The LATE is only slightly higher than the ATE estimated with OLS (2) — 42 vs. 38 p.p. The lower results obtained with OLS are more pronounced when using broad definitions for our variables, as can be seen in appendix (Table 2.E.5). This discrepancy may be due to a bias in the OLS, or to the specificity of compliers : people who are most likely to change their mind following our information might also be more willing to accept the policy. Finally, we obtain identical results when running a 2SLS or a LIML for our main specification (1). For the strict definition of effectiveness, the LIML estimate (A2) is broadly consistent with the 2SLS (3), though somewhat higher (64 p.p. vs. 51 p.p.).

2.5.3 Progressivity

As informing respondents does not convince them that our Tax & Dividend is progressive (see Section 2.4.3), we cannot perform an IV estimation to identify the causal effect of understanding the progressivity on support for the policy. In our online Appendix 2.J, we estimate how one's belief in progressivity — interacted with other motives — correlates with acceptance using simple OLS and logit regressions. Controlling for many respondents' characteristics and other motives of support, the effect of progressivity remains statistically significant, and as high as 27 p.p. in our preferred specification. Of course, this result should be taken with caution since we can still suspect the results to be affected by unobserved confounders and reverse causality.

2.6 Conclusion

In this chapter, we study how beliefs about a policy form and then determine attitudes towards it. We investigate this question through the study of carbon taxation in France during the Yellow Vests movement, that started against fuel price increases. Our analysis is based on a new survey and official household survey data, enabling one to compare subjective beliefs with objective impacts on French households. We find that 70% disapprove of a carbon Tax & Dividend policy, which can be explained by pessimistic beliefs about its properties. 89% of our survey respondents overestimate its negative impact on their purchasing power, and most of them do not perceive it as environmentally effective, nor progressive. Pessimistic beliefs appear correlated with people's support for the scheme : the more they oppose the mechanism, the more pessimistic they are. Our results support a bi-directional causality between beliefs and attitude towards the policy. People more opposed to the tax are more (pessimistically) biased in their treatment of *new* information with respect to it, indicating that beliefs about tax impacts are shaped by political identity. At the same time, we find that acceptance is causally determined by beliefs and that if people could be convinced about the incidence and effectiveness of a Tax & Dividend, this policy would likely be accepted by a majority, given the large effects of these motives (about 50 p.p. each).

However, our treatments that provide accurate arguments in favor of the scheme mostly fail to convince people. The pessimism could be related to a strong distrust of the government, documented e.g. in Alesina et al. (2018) and Algan et al. (2019), echoing recent findings that the ambition of climate policies increases with the level of trust (Rafaty, 2018). These results leave us with three main challenges. First, as it is unlikely that the issue of trust can be resolved in the short run, it seems necessary to find climate policies that would be accepted by a majority. We address this question in a companion paper (Douenne & Fabre, 2020), in which we assess both knowledge and beliefs about climate change, and the preferred policies of French people. Second, as trust in government needs to be restored in the longer run, it is crucial to analyze what causes the distrust and how it can be overcome. Third, it is important to assess to what extent the mechanisms of belief formation and their effects on political attitudes we document can be generalized to other policies and other contexts. Although rejection of the tax may be lower in a different country, biases in perceptions and political polarization may happen everywhere. Thus, a lesson must be learned for policy design and implementation, to avoid another carbon tax debacle *à la Française*.

2.A Raw data

Table 2.A.1 – Sample characteristics : quotas.

	Population	Sample
Sex		
woman	*0.52*	0.53
man	*0.48*	0.47
Age		
18-24	*0.12*	0.11
25-34	*0.15*	0.11
35-49	*0.24*	0.24
50-64	*0.24*	0.26
>65	*0.25*	0.27
Profession		
farmer	*0.01*	0.01
independent	*0.03*	0.04
executive	*0.09*	0.09
intermediate	*0.14*	0.14
employee	*0.15*	0.16
worker	*0.12*	0.13
retired	*0.33*	0.33
inactive	*0.12*	0.11
Education		
No diploma or *Brevet*	*0.30*	0.24
CAP or *BEP*	*0.25*	0.26
Bac	*0.17*	0.18
Higher	*0.29*	0.31
Size of town		
rural	*0.22*	0.24
<20k	*0.17*	0.18
20-99k	*0.14*	0.13
>100k	*0.31*	0.29
Paris area	*0.16*	0.15
Region		
IDF	*0.19*	0.17
Nord	*0.09*	0.10
Est	*0.13*	0.12
SO	*0.09*	0.09
Centre	*0.10*	0.12
Ouest	*0.10*	0.10
Occ	*0.09*	0.08
ARA	*0.12*	0.13
PACA	*0.09*	0.08

Table 2.A.2 – Households' characteristics.

	Population	Sample
Household composition (mean)		
Household size	*2.36*	2.38
Number of adults	*2.03*	1.93
c.u.	*1.60*	1.61
Energy source (share)		
Gas	*0.42*	0.36
Heating oil	*0.12*	0.09
Size of accommodation (m^2)		
mean	*97*	96
p25	*69*	66
p50	*90*	90
p75	*120*	115
Distance travelled by car (km/year)		
mean	*13,735*	15,328
p25	*4,000*	4,000
p50	*10,899*	10,000
p75	*20,000*	20,000
Fuel economy (L/100 km)		
mean	*6.39*	7.18
p25	*6*	5
p50	*6.5*	6
p75	*7.5*	7

Sources : Matched BdF; except for number of adults (ERFS) and heating oil (CEREN).

Note : After controlling the False discovery rate at 5%, *t*-tests reject that the sample mean is equal to the population mean for 12 of our 42 variables in Tables 2.A.1 and 2.A.2. Back to Section 2.2.2.2 on page 87.

2.B Notations

To improve the understanding of our specifications in the regression Tables, we adopt consistent notations throughout the chapter. For questions where possible answers are "Yes"/"No"/"PNR", we define two kinds of dummy variables : the default ones correspond to *not "No"* answers, while we put a dot on dummy variables for *"Yes"*. For example, acceptance is denoted A while approval is denoted $\dot{A}$. Furthermore, for questions that are asked several times, namely acceptance and win/lose category, an exponent is added to specify the step at which the question is asked. Table 2.B.1 describes these exponents as well as the notations corresponding to the different notions of gain that we use. Uppercase is used for binary and lowercase for continuous variables, Greek letters denote objective notions, with a hat for our estimation of gains and without for the true (unknown) ones. To give another example, the broad notion of self-interest at the initial step, i.e. the belief that one does not lose, is denoted G^0, and the strict belief that one wins at Tax & Targeted dividend is denoted $\dot{G}^T$.

TABLE 2.B.1 – Notations for the different reforms and for gain notions.

Step :	Initial	after information : 1		with Targeting
Variants :	–	Progressivity	Feedback	–
Exponent	0	P	F	T

Gain	Subjective	True	Estimated
Numeric	g	γ	$\widehat{\gamma}$
Binary	$\dot{G}\ (g > 0), G\ (g \geq 0)$	Γ	$\widehat{\Gamma}$

NOTE : Back to Section 2.2.3 on page 93.

2.C The use of official household survey data

The chapter makes use of official survey data for two purposes : (i) computing the distribution of increases in fossil fuels expenditures, (ii) predicting the expected net gain of each respondent based on their energy characteristics. Section 2.C.1 presents the three official surveys from Insee (the French national statistics bureau) that are used. Section 2.C.2 details the formulas needed to compute the value of the dividend and households' expected net gains from their expenditures. Section 2.C.3 explains how using two distinct survey we can obtain a simple formula to predict respondents' net gain simply based on their energy characteristics and then test out-of-sample the likelihood to make a correct prediction. Finally, Section 2.C.4 displays the objective net gain of the policy by income decile to show that it is progressive.

2.C.1 Official households surveys from Insee

Consumer survey "Budget de Famille" The consumer survey (BdF 2011) is a household survey providing information over all households' revenues and expenditures, together with many socio-demographic characteristics. It was conducted in several waves from October 2010 to September 2011, over a representative sample of 10,342 French households. The main advantage of BdF when studying the incidence of carbon taxation is that expenditures in both housing and transportation energies are reported. Consumption of housing energies is taken from households' bills, and for most other goods respondents report their expenditures over the past week. However, as explained in Douenne (forthcoming), this data collection is problematic when looking at the incidence of a tax on transportation energies, as short-run fluctuations in consumption lead to overestimate the heterogeneity in expenditures.

Transport survey "Enquête Nationale Transports et Déplacements" To overcome this limitation, BdF is matched with the transport survey (ENTD 2008). ENTD was conducted in several waves from April 2007 to April 2008, over a representative sample of 20,178 French households. It provides information on households characteristics, their vehicle fleet and use over the past week, but most importantly it gives information on annual distances travelled with these vehicles. This last information enables us to recover the distribution of transport fuel expenditures without over-estimating its spread. Such matching is not necessary for housing energies as these already represent consumption over long periods in BdF.

Housing survey "Enquête Logement" The housing survey (EL 2013) was conducted between June 2013 and June 2014 over a sample of 27,137 households in metropolitan France. It includes many information on households' characteristics, as well as their housing energy bills. The distribution of energy expenditures is very close to that of BdF.

2.C.2 Formulas to compute monetary effects of carbon tax policy

In order to compute the monetary impact of a carbon tax increase on a household h, we decompose current energy expenditures $E_h(\tau)$ as a product of current price $P(\tau)$ and current quantities consumed $Q_h(\tau)$, each being a function of the excise tax τ within which the carbon tax is comprised :[30]

$$E_h(\tau) = P(\tau) Q_h(\tau)$$

Small variations in expenditures can then be expressed as :

$$\frac{dE}{E}(\tau) = \frac{dP}{P}(\tau) + \frac{dQ}{Q}(\tau)$$

The variation in quantities can be rewritten as a function of the price variation :

$$\frac{dQ}{Q}(\tau) = e\frac{dP}{P}(\tau)$$

where $e = \frac{dQ_h}{dP} \cdot \frac{P}{Q_h}$ is the price elasticity of the energetic good considered, that is assumed constant and identical across households. For all energies, the final price can itself be decomposed as :

$$P(\tau) = (p + i\tau)(1 + t)$$

where t is the value added tax (VAT) rate (assumed constant) that applies after excise taxes, i the incidence of excise taxes on consumers (assumed constant), and $p + (i-1)\tau$ the producer price as a function of τ.[31] When the carbon price changes so that the excise taxes varies from τ to some level τ', we therefore have :

$$\frac{\Delta P(\tau)}{P} = \frac{P(\tau') - P(\tau)}{P(\tau)} = \frac{(p + i\tau')(1+t) - (p + i\tau)(1+t)}{(p + i\tau)(1+t)} = \frac{i(\tau' - \tau)}{p + i\tau}$$

Thus, carrying on the first-order approximation, one can express increase in expenditures associated with a carbon price increase as :

$$\Delta E_h(\tau) = E_h(\tau)(1+e)\frac{\Delta P}{P} = E_h(\tau)(1+e)\frac{i(\tau' - \tau)}{p + i\tau} \tag{2.11}$$

We can replicate similar calculations to obtain the expected variations in tax paid on energies by household h, ΔT_h. Starting from the expression of T_h — which is the sum of excise taxes and the VAT over the energy good — we have :

$$T_h(\tau) = Q_h(\tau)\Big((1+t)\tau + t\big(p + (i-1)\tau\big)\Big)$$

30. The French carbon tax "Contribution Climat Energie" is a component of existing taxes on energetic products : TICPE for transport and heating oils, TICGN for natural gas.
31. Hence p is the producer price when $\tau = 0$.

from which we obtain :

$$\Delta T_h(\tau) = Q_h(\tau)\left(1 + e\frac{i(\tau' - \tau)}{p + i\tau}\right)\left(t\left(p + (i-1)\tau'\right) + (1+t)\tau'\right) - Q(\tau)\left(t\left(p + (i-1)\tau\right) + (1+t)\tau\right) \tag{2.12}$$

Finally, the net gain of an household h from a Tax & Dividend writes :

$$\gamma_h(\tau) = N_h^a \cdot \frac{\sum_h \Delta T_h(\tau)}{N^a} - \Delta E_h^{transport}(\tau) - \Delta E_h^{housing}(\tau) \tag{2.13}$$

where γ_h denotes its net gain from the policy, N_h^a the number of adults receiving the dividend in this household, N^a the total number of adults receiving it, and $\Delta E_h^{transport}$ (resp. $\Delta E_h^{housing}$) the increase in their expenditures in transport (resp. housing) energies. From households' energy expenditures, and making assumptions on elasticities and tax incidence, equations (2.11) to (2.13) enable us to obtain the value of dividend and the impact of the policy on households' purchasing power. We use equation (2.13) to estimate the biases and objective distribution of net gains in Section 2.3, as well as the customized feedback in Section 2.4.

When asked to estimate the impact of the policy on their own purchasing power, respondents simply had to make an estimation over :

$$\Delta E_h(\tau) = E_h(\tau)(1+e)\frac{\Delta P}{P}$$

where for simplicity ΔP was given for transport fuels, and $\frac{\Delta P}{P}$ for housing energies. Thus, they were not required to make any specific assumption about existing taxes or tax incidence, but simply to estimate their consumption and price elasticity.

2.C.3 Predicting gains and losses

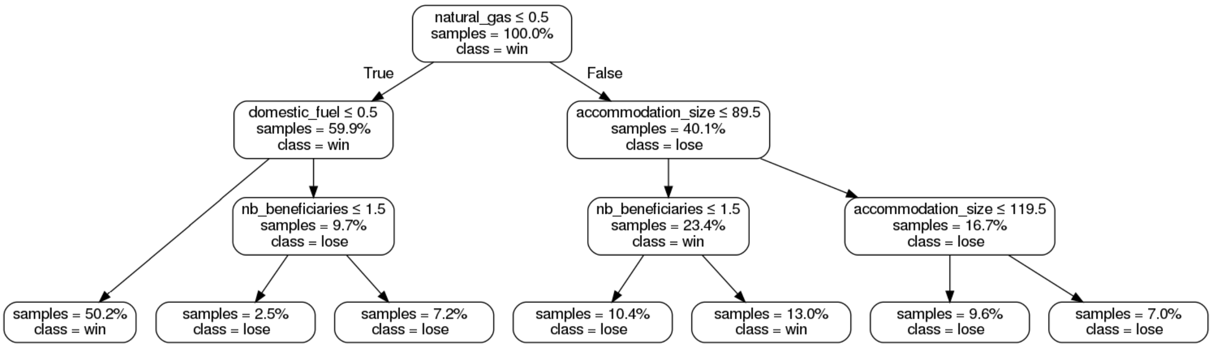
As explained in Section 2.2.3, to estimate respondents' bias and provide a customized feedback on their win/lose category, we need to estimate their increase in housing energy expenditures, $\Delta E_h^{housing}$, based on their energy characteristics.

To do so, we regress $\Delta E_h^{housing}$ on households' characteristics using the housing survey. Table 2.C.1 presents several specifications for such regression, and its last row shows the out-of-sample error rate, computed with the consumer survey. All specifications yield a similar error rate of 15-17%. Fearing that respondents could make mistakes when filling the accommodation size in the entry field, we used the first specification in our survey, as it does not rely as heavily as the others on the accommodation size. In order to balance the error rates for losing households that are mistakenly estimated winners and for winners who are mistakenly estimated losers, we add a constant of 16.1 in our estimation of yearly net gain, which is thus the sum of 16.1 plus 110 times one or two (depending on the number of adults) minus increases in transport and housing energy expenditures. We selected OLS as our prediction method for the estimation of net gain because it compares well with respect to alternative methods. We also classified winners and losers using a decision tree, and obtained a very close error rate : 17.4% (see Figure 2.C.1). Finally, statistical matching provided an error rate of 17.7%.

TABLE 2.C.1 – Determinants of housing energy expenditures.

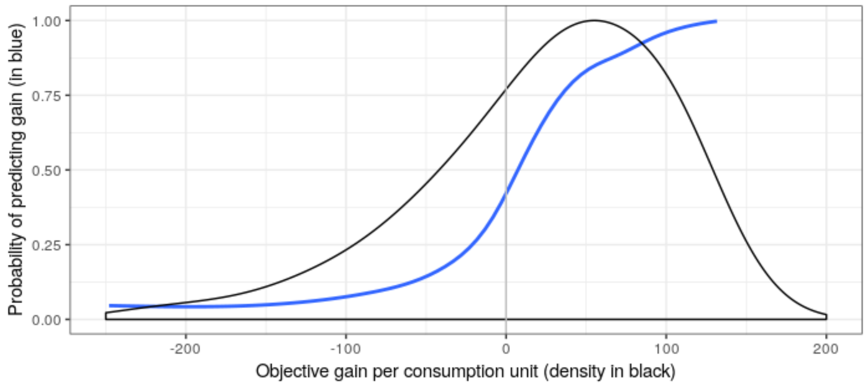
	Increase in housing energy expenditures (€/year)		
	(1)	(2)	(3)
Constant	−55.51		−0.634
	(1.237)		(1.489)
Housing energy : Gas	124.6		1.173
	(1.037)		(2.323)
Housing energy : Heating oil	221.1	129.8	130.4
	(1.719)	(3.752)	(4.002)
Accommodation size (m^2)	0.652		0.024
	(0.012)		(0.015)
Accommodation size × Gas		1.425	1.397
		(0.007)	(0.024)
Accommodation size × Heating oil		0.945	0.922
		(0.029)	(0.032)
Observations	26,729	26,729	26,729
R^2	0.545	0.716	0.599
Error rate	0.166	0.155	0.155

NOTE : The increase in energy expenditures is directly computed from households' energy bills in the housing survey, based on equation (2.11) in Appendix 2.C.2. See discussion in the main text, Section 2.2.3.2 on page 94.



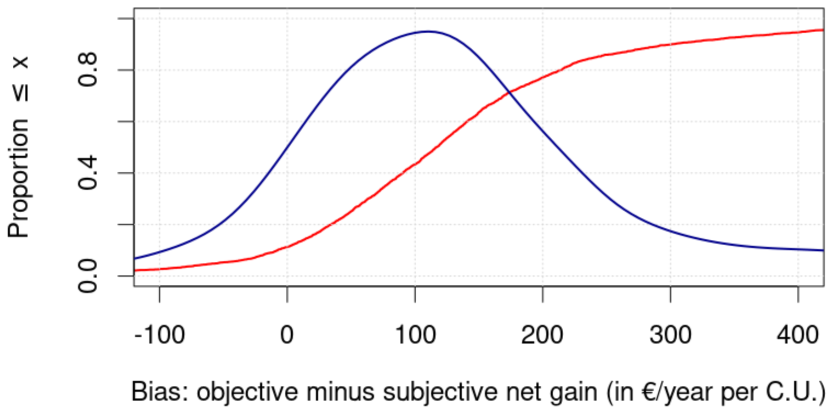
Note : This figure reads : the 50.2% of respondents who do not use natural gas nor heating oil (≤ 0.5) as their heating source are predicted to win from the Tax & Dividend.

Figure 2.C.1 – Decision tree that classifies households between winners and losers.



Note : The black curve corresponds to the density of households' objective net gains in the consumer survey. As shown by the blue curve, households in the consumer survey who would gain 100€ per C.U. —as directly computed from their energy bills— were predicted to be winner —from their energy characteristics— in 96% of cases. See discussion in the main text, Section 2.4.1.1 on page 100.

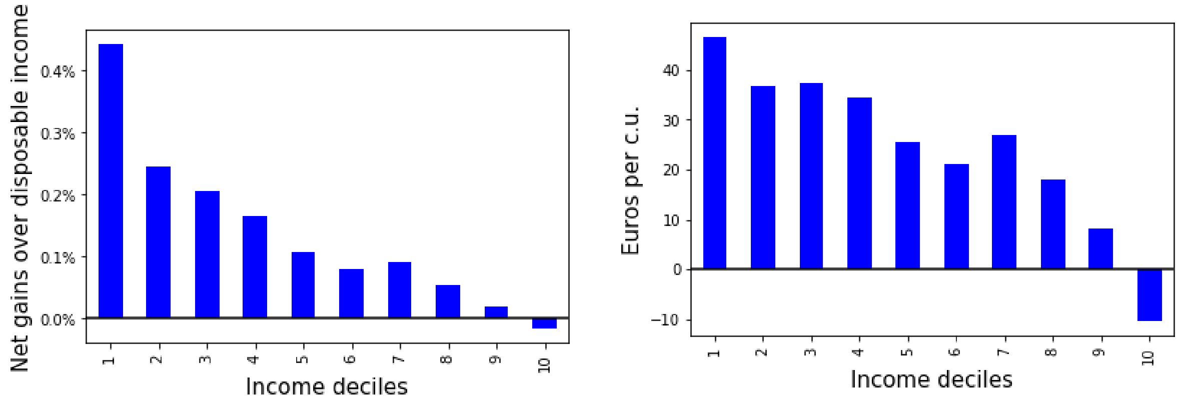
Figure 2.C.2 – Probability that our net gains' estimation correctly predicts the win/lose category.



Note : The red curve indicates for 11% of respondents, objective gains are lower than subjective ones, while for 23% of them they are higher by at least 200€. The blue curve indicates that the most common bias is an underestimation of gains by about 100€. See discussion in the main text, Section 2.3.1 on page 95.

Figure 2.C.3 – CDF (in red) and PDF (in blue) of the bias.

2.C.4 Distributive effects



NOTE : Net gains are defined in equation (2.13). They correspond to the dividend minus the increase in expenditures (ΔE), not in taxes (ΔT). Although the latter would sum to zero in aggregate because the reform is budget neutral, the former does not because fossil fuels expenditures adjust downwards following the increase in the carbon tax. See discussion in the main text, Section 2.3.3 on page 99.

FIGURE 2.C.4 – Average net gain of the carbon tax and dividend policy, by income decile (computed using Insee data).

2.D Beliefs and persistence

2.D.1 Elasticities

TABLE 2.D.1 – Effect of subjective elasticities on perceived environmental effectiveness.

	Environmental effectiveness : not 'No'			
	(1)	(2)	(3)	(4)
Price elasticity : Housing	−0.062		−0.055	
	(0.032)		(0.032)	
Price elasticity : Transports		−0.056		−0.060
		(0.030)		(0.030)
Controls : Socio-demo, energy incomes, estimated gains			✓	✓
Observations	1,501	1,501	1,501	1,501
R^2	0.003	0.002	0.089	0.090

NOTE : See discussion in the main text, Section 2.3.2 on page 98.

2.D.2 Self-interest

TABLE 2.D.2 – Transition matrix after telling respondents they are expected to *win* (75.8%).

Before \ After	**Winner** (25%)	**Unaffected** (28%)	**Loser** (47%)
Winner (16%)	79%	13%	8%
Unaffected (24%)	22%	63%	15%
Loser (60%)	12%	18%	70%

NOTE : See discussion in the main text, Section 2.4.1.1 on page 100.

TABLE 2.D.3 – Transition matrix after telling respondents they are expected to *lose* (24.2%).

Before \ After	**Winner** (3%)	**Unaffected** (12%)	**Loser** (86%)
Winner (7%)	16%	3%	81%
Unaffected (15%)	5%	50%	46%
Loser (78%)	1%	5%	94%

NOTE : See discussion in the main text, Section 2.4.1.1 on page 100.

TABLE 2.D.4 – Share with new beliefs aligned with feedback, among those with large gain or loss ($|\widehat{\gamma}| > 110$).

	Aligned with feedback : $G^F = \widehat{\Gamma}$	
	win ($\widehat{\Gamma} = 1$) (81.6%)	lose ($\widehat{\Gamma} = 0$) (18.4%)
Initial belief winner ($g > 0$) (19.4%)	77.6% [68.5%; 84.7%]	78.4% [43.2%; 94.5%]
Initial belief unaffected ($g = 0$) (28.2%)	20.7% [14.8%; 28.1%]	32.7% [14.7%; 57.7%]
Initial belief loser ($g < 0$) (52.3%)	10.8% [7.3%; 15.8%]	92.2% [84.5%; 96.3%]
Initial belief affected ($g \neq 0$) (70.8%)	32.7% [27.7%; 38.1%]	91.1% [83.5%; 95.4%]
All (100%)	28.9% [24.8%; 33.3%]	83.0% [74.8%; 88.9%]

NOTE : The 95% confidence intervals for binomial probabilities are given in brackets. The Table reads as follows : among those who initially think they would win ($g^0 > 0$) but are told they are expected to lose ($\hat{\Gamma} = 0$), 78.4% agree that they would lose ($G^F = 0$). Compared to Table 4.1, this Table focuses on the sub-sample of people with large gain or loss ($|\widehat{\gamma}| > 110$)). See discussion in the main text, Section 2.4.1.1 on page 100.

2.D.3 Environmental effectiveness

TABLE 2.D.5 – Effect of primings on beliefs about environmental effectiveness

	Environmental effectiveness			
	not "No"			"Yes"
	OLS		*logit*	*OLS*
	(1)	(2)	(3)	(4)
Info on Environmental Effectiveness (Z_E)	0.043	0.063	0.052	0.059
	(0.017)	(0.018)	(0.018)	(0.014)
Info on Climate Change (Z_{CC})	0.044	0.041	0.043	0.029
	(0.024)	(0.024)	(0.024)	(0.018)
Info on Particulate Matter (Z_{PM})	0.039	0.029	0.037	0.017
	(0.024)	(0.024)	(0.024)	(0.019)
$Z_{CC} \times Z_{PM}$	−0.040	−0.033	−0.042	−0.005
	(0.035)	(0.034)	(0.033)	(0.027)
Controls : Socio-demo		✓	✓	✓
Observations	3,002	3,002	3,002	3,002
R^2	0.003	0.047		0.075

NOTE : See discussion in the main text, Section 2.4.2 on page 106.

2.D.4 Progressivity

TABLE 2.D.6 – Effect of information on perceived progressivity

	Progressivity : not "No" (P)		
	(1)	(2)	(3)
Constant	0.419	0.435	0.052
	(0.022)	(0.033)	(0.319)
Information on progressivity (Z_P)	−0.021	0.050	0.051
	(0.027)	(0.040)	(0.041)
Large bias ($\lvert\widehat{\gamma} - g\rvert > 110$)		−0.028	−0.040
		(0.045)	(0.045)
Interaction $Z_P \times (\lvert\widehat{\gamma} - g\rvert > 110)$		−0.130	−0.117
		(0.055)	(0.055)
Controls : Socio-demo, politics			✓
Observations	1,444	1,444	1,444
R^2	0.0004	0.018	0.094

NOTE : A large bias is defined as a difference between subjective (g) and objectively estimated ($\hat{\gamma}$) net gain larger than 110€/year per c.u. See discussion in the main text, Section 2.4.3 on page 106.

2.E Estimation of acceptation motives

2.E.1 Two-stage least squares : first stage results

TABLE 2.E.1 – First stage regressions results for self-interest

	Believes does not lose		
	Targeted Dividend (G^T)		After feedback (G^F)
	(1)	(2)	(4)
Transfer to respondent (T_1)	0.199	0.224	
	(0.034)	(0.030)	
Transfer to spouse (T_2)	0.172	0.156	
	(0.042)	(0.039)	
$T_1 \times T_2$	−0.145	−0.158	
	(0.045)	(0.037)	
Simulated winner ($\widehat{\Gamma}$)			0.269
			(0.058)
Initial tax Acceptance (A^0)	0.123	0.154	0.306
	(0.041)	(0.033)	(0.066)
Controls : Incomes (piecewise continuous) estimated gains, socio-demo, other motives	✓	✓	✓
Controls : Policy assigned	✓	✓	
Sub-sample	[p10 ; p60]		$\lvert\widehat{\gamma}\rvert < 50$
Effective F-Statistic	15.6	23.8	21.3
Observations	1,969	3,002	757
R^2	0.221	0.196	0.301

NOTE : In (1,2), the random eligibility to the dividend (conditionally on income) is used as source of exogenous variation in the belief. In (4), the discontinuity in the win/lose feedback when the net gain switches from negative to positive is used. Column numbers correspond to second stage results, Table 2.5.1 on page 110.

TABLE 2.E.2 – First stage regressions results for environmental effectiveness

	Environmental effectiveness	
	"Yes"	not "No"
	(1 ; 3)	(A4)
Info on Environmental Effectiveness (Z_E)	0.059	0.062
	(0.014)	(0.017)
Info on Climate Change (Z_{CC})	0.028	0.030
	(0.013)	(0.017)
Controls : Socio-demo, other motives, incomes, estimated gains	✓	✓
Effective F-Statistic	11.2	6.0
Observations	3,002	3,002
R^2	0.123	0.121

NOTE : In column names, (A4) refer to columns of alternative second stages in Table 2.E.5. The information randomly displayed about climate change (Z_{CC}) and the effectiveness of carbon taxation (Z_E) are used as sources of exogenous variation in the belief. We chose the set of instruments that maximizes the effective F-statistics. Our specification is well-founded as the Sargan test does not reject the validity of our over-identification restrictions (p-value of 0.93). See discussion in the main text, Section 2.5.2 on page 111.

2.E.2 Additional specifications

TABLE 2.E.3 – Effect of self-interest on acceptance : second stages of alternative specifications

	Targeted Dividend (A^T)			After Feedback (A^F)		
	Acceptance	Approval		Acceptance	Approval	
	(1)	(2)	(3)	(4)	(5)	(6)
Believes wins	0.574	0.357		1.131	0.609	
	(0.136)	(0.117)		(0.298)	(0.233)	
Believes does not lose			0.343			0.347
			(0.113)			(0.133)
Controls : Incomes (piecewise continuous) estimated gains, socio-demo, other motives	✓	✓	✓	✓	✓	✓
Controls : Policy assigned	✓	✓	✓			
Sub-sample : [p10 ; p60] (A^T) or $\lvert\widehat{\gamma}\rvert < 50$ (A^F)	✓	✓	✓	✓	✓	✓
Effective F-Statistic	21.3	21.3	15.6	11.4	11.4	21.3
Observations	1,969	1,969	1,969	757	757	757
R^2	0.321	0.217	0.217	0.541	0.518	0.518

NOTE : See results of main specifications, Table 2.5.1 on page 110. As in the latter Table, the source of exogenous variation in the belief used in first-stages for the targeted dividend is the random assignment of the income threshold, which determines eligibility to the dividend. The first-stage for the non-targeted dividend exploits instead the discontinuity in the win/lose feedback when the net gain switches from negative to positive.

TABLE 2.E.4 – Effect of self-interest on acceptance : the role of incomes

	Acceptance of Tax & Targeted Dividend (A^T)				
	(1)	(2)	(3)	(4)	(5)
Believes does not lose (G^T)	0.773	0.556	0.549	0.535	0.502
	(0.222)	(0.133)	(0.133)	(0.133)	(0.130)
Income above 35th percentile ($\mathbb{1}_{I>p35}$)	0.343				
	(0.508)				
$G^T \times \mathbb{1}_{I>p35}$	−0.392				
	(0.311)				
Initial tax Acceptance (A^0)	0.387	0.353	0.354	0.356	0.359
	(0.058)	(0.041)	(0.041)	(0.041)	(0.040)
Percentile with additional income slope change		30	40	50	60
Controls : Incomes (piecewise continuous) estimated gains, socio-demo, other motives	✓	✓	✓	✓	✓
Sub-sample : [p10 ; p60] ; Controls : Policy assigned	✓	✓	✓	✓	✓
Effective F-Statistic	5.5	15.3	15.2	15.2	16.1
Observations	1,969	1,969	1,969	1,969	1,969
R^2	0.571	0.321	0.321	0.321	0.321

NOTE : See results of main specifications, Table 2.5.1 on page 110. The source of exogenous variation in the belief used in the first-stage is the random assignment of the income threshold, which determines eligibility to the dividend.

TABLE 2.E.5 – Effect of believing in environmental effectiveness on support : second stages of alternative specifications

	Initial Tax & Dividend			
	Approval ($\dot{A}^0$)			
	LIML	*OLS*	*IV*	*OLS*
	(A1)	(A2)	(A3)	(A4)
Environmental effectiveness : "Yes"	0.643	0.367		
	(0.320)	(0.020)		
Environmental effectiveness : not "No"			0.479	0.413
			(0.230)	(0.015)
Instruments : info E.E. & C.C.	✓		✓	
Controls : Socio-demo, other motives	✓	✓	✓	✓
Effective F-Statistic			6.0	
Observations	3,002	3,002	3,002	3,002
R^2	0.295	0.295	0.218	0.379

NOTE : Standard errors are reported in parentheses. The list of controls can be found in Appendix 2.F, and the main results in Table 2.5.2 on page 112. As in the latter Table, the dependent variable corresponds to either initial approval (answer "Yes" to support of the policy) or acceptance (answer not "No"). The first stage exploits the information randomly displayed about climate change (C.C.) and the effectiveness of carbon taxation (E.E.) as exogenous instruments.

2.F Control variables

Socio-demo : *respondent's income, household's income, sex, age* (5 categories)*, employment status* (9 categories)*, socio-professional category* (8 categories)*, region of France* (10 categories)*, size of town* (5 categories)*, diploma* 4 categories*, household size, number of people above 14, number of adults, number of c.u., income per c.u., smokes, favored media for news* (5 categories).

Politics : *extreme left, left, center, right, extreme right, interest in politics* (3 categories)*, conservative, liberal, humanist, patriot, environmentalist, apolitical.*

Political leaning : *extreme left, left, center, right, extreme right, indeterminate.*

Energy : *heating mode* (collective vs. indivual)*, heating energy* (7 categories)*, annual distance travelled, fuel economy, diesel* (binary)*, gasoline* (binary)*, number of vehicles.*

Incomes : *income of respondent, income of the second adult, income of respondent squared, income of the second adult squared, dummy for absence of second adult.*

Incomes (piecewise continuous) : *income percentile of respondent* (I_1)*, income percentile of the second adult* (I_2)*, dummy for absence of second adult,* $\min(I_1 - 20, 0)$, $\min(I_1 - 70, 0)$, $\min(I_2 - 20, 0)$, $\min(I_2 - 70, 0)$.

Estimated gains : *simulated net gain, squared simulated gain.*

Online Appendix

2.G Questionnaire

Priming

1. [No priming] Welcome to this survey.

   It was conceived by two researchers in social science. It lasts about 15-20 minutes.

2. [Info PM] Welcome to this survey.

   It was conceived by two researchers in social science. It lasts about 15-20 minutes.

   Before starting, please read carefully the information below on particulate matter pollution :

   — particulate matter are responsible for 48,000 deaths in France each year ;

   — particulate matter reduce the life expectancy of French people by 9 months ;

   — reducing fuel consumption would reduce the health problems associated with particulate matter.

   Source : France Public Health Report (2016)

3. [Info CC] Welcome to this survey.

   It was conceived by two researchers in social science. It lasts about 15-20 minutes.

   Please read carefully the information below on climate change.

   — Climate change is already responsible for 150,000 deaths annually.

   — If greenhouse gas emissions continue on their current trend, the average global warming will be +5°C in 2100 and +8°C in 2250.

   — A rapid transition to renewable energies is technically possible and would contain global warming at +2°C.

According to scientists, in the absence of ambitious measures :

— a large proportion of species face an increased risk of extinction ;

— natural disasters will intensify (hurricanes, heat waves, droughts, floods, forest fires, etc.) ;

— by 2100, 270 million more people would be flooded each year due to sea-level rise ;

— violent conflicts and migration flows can be expected to increase.

Sources : Burke et al (2009), Hinkel et al (2014), IPCC Report (2014), Meinshausen et al (2011), Patz et al (2005)

Socio-demographics

4. What is your postal code ?

5. What is your gender (in the sense of civil status) ?

   Female ; Male

6. What is your age group ?

   18 to 24 years old ; 25 to 34 years old ; 35 to 49 years old ; 50 to 64 years old ; 65 years old or more

7. What is your employment status ?

   Permanent ; Temporary contract ; Unemployed ; Student ; Retired ; Other active ; Inactive

8. What is your socio-professional category ? (Remember that the unemployed are active workers).

   Farmer ; Craftsperson, merchant ; Independent ; Executive ; Intermediate occupation ; Employee ; Worker ; Retired ; Other Inactive

9. What is your highest degree ?

   No diploma ; Brevet des collèges ; CAP or BEP [secondary] ; Baccalaureate ; Bac +2 (BTS, DUT, DEUG, schools of health and social training...) ; Bac +3 (licence...) [bachelor] ; Bac +5 or more (master, engineering or business school, doctorate, medicine, master, DEA, DESS...)

10. How many people live in your household ? Household includes : you, your family members who live with you, and your dependents.

11. What is your net **monthly** income (in euros) ? **All income** (before withholding tax) is included here : salaries, pensions, allowances, APL [housing allowance], land income, etc.

12. What is the net **monthly** income (in euros) **of your household** ? **All income** (before withholding tax) is included here : salaries, pensions, allowances, APL [housing allowance], land income, etc.

13. In your household how many people are 14 years old or older (**including yourself**) ?

14. In your household, how many people are over the age of majority (**including yourself**) ?

Energy characteristics

15. What is the surface area of your home ? (in m²)
16. What is the heating system in your home ?

    Individual heating ; Collective heating ; PNR (*Don't know, don't say*)
17. What is the main heating energy source in your home ?

    Electricity Town gas ; Butane, propane, tank gas ; Heating oil ; Wood, solar, geothermal, aerothermal (*heat pump*) *; Other ; PNR* (*Don't know, don't say*)
18. How many motor vehicles does your household have ?

    None ; One ; Two or more
19. [Without a vehicle] How many kilometers have you driven in the last 12 months ?
20. [One vehicle] What type of fuel do you use for this vehicle ?

    Electric or hybrid ; Diesel ; Gasoline ; Other
21. [One vehicle] What is the average fuel economy of your vehicle ? (in Liters per 100 km)
22. [One vehicle] How many kilometers have you driven with your vehicle in the last 12 months ?
23. [At least two vehicles] What type of fuel do you use for your main vehicle ?

    Electric or hybrid ; Diesel ; Gasoline ; Other
24. [At least two vehicles] What type of fuel do you use for your second vehicle ?

    Electric or hybrid ; Diesel ; Gasoline ; Other
25. [At least two vehicles] What is the average fuel economy of all your vehicles ? (in Liters per 100 km)
26. [At least two vehicles] How many kilometers have you driven with all your vehicles in the last 12 months ?

Partial reforms [transport / housing]

27. Do you think that an increase in VAT would result in a loss of more purchasing power for your household than for the average French household ?

    Yes, much more ; Yes, a little more ; As much as the average ; No, a little less ; No, a lot less ; PNR (*Don't know, don't say*)
28. Do you think that an increase in [fuel taxes / taxes on gas and heating oil] would cause your household to lose more purchasing power than an average French household ?

Yes, much more ; Yes, a little more ; As much as the average ; No, a little less ; No, a lot less ; PNR (*Don't know, don't say*)

29. The government is studying a fuel tax increase, whose revenues would be redistributed to all households, regardless of their income. This would imply :

    — [an increase in the price of gasoline by 11 cents per liter and diesel by 13 cents per liter / a 13% increase in the price of gas, and a 15% increase in the price of heating oil] ;

    — an annual payment of [60 / 50]€ to each adult, or [120 / 100]€ per year for a couple.

    In terms of purchasing power, would your household be a winner or a loser with such a measure ?

    Winner ; Unaffected ; Loser

30. [*Winner* selected] **According to you, your household's purchasing power would increase :**
From 0 to [10·uc] € per year ; From [10·uc] to [20·uc] € per year ; From [20·uc] to [30·uc] € per year ; From [30·uc] to [40·uc] € per year ; More than [40·uc] € per year

31. [*Loser* selected] **According to you, the purchasing power of your household would decrease :**
From 0 to [15·uc] € per year ; From [15·uc] to [40·uc] € per year ; From [40·uc] to [70·uc] € per year ; From [70·uc] to [110·uc] € per year ; From [110·uc] to [160·uc] € per year ; From more than [160·uc] € per year

32. If fuel prices increased by 50 cents per liter, by how much would **your household** reduce its fuel consumption ?
0% - [I already consume almost none / I am already not consuming] ; 0% - [I am constrained on all my trips / I will not reduce it] ; From 0% to 10% ; From 10% to 20% ; From 20% to 30% ; More than 30% - [I would change my travel habits significantly / I would change my consumption significantly]

33. In your opinion, if [fuel prices increased by 50 cents per liter / gas and heating oil prices increased by 30%], by how much would **French people** reduce their consumption on average ?
From 0% to 3% ; From 3% to 10% ; From 3% to 10% ; From 10% to 20% ; From 20% to 30% ; More than 30%

34. Do you think that an increase in taxes on gas and heating oil would cause your household to lose more purchasing power than the average French household ?
Yes, a lot more ; Yes, a little more ; As much as average ; No, a little less ; No, a lot less ; PNR (*Don't*

know, don't say)

Tax & dividend : initial

35. The government is studying an increase in the carbon tax, whose revenues would be redistributed to all households, regardless of their income. This would imply :

— an increase in the price of gasoline by 11 cents per liter and diesel by 13 cents per liter;

— an increase of 13% in the price of gas, and 15% in the price of heating oil;

— an annual payment of 110€ to each adult, or 220€ per year for a couple.

In terms of purchasing power, would your household win or loser with such a measure?
Win; Be unaffected; Lose

36. [*Winner* selected] **According to you, your household's purchasing power would increase :**
From 0 to [20·uc] € per year; From [20·uc] to [40·uc] € per year; From [40·uc] to [60·uc] € per year; From [60·uc] to [80·uc] € per year; From more than [80·uc] € per year

37. [*Loser* selected] **According to you, the purchasing power of your household would decrease :**
From 0 to [30·uc] € per year; From [30·uc] to [70·uc] € per year; From [70·uc] to [120·uc] € per year; From [120·uc] to [190·uc] € per year; From [190·uc] to [280·uc] € per year; From more than [280·uc] € per year

38. [[empty] / Scientists agree that a carbon tax would be effective in reducing pollution.] Do you think that such a measure would reduce pollution and fight climate change?
Yes; No; PNR (*Don't know, don't say*)

39. In your opinion, which categories would lose [[blank] / purchasing power] with such a measure? (Several answers possible)
No one; The poorest; The middle classes; The richest; All French people; Rural or peri-urban people; Some French people, but not a particular income category; PNR (*Don't know, don't say*)

40. In your opinion, what categories would gain purchasing power with such a measure? (Several answers possible)
No one; The poorest; The middle classes; The richest; All French people; Urban dwellers; Some French people, but not a particular income category; PNR (*Don't know, don't say*)

41. Would you approve of such a measure ?
    Yes ; No ; PNR (Don't know, don't say)

Tax & dividend : after information

42. [Feedback] We always consider the same measure. As a reminder, it would imply :

    — an increase in the price of petrol by 11 cents per liter and diesel by 13 cents per liter ;

    — an increase of 13% in the price of gas, and 15% in the price of heating oil ;

    — an annual payment of 110€ to each adult, or 220€ per year for a couple.

    In five out of six cases, a household with the same characteristics as yours would **[win / lose]**. (The characteristics taken into account are : heating with [source] for a dwelling of [size] m² ; [distance] km covered with an average consumption of [fuel economy] liters per 100 km).

    Based on this estimate, do you now think that your household would be :
    Winner ; Unaffected ; Loser

43. [Info on progressivity] On average, this measure would increase the purchasing power of the poorest households, and decrease that of the richest, who consume more energy.

    In view of this new information, do you think this measure would benefit the poorest ?
    Yes ; No ; PNR (Don't know, don't say)

44. [No info on progressivity] Do you think this measure would benefit the poorest ?
    Yes ; No ; PNR (Don't know, don't say)

45. In view of the above estimate, would you approve of such a measure ?
    Yes ; No ; PNR (Don't know, don't say)

46. Why do you think this measure is beneficial ? (Maximum three responses)
    Contributes to the fight climate change ; Reduces the harmful effects of pollution on health ; Reduces traffic congestion ; Increases my purchasing power ; Increases the purchasing power of the poorest ; Fosters France's independence from fossil energy imports ; Prepares the economy for tomorrow's challenges ; For none of these reasons ; Other (specify) :

47. Why do you think this measure is unwanted ? (Maximum three answers)
    Is ineffective in reducing pollution ; Alternatives are insufficient or too expensive ; Penalizes rural areas ; Decreases my purchasing power ; Decreases the purchasing power of some modest households ;

Harms the economy and employment ; Is a pretext for raising taxes ; For none of these reasons ; Other (specify) :

Tax & targeted dividend

48. The government is studying an increase in the carbon tax, whose revenues would be redistributed **to the [20 / 30 / 40 / 50]% of the poorest French people only**. This would imply :
    - an increase in the price of gasoline by 11 cents per liter and diesel by 13 cents per liter ;
    - an increase of 13% in the price of gas, and 15% in the price of heating oil ;
    - an annual payment of [550 / 360 / 270 / 220]€ for each adult earning less than [780 / 1140 / 1430 / 1670]€ per month (welfare benefits included, before withholding tax) ;
    - no compensation for the others.

We estimate that in your household, [number of recipients] persons would receive this payment.

In terms of purchasing power, would your household win or lose with such a measure ?
Win ; Be unaffected ; Lose

49. Would you approve such a measure ?
    Yes ; No ; PNR (Don't know, don't say)

Other questions The survey is completed by other attitudinal questions, treated in our companion paper, Douenne & Fabre (2020). Hereafter, we only describe questions that are used in the present chapter.

50. Please select "A little" (test to check that you are attentive).
    Not at all ; A little ; A lot ; Completely ; PNR (Don't know, don't say)
51. Do you smoke regularly ? *Yes ; No*
52. How much are you interested in politics ?
    Almost not ; A little ; A lot
53. How would you define yourself ? (Several answers possible)
    Extreme left ; Left ; Center ; Right ; Extreme right ; Liberal ; Conservative ; Liberal ; Humanist ; Patriot ; Apolitical ; Environmentalist
54. How do you keep yourself informed of current events ? Mainly through...
    Television ; Press (written or online) ; Social networks ; Radio ; Other

55. What do you think of the Yellow Vests ? (Several answers possible)

    I am part of them ; I support them ; I understand them ; I oppose them ; PNR (*Don't know, don't say*)

56. The survey is nearing completion. You can now enter any comments, comments or suggestions in the field below.

2.H Profile of the Yellow Vests

Table 2.H.1 – Positioning towards Yellow Vests, per category.

	Opposed	Understands	Supports	Is part	PNR
Extreme-left (2%)	6%	26%	51%	12%	5%
Left (20%)	17%	36%	36%	5%	7%
Center (13%)	49%	30%	15%	2%	6%
Right (16%)	40%	32%	20%	3%	6%
Extreme-right (9%)	11%	28%	47%	10%	5%
Indeterminate (40%)	19%	32%	30%	4%	13%
Liberal (5%)	48%	26%	18%	2%	6%
Conservative (2%)	22%	28%	30%	10%	11%
Humanist (11%)	21%	35%	29%	5%	10%
Patriot (8%)	21%	27%	39%	7%	6%
Apolitical (21%)	21%	31%	32%	4%	12%
Environmentalist (15%)	17%	39%	27%	5%	12%
Rural (21%)	20%	31%	34%	6%	9%
<20k (17%)	24%	28%	34%	6%	9%
20-100k (14%)	22%	33%	32%	4%	9%
>100k (31%)	29%	34%	26%	3%	8%
Paris (17%)	28%	33%	25%	4%	11%
No diploma or *Brevet* (30%)	21%	29%	34%	5%	10%
CAP or *BEP* (24%)	23%	28%	36%	6%	7%
Baccalauréat (17%)	22%	35%	29%	4%	11%
Higher (29%)	32%	21%	36%	3%	8%
Age : 18–24 (12%)	23%	34%	27%	4%	12%
Age : 25–34 (15%)	21%	33%	28%	7%	11%
Age : 35–49 (24%)	25%	32%	29%	5%	9%
Age : 50–64 (24%)	21%	32%	36%	4%	7%
Age : $\geq$ 65 (25%)	32%	30%	28%	3%	7%
Income decile : 1	25%	33%	26%	3%	14%
Income decile : 2	18%	31%	35%	5%	11%
Income decile : 3	17%	31%	32%	7%	12%
Income decile : 4	15%	33%	37%	6%	9%
Income decile : 5	21%	29%	36%	5%	8%
Income decile : 6	26%	33%	29%	6%	7%
Income decile : 7	25%	36%	28%	4%	7%
Income decile : 8	31%	31%	28%	3%	8%
Income decile : 9	39%	32%	20%	3%	6%
Income decile : 10	47%	29%	15%	3%	6%
Female (52%)	21%	34%	29%	5%	12%
Male (48%)	29%	30%	31%	5%	6%
Average	*25%*	*32%*	*30%*	*5%*	*9%*

Note : The percentages in parenthesis express the weighted share of each category from our sample. See discussion in the main text, Section 2.2.1 on page 86.

TABLE 2.I.1 – Support for Tax & Dividend policies at different stages of the survey.

	"Would you approve of this reform ?"		
	"Yes"	"No"	"PNR"
Initial stage (A^0)	10.4%	70.3%	19.3%
After feedback (A^F)	16.8%	63.0%	20.2%
Targeted dividend (A^T)			
bottom 20% (A^T)	19.1%	63.2%	17.7%
bottom 30%	15.0%	66.0%	19.0%
bottom 40%	17.3%	67.6%	15.1%
bottom 50%	12.8%	73.3%	13.9%
all	16.1%	67.6%	16.2%

NOTE : The table reads as follows : at the initial stage, 10.4% of respondents approved a Tax & Dividend. After receiving a customized feedback (either win or lose), 16.8% of them approved it. When the dividend targets only people below the bottom 20% (to which the respondent or its spouse may be eligible or not), 19.1% of them approve it. Back to Paragraph 2.2.2.2.

2.I Support rates for Tax & Dividend policies

2.J Relation between support and belief in progressivity

Specifications used As noticed in Section 2.5.3, the ambiguous responses to our priming on progressivity do not allow us to perform an IV estimation to identify the causal effect of this motive. To explore how respondents' beliefs about progressivity relate to their support for the policy, we therefore estimate simple OLS and logit regressions. Even though we control for many variables, including beliefs over other motives of support, we may suspect that the coefficients obtained remain biased by omitted variables or reverse causality. They should therefore be taken as partial correlations and not causal estimates.

We focus on the acceptance question *after information*, i.e. after asking whether the reform is progressive or not. Table 2.J.1 presents the results of different regressions, depending on the set of controls and on the choice of variables. Columns (1)-(4) report regressions of acceptance on the broad definition of motives of acceptance : answers *not "No"* to progressivity, effectiveness and *not "lose"* to win/lose category. On the contrary, columns (5)-(6) use strict definitions for both approval and the covariates, where only *"Yes"* (or *"win"*) answers activate the dummy variables.

Results On average, believing that the reform is *not regressive* is associated with a higher *acceptance* rate by 56 p.p. (column 3), while believing it is *progressive* is associated with a higher

Table 2.J.1 – Support of the Tax & Dividend in function of beliefs in each motive.

	Support (after information)					
	Broad definition of variables (*not "No"*)				Strict definitions (*"Yes"*)	
		OLS		*logistic*	*OLS*	
	(1)	(2)	(3)	(4)	(5)	(6)
Progressivity (P)	0.223	0.214	0.560	0.544	0.228	0.482
	(0.038)	(0.039)	(0.023)	(0.019)	(0.041)	(0.023)
Winner (G^1)	0.332	0.264			0.303	
	(0.020)	(0.018)			(0.019)	
Effective (E)	0.258	0.112			0.244	
	(0.023)	(0.021)			(0.020)	
($G^1 \times E$)	0.127	0.054			0.126	
	(0.034)	(0.030)			(0.037)	
Interaction : winner ($P \times G^1$)	0.183	0.144			0.098	
	(0.050)	(0.044)			(0.048)	
Interaction : effective ($P \times E$)	0.172	0.090			0.281	
	(0.057)	(0.050)			(0.059)	
Income (I, in k€/month)	0.017	0.025			0.037	
	(0.022)	(0.019)			(0.018)	
Interaction : income ($P \times I$)		−0.009			−0.019	
		(0.012)			(0.014)	
$P \times G^1 \times E$	−0.400	−0.320			−0.314	
	(0.072)	(0.063)			(0.083)	
Initial tax Acceptance (A^0)		0.467				
		(0.016)				
Controls : Socio-demo	✓	✓			✓	
Observations	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.460	0.586	0.162		0.391	0.130

Note : Standard errors are reported in parentheses. For logit, average marginal effects are reported and not coefficients. The list of controls can be found in Appendix 2.F. Covariates and dependent variables refer either to broad (1-4) or strict (5-6) definitions of the beliefs, where strict dummies do not cover "PNR" or "Unaffected" answers. See discussion in the main text, Section 2.5.3 on page 113.

approval rate by 48 p.p. (6). However, when one introduces other motives of acceptance and their interactions as covariates, with households characteristics as controls, one observes that the effect of progressivity is lower : its marginal effect at the sample mean — i.e. accounting for the average marginal effect of interaction terms — is 27 p.p.[32] To disentangle the link between beliefs over net gains and progressivity, we also include the interaction between progressivity and income as a covariate (2, 5). Although the coefficient is negative, in accordance with intuition, the effect is small and not significant. Adding the powerful control of initial tax acceptance in column (2) has negligible influence on the effect of progressivity, at 24 p.p. (instead of 27 p.p.), which validates our choice of preferred specification (1). Despite the powerful control,

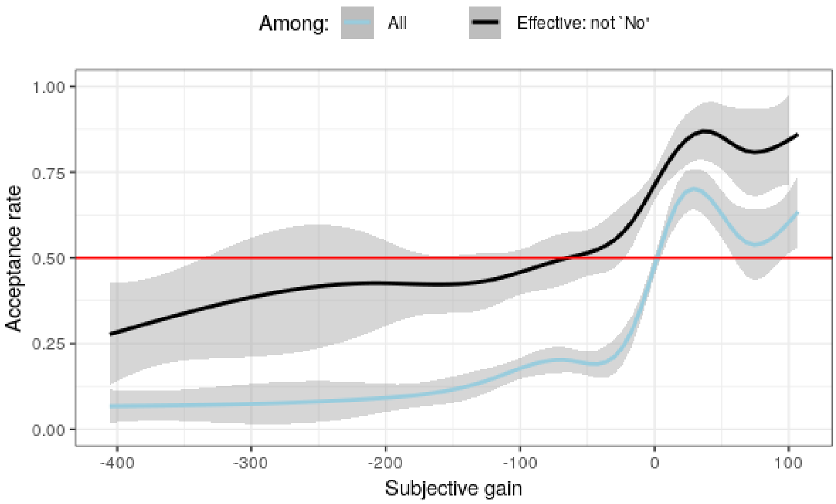
32. Although these results are not causal, they show that 90% of those who believe in the three motives approve of the policy, along with 65-75% of those who believe in two of them.

column (2) is not our preferred specification because the effect of environmental effectiveness is mostly captured by the covariate "initial tax acceptance", as the priming on climate change predated the initial question on acceptance. Finally, using the strict definitions of beliefs and approval yields a smaller correlation (6) but similar results when accounting for relevant controls (5), showing that the effects are not driven by a correlation between "PNR" answers. Overall, although these results are not causal, they suggest that the belief that the tax is progressive is associated with a higher support, all else equal.

2.K Willingness to pay

For respondents who believe in effectiveness of our Tax & Dividend, we are able to infer their willingness to pay (WTP) for climate mitigation by studying the acceptance rate in function of subjective gain. We adopt a common practice in the literature and define the WTP as the monetary loss that the *median* agent is willing to incur (Hanemann, 1984). Figure 2.K.1 indicates that this WTP is about 60€/year per c.u., as this corresponds to the subjective loss below which a majority accepts the policy. This WTP is computed only among people who believe that the tax is not ineffective, as it would make little sense to assume that some people are willing to pay for an instrument that does not achieve its expected goal. Indeed, Figure 2.K.1 shows that the "WTP" of the whole sample is zero, meaning that the median person accepts the policy only when they personally gain from it. Our method has several advantages. First, it can be interpreted as a willingness to accept as much as a willingness to pay, because our instrument is neither framed as a good to buy nor as damage to be compensated for, and net gains do not distinguish cost increases from payments received. Second, our method is more akin to revealed preferences — and hence probably less biased (Murphy et al., 2005) — than previous ones, because most studies directly ask respondents to select their preferred option for climate mitigation, be it in a contingent valuation method (Berrens et al., 2004; Cameron, 2005; Kotchen et al., 2013) or in a discrete choice experiment (Longo et al., 2008; Alberini et al., 2018). Still, our estimation has two notable limitations relative to the literature : it relies on a non-representative sub-sample, and subjective gains are endogenous with acceptance.

To compare our estimation with those of the literature, expressed per household, we have to multiply our WTP by the average number of consumption units by households : 1.6. The WTP per household we get, 96€, lies in the typical range of the literature (Jenkins, 2014; Streimikiene et al., 2019), suggesting that the protests against carbon taxation encountered in France do not reflect specific preferences for environmental policies.



NOTE : The black curve indicates that a majority of those who did not answer "No" to the question on the effectiveness of the policy accepted the reform when their subjective gain was above −60€ per c.u. For the whole sample (blue curve), this majority acceptance is reached only when subjective gains are positive. Back to Section 2.2.2.

FIGURE 2.K.1 – Acceptance rate by subjective gain, informative of the willingness to pay for climate mitigation.

2.L Ensuring data quality

We took several steps to ensure the best possible data quality. We excluded the 4% of respondents who spent less than 7 minutes on the full survey. We confirm that our main results are robust to choosing another cutoff than 7 minutes (see Table 2.L.1). In order to screen out inattentive respondents, a test of quality of the responses was inserted, which asked to select "A little" on a Likert scale. The 9% of respondents who failed the test were also excluded, which yields a final sample of 3,002 respondents. Also, when the questions about a reform were spread over different pages, we recalled the details of the reform on each new page. We checked for careless or strange answers on numerical questions, such as income or the size of the household. We flagged 10 respondents with aberrant answers to the size of the household (and capped it to 12) and up to 273 respondents with inconsistent answers, such as a household income smaller than individual income, or a fuel economy higher than 90 liters per 100 km. Being flagged or response time are not significantly correlated with our variables of interest such as policy support or subjective gain (the correlation is always between −1% and 3%). An examination of flagged answers suggests that these respondents have simply mistaken the question. Among these inconsistent answers, 58 respondents have answered more than 10,000€ as their monthly income (despite the word "monthly" being in bold and underlined), with answers in the typical range of French annual incomes. We have divided these figures by 12.

TABLE 2.L.1 – Robustness of main results to the exclusion of answers of poor quality.

	Acceptance (A^T)			Correct updating (U)		
	all	> 11 min	not flagged	all	> 11 min	not flagged
Believes does not lose (.53)	0.526	0.547	0.558			
	(0.134)	(0.137)	(0.153)			
Winner, before feedback (.55)				0.542	0.532	0.553
				(0.083)	(0.085)	(0.091)
Initial tax : Approves (.18)				0.180	0.213	0.197
				(0.046)	(0.049)	(0.049)
Original regression : Table (column)	2.5.1 (1)	2.5.1 (1)	2.5.1 (1)	2.4.2 (2)	2.4.2 (2)	2.4.2 (2)
Effective F-statistic	15.2	14.5	11.8			
Whole sample size	2777	3165	2729	2777	3165	2729
Observations	1,978	1,825	1,826	1,370	1,261	1,242
R^2	0.320	0.318	0.326	0.142	0.150	0.155

NOTE : Two of our main results are checked on three alternative sampling restrictions : (1) inclusion of answers < 7 min, (2) exclusion of the 10% of answers < 11 min, (3) exclusion of flagged (inconsistent) respondents. Weights have been recalculated for each sample. Estimates on the original sample are reported next to variable name. See the original Tables for more details. Correlation between our main variables of interest and response time or being flagged is always below 3%. Standard errors are reported in parentheses. Back to Section 2.2.2.2.

Chapitre 3

French Attitudes on Climate Change, Carbon Taxation, and other Climate Policies [1]

1. Acknowledgments : This chapter is based on a joint work with Adrien Fabre. We are grateful to Mouez Fodha, Fanny Henriet and Katheline Schubert for their comments and their help to get funding. We also thank Stefano Carattini, Mathias Lé, seminar participants at the Paris School of Economics, an anonymous referee of the FAERE Working Paper series and two anonymous referees and an editor of *Ecological Economics*. We are thankful to Christina Hobbs for the proof-reading. We acknowledge financial support from the Cepremap, EUR PGSE (ANR-17-EURE-0001), ANR (ANR16-CE03-0011), and Université Paris 1 Panthéon-Sorbonne economics doctoral school (ED 465).

Abstract :

This chapter aims to assess the prospects for French climate policies after the Yellow Vests crisis halted the planned increase in the carbon tax. From a large representative survey, we elicit knowledge, perceptions and values over climate change, we examine opinions relative to carbon taxation, and we assess support for other climate policies. Specific attention is given to the link between perceptions of climate change and attitudes towards policies. The chapter also studies in detail the determinants of attitudes in terms of political and socio-demographic variables. Among many results, we find limited knowledge but high concern for climate change. We also document a large rejection of the carbon tax but majority support for stricter norms and green investments, and reveal the rationales behind these preferences. Our study entails policy recommendations, such as an information campaign on climate change. Indeed, we find that climate awareness increases support for climate policies but no evidence for the formation of opinions through partisan cues as in the US, suggesting that better access to science could foster support for climate policies.

3.1 Introduction

The French government is currently facing a two-sided challenge on climate policies. On the one hand, the protest of the Yellow Vests that originated in November 2018 against the planned doubling in the carbon tax — from 44.6 to 86.2€/tCO_2 in 2022 — led the government to halt the increasing trajectory that started at 7€/tCO_2 in 2014. On the other hand, a large campaign called "Affaire du siècle" started in December 2018 against its inaction for the environment, gathering over two millions signatories in a month. It is so far unclear how the tension between these two *a priori* antagonistic objectives will be resolved. In particular, one may wonder whether the two movements involve distinct groups with opposite interests, or rather reflect a commonly perceived inadequacy of the solution proposed by the government to address the climate threat.

This chapter aims to understand French perceptions over the carbon tax and other climate policies. It builds on a new survey conducted on a sample of 3,002 respondents representative of the French population. Our survey contains questions to assess respondents' knowledge about climate change (CC) and their perceptions over its causes and consequences. As the chapter was primarily motivated by the failed attempt to increase the French carbon tax, we examine in detail attitudes towards this instrument. We propose to respondents a Tax & Dividend policy, i.e. a carbon tax whose revenue would be returned lump-sum uniformly to all adults. This policy differs from the one proposed by the government, since the revenue would have been used to fund the general budget instead. We identify respondents' expected winners and losers, and the perceived problems and benefits of this instrument. We devote particular attention to the issue of mobility that appears critical in the current debate. We then turn to the support for a carbon tax with alternative uses of the revenue, such as more targeted transfers, earmarking, and double-dividend strategies. We also study the support for other climate policies, including norms and other Pigouvian taxes, and local policies for urban transport. Finally, we identify the determinants of attitudes over both climate change and climate policies, as well as the link between the two.

For a general presentation of attitudes over climate change, we suggest Whitmarsh & Capstick (2018), while for a more specific review on their trends and determinants, we redirect to Brechin (2010) and Ziegler (2017). Our paper contributes mainly to a growing literature on the political economy of climate policies. As an entry point to previous related studies, refer to

Maestre-Andrés et al. (2019) who review the perceptions of climate policies, Drews & van den Bergh (2016) who review the determinants of their support, and to Carattini et al. (2018) for a comprehensive overview on attitudes over the carbon tax.

A large extent of the literature has focused on the carbon tax. Using a post-electoral survey in Switzerland, Thalmann (2004) finds that political leaning, education and self-interest are correlated with acceptance. Subsequent literature has confirmed the importance of self-interest (e.g. Fischer et al., 2011; Baranzini & Carattini, 2017) although Kallbekken & Sælen (2011) find that perception of the tax' effectiveness and its distributive properties play a larger role in Norway. The critical role of the tax' effectiveness has been confirmed by numerous contributions that pointed out the higher acceptance of taxes whose revenue was earmarked towards green investments (e.g. Sælen & Kallbekken, 2011; Baranzini & Carattini, 2017). Similarly, studies have confirmed that people tend to prefer more progressive schemes (Brannlund & Persson, 2012; Gevrek & Uyduranoglu, 2015) and more targeted revenue recycling (Kallbekken et al., 2011). In a companion paper (Douenne & Fabre, 2019b) based on the same survey, we show that French people reject the carbon tax because of biased beliefs over its properties, but if convinced about their own gain, the environmental effectiveness and the progressivity of the mechanism, they would largely approve it. Among the potential barriers to the implementation of carbon taxation, Kallbekken & Aasen (2010) emphasize the importance of the availability of alternatives to fossil fuels. When these alternatives are lacking or not easily affordable, carbon taxation is perceived as just a pretext to increase taxes (Dresner et al., 2006a; Klok et al., 2006). Finally, as shown by Harring & Jagers (2013), trust in politicians is also a key factor for carbon tax acceptance, which relates to the recent findings of Rafaty (2018) who shows that higher political distrust is associated with weaker climate policies.

While a lot of attention has recently been put on carbon taxation, fewer studies have investigated attitudes towards other climate policies. Yet, as highlighted by Stern & Stiglitz (2017) and Stiglitz (2019) a single price instrument may not be the best response to climate change in a second-best world. The main factors driving people's preferences between various policies appear to be their degree of coercion, the behavior targeted by the policy (de Groot & Schuitema, 2012), and the perceived cost. It follows that subsidies are in general preferred over taxes (e.g. Tobler et al., 2012; Cherry et al., 2017), and more voluntary measures over hard regulations (Attari et al., 2009). The present chapter contributes to the literature by providing a comprehensive analysis of perceptions and attitudes towards CC, carbon taxation and other climate policies in a country that has recently experienced a carbon tax increase and a large debate ensuing. As it is based on an unusually large sample representative of the French population, the chapter also goes further than previous studies in identifying the heterogeneity in people's attitudes over climate policies.

Section 3.2 presents the survey. Section 3.3 describes attitudes towards climate change. Section 3.4 focuses on tax & dividend policies, its perceptions, and the reasons explaining the low support for this policy. Section 3.5 studies the support for alternative revenue recycling mechanisms as well as for other climate policies. Section 3.6 examines the heterogeneity in attitudes expressed in the previous sections and characterize their determinants. Section 3.7 concludes. Finally, further material can be found in appendix and online Appendix.

3.2 The survey

3.2.1 Presentation of the survey

We collected 3002 responses in February and March 2019 through the survey company Bilendi. This company maintains a panel of French respondents to whom they can email survey links. Respondents are paid 3€ if they fully complete the survey. The respondents who choose to respond are first filtered through some screening questions which ensure that the final sample is representative along six socio-demographic characteristics : gender, age (5 brackets), education (4), socio-professional category (8), size of town (5), and region (9). The quotas are relaxed by 5% to 10% relative to actual proportions. Table 2.A.1 in Appendix 2.A shows that our sample is still extremely representative. Nonetheless, observations are weighted to correct small differences between sample and population proportions. The median time for completion of the survey was 19 minutes.

The full survey in French can be seen online,[2] the questions analyzed are translated in Appendix 3.D, and the code is available on github. Figure 3.2.1 presents in a diagram the sequence of questions.

2. preferences-pol.fr/doc_q.php#_e

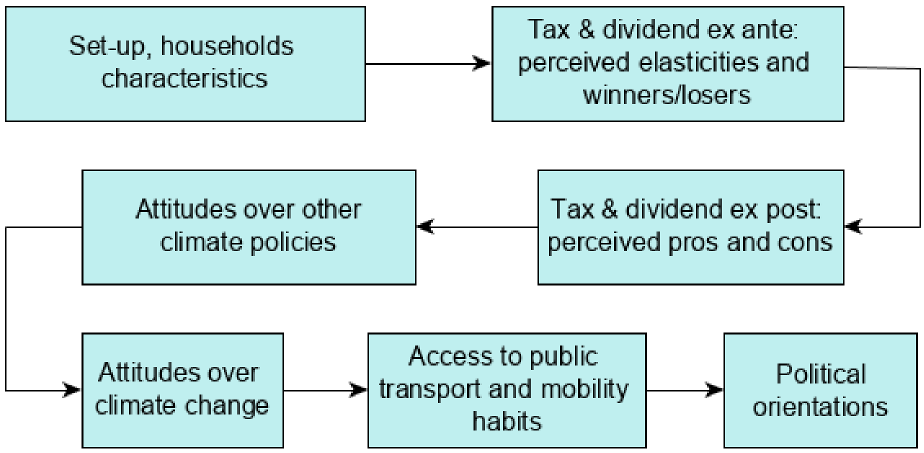


FIGURE 3.2.1 – Diagram of the sequence of questions.

The survey starts by asking for households' socio-demographics and energy usage. The distribution of answers are much in-line with official statistics, as shown in Table 2.A.2 in Appendix 2.A. Then, we describe Tax & Dividend reforms where the revenues of an increase in the French carbon tax by 50€/tCO_2 are redistributed uniformly to all adults. We first allocate respondents randomly to a sectoral Tax & Dividend reform, which concerns either gas and domestic fuel (i.e. housing energy), or gasoline and diesel (i.e. transportation energy). Respondents are asked to estimate their reaction to price changes, the reaction of French people, and how much purchasing power they would gain or lose from the policy. To this end, exact price variations and the amount transferred are provided, and respondents can choose among answers given in different brackets. Then, we study perceptions and support for a Tax & Dividend on both sectors combined, before and after providing new information to the respondents. This new information is either that the policy is progressive, or whether their household would win or lose some purchasing power through the reform. Before providing information, we let respondents pick the categories of losers and winners from the reform ; and after the information, they choose the benefits and the problems associated with this reform. We study these perceptions of the policy in the present chapter, but please refer to our companion paper (Douenne & Fabre, 2019b) for details and analyses on the other questions about Tax & Dividend reforms.

3.2.2 Eliciting attitudes

After inquiring about the support for Tax & Dividend, we ask respondents to assess on a Likert scale different ways to recycle the revenues of a carbon tax. On another Likert scale, we examine opinions on other climate policies, notably new norms or Pigouvian taxes. We then measure respondents' knowledge about climate change by asking for its origin (anthropogenic or natural), its causes (in terms of gases and activities), which region it will most affect (between India and the European Union), and what reduction of emissions is needed by 2050 to respect the +2°C target. At the same time, we assess attitudes over climate change by asking respondents about the frequency with which they talk about it, the gravity of its consequences, the generations it will severely affect, and the entities responsible for its occurrence. We continue by surveying if and how climate change influences one's decision to have a child, under which conditions one would be ready to change their lifestyle to fight climate change, and whether one would be ready to adopt a sustainable lifestyle if policies were aligned to this goal. We also ask questions about diesel taxation. Then, we evaluate the respondents access to public transport, their mobility habits, and if there is room for changing these habits. Finally, we ask for their political preferences, including their positioning in relation to the Yellow Vests. The survey ends with a text box where the respondents can leave a comment.

3.3 Perceptions and Attitudes over Climate Change

To fully understand the root motivations to the support or rejection of climate policies, we first analyze the knowledge and perceptions over CC, as well as the reaction that people expect to address this phenomenon. As the chapter focuses on explaining attitudes over policies, we relegate to online Appendix 1 some figures and some results from other surveys.

3.3.1 Knowledge

As shown in Figure 3.3.1, knowledge that CC is anthropogenic is widespread (72%) and the share who do not believe in climate change (CC) is marginal (4%). The level of knowledge on the anthropogenic origin of CC is similar to that of other Western countries (Leiserowitz, 2007; Lee et al., 2015; Stokes et al., 2015) : it is 66% in the U.S. (Gallup, 2019) for example.

At the same time, knowledge about climate science appears limited. Although 77% of people correctly tick "CO_2" as a greenhouse gas (GHG), Figure 3.3.2 shows that almost as many people tick particulate matter (39%) as methane (48%). Admittedly, understanding the impacts of activities is more useful than erudition about chemical factors, but here again, knowledge is quite low. We assess such awareness using pairs of comparable activities whose GHG footprint differ by a factor 20 (beef steak vs. pasta, plane vs. train) or whose footprint are similar (nuclear vs. wind power).[3] We ask whether it is true that one activity emits 20 times more GHG than the other, as a way to express precisely that one is "much more" polluting than the other. For each pair, around half of the sample is correct. The bulk of respondents pick two correct answers out of three (44%), but more get them all wrong (19%) than all right (15%).

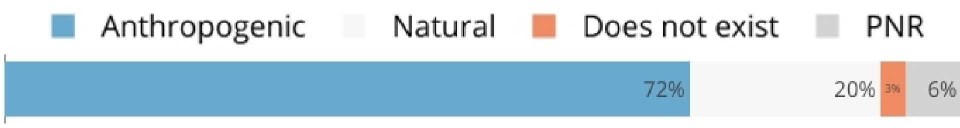


FIGURE 3.3.1 – Perceived cause of climate change.

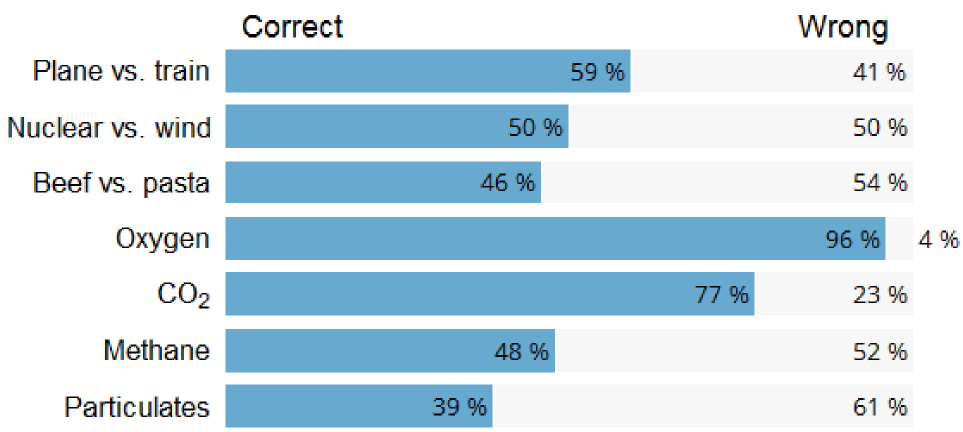


FIGURE 3.3.2 – Perceived factors of climate change.

Not only do most people fail to fully understand the factors and consequences of CC, but they also fail to grasp the degree of reaction needed to tackle it. When informed that "each French person emits on average the equivalent of 10 tons of CO_2 per year" and asked what the figure should be in 2050 to "hope to contain global warming to +2°C in 2100 (if all countries did the same)", 59% answer 5 or more (see Figure 3.3.3). Only 17% select a correct answer : 0,

3. Appendix 3.B.1 details how the figures were obtained.

1 or 2 (see Appendix 3.B for why these are correct).

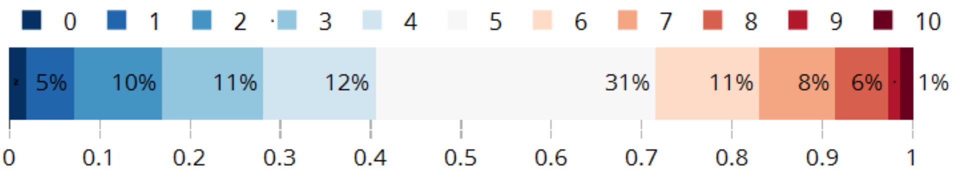


FIGURE 3.3.3 – Perceived GHG emission p.c. required in 2050 to limit global warming to +2°C (in tCO_2eq/yr), given that it is now 10.

Millner & Ollivier (2016) propose several mechanisms to explain people's lack of understanding about climate change : in addition to the difficulty of grasping gradual changes, they emphasize the complexity of drawing a causal link between diffuse causes and distant consequences.[4] Failing to assimilate the underlying channels may blur the link between people's own behavior and consequences for the climate. Thus, we can wonder if people understand who would have to make the mitigation effort in a sustainable scenario, i.e. who is responsible for CC.

3.3.2 Positions

As shown in Figure 3.3.4, 63% acknowledge that "each one of us" is responsible for CC, and less people ascribe the responsibility to "certain foreign countries" (47%), "the richest" (42%), or any other agent. Not only do people seem lucid concerning the agents causing CC, but a vast majority also foresees worrying consequences if humanity does nothing to limit it. Figure 3.3.5 shows that 18% see the impacts as "cataclysmic, humankind would disappear", 28% as "disastrous, lifestyles would be largely altered", 34% as "grave, because there would be more natural disasters", while only 11% think damages would be "small, because humans would be able to live with it" or "insignificant, or even beneficial".

Overall, these results indicate that most people understand the fundamentals of climate issues, including the root causes and the scale of the problem, but that only a minority has thought of CC deeply enough to comprehend its factors and the pathways to tackle it.

4. Actually, even MIT students struggle with this (Sterman, 2008).

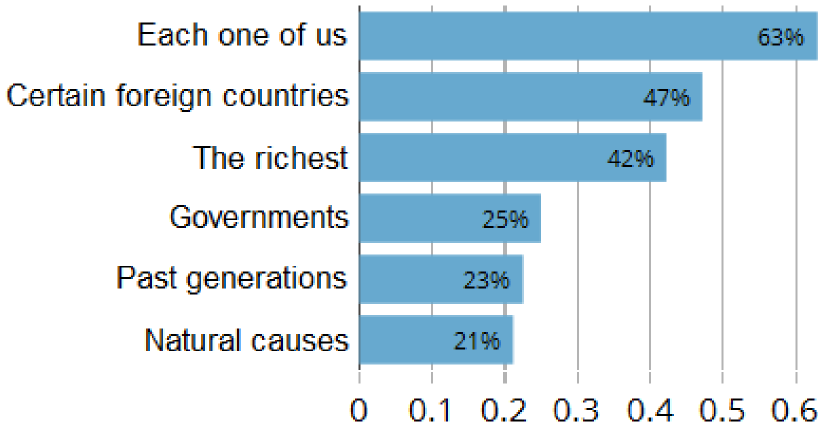


Figure 3.3.4 – Entities perceived responsible for climate change.

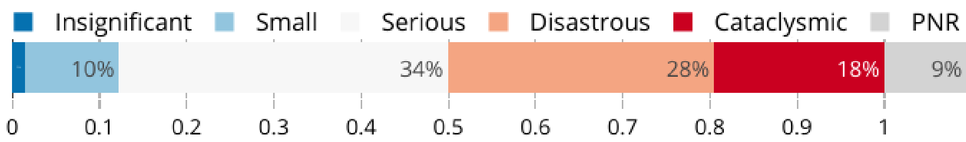


Figure 3.3.5 – Perceived gravity of climate change.

3.3.3 The Reaction Needed

Given that many people may not realize the extent of the transition needed to reach sustainability, and that others may be discouraged precisely by the sheer magnitude of such a transition, we can wonder how willing people are to contribute to its success. An encouraging finding for the transition is that 65% are "willing to adopt an ecological lifestyle (i.e. eat little red meat and make sure to use almost no gasoline, diesel nor kerosene)", assuming that "all states in the world agree to firmly fight climate change, notably through a transition to renewable energy, by making the richest contribute, and imagining that France would expand the supply of non-polluting transport very widely", while only 17% answer "No" (the others do not take a side). While the phrasing removes most grounds against a change in lifestyle, we inquire under which conditions people would be willing to adopt such a change (see Figure 3.3.6). 82% of respondents would be willing to change their lifestyle under at least one of the three conditions proposed : sufficient financial resources, an alignment of policies to this goal, or an adjustment of others' behavior (about 45% each).

Finally, a substantial fraction of people incorporates ecological constraints in their life choices. Indeed, 15% call themselves ecologist (the most picked political identity outside of the left-right

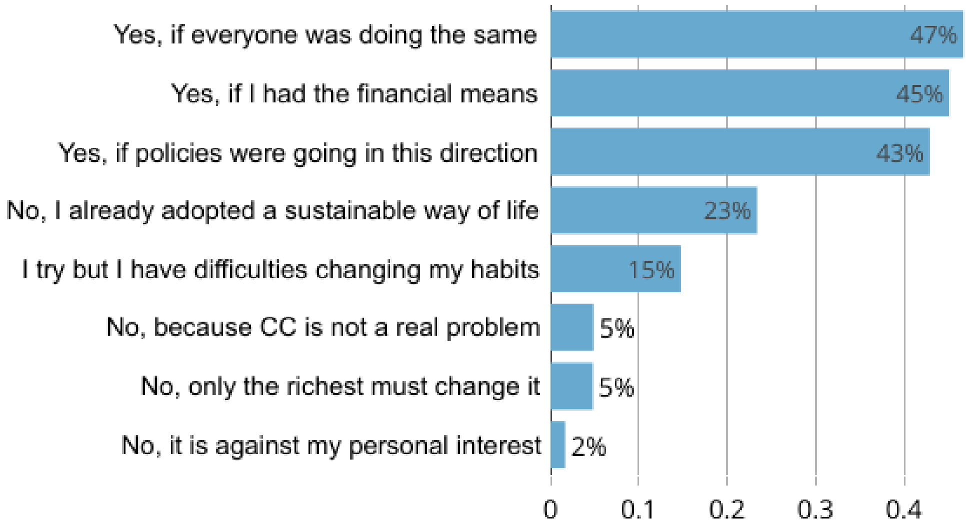


FIGURE 3.3.6 – Respondent could change their lifestyle under a condition.

spectrum, see Appendix 3.E), 23% claim they already adopted a sustainable way of life, and 20% say the CC "has had or will have an influence in their decision to have a child".

3.4 Attitudes over Carbon Tax and Dividend

Most French people are aware and concerned about climate change and claim to be willing to exert efforts to fight it. Yet, the government's attempt to introduce a carbon tax to deal with French emissions resulted in a widespread popular protest. To understand this paradox, we investigate the preferences over a Tax & Dividend policy : an increase of 50€/tCO_2 in the current French carbon tax, with a uniform lump-sum redistribution of the additional revenue to all adults. This policy differs from the official one whose revenue was mostly used to fund the general budget. Respondents are given the associated increase in energy prices so that the direct costs are salient : +13% (resp. +15%) for gas (resp. domestic fuel), and +0.11€ (resp. +0.13€) for a liter of gasoline (resp. diesel). They are also told that the transfer would amount to 110€ per adult annually.

3.4.1 Widespread rejection

French people would largely reject the proposed policy. Only 10% of our respondents declare they would approve it, while 70% say they would not (see Figure 3.4.1). As shown in our companion paper (Douenne & Fabre, 2019b), this rejection can be explained by erroneous perceptions about the policy's outcome, such as an overestimation of its impact on one's purchasing power. For instance, 30% of people who use neither gas nor domestic fuel believe their household would lose from an equally redistributed increase in taxes on these goods. Interestingly, the salience of costs appears critical in people's answer. At a later stage of the survey, we ask respondents whether they would agree to increase the carbon tax if the revenue was returned to all households, without mentioning the impact on prices. The question is asked along with a package of other environmental policies (see section 3.5). In this case — where the benefits are more salient than the costs — we find a much higher approval rate of 37%. Another survey conducted in March 2019 (OpinionWay, 2019) assesses acceptance for a *reintroduction* of the carbon tax increase in 2021. They find intermediary results with an approval rate of 21%.

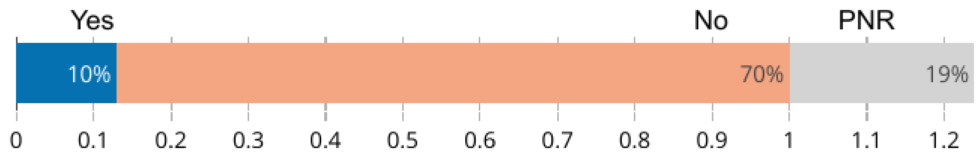


FIGURE 3.4.1 – Approval of Tax & Dividend.

The low level of acceptance observed partly results from recent events. In July 2018, ADEME (2018) found that 48% of French people thought it was desirable to increase the carbon tax, a figure similar to those of other countries (Brechin, 2010). The discrepancy between 2018 and 2019 can be explained by the "campaign effect" highlighted by Anderson et al. (2019) : support for a carbon tax decreases substantially after it enters the public debate. Indeed, the French carbon tax was brought under the spotlight in the end of 2018, after high oil prices triggered the Yellow Vests movement.

3.4.2 Perceived winners and losers

Figure 3.4.2 represents the share of respondents who expect different household categories to win or lose from the policy. Income appears to be the most critical divide, with a non-monotonic relationship. 30% of respondents expect the richest to win while only 2% think they would lose. On the contrary, 40% more people think that the poorest would lose rather than win, a difference even higher for the middle class — the category most expected to lose — at 53%. To half of respondents, we framed the question about winners and losers specifically in terms of "purchasing power". The objective was to see if some categories were commonly seen as losing in welfare although they could gain in monetary terms, or conversely. The results look very much alike for both formulations, except that the shares of people expecting poorer households to gain (5.8%) and richer households to lose (0.9%) are significantly larger when asked in terms of purchasing power : 10.2% and 2.1%, respectively (see online Appendix 2). Overall, respondents perceive the Tax & Dividend as regressive. As shown by a large body of literature (e.g. West & Williams, 2004; Bento et al., 2009; Williams et al., 2015), and more specifically in our companion paper (Douenne & Fabre, 2019b), these beliefs are at odds with the true distributive effects of this proposed policy.

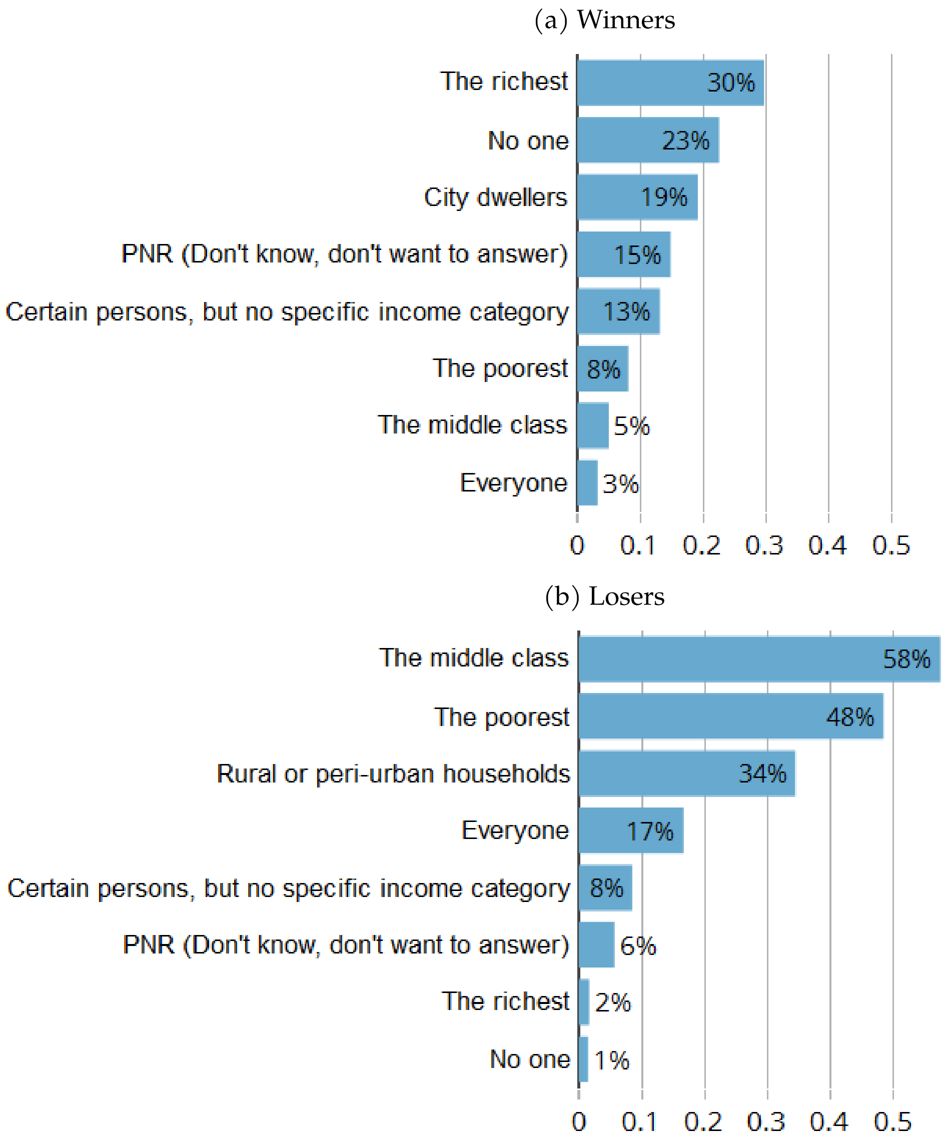


FIGURE 3.4.2 – Perceived winners and losers from Tax & Dividend

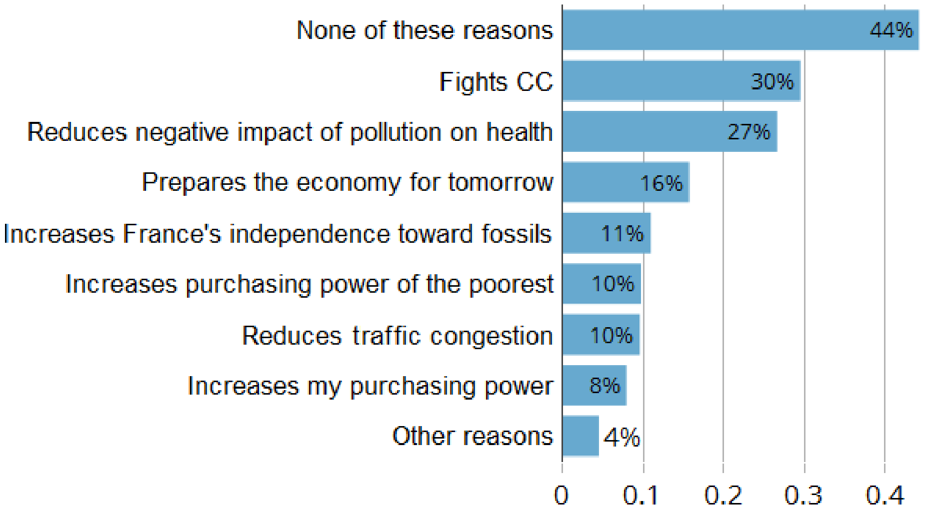
Beyond the income dimension, people tend to identify city dwellers as potential winners from the Tax & Dividend (third position at 19%), while rural and peri-urban households are rather expected to lose (third position at 34%). We also see that people report on average more categories for expected losers than winners : 1.74 vs. 1.16. The high ranks of "no one" for winners (second) and of "everyone" for losers (fourth) further suggest that respondents do not see our policy as a zero-sum game.

3.4.3 Perceived pros and cons

Previous studies have highlighted that distributive effects are a critical determinant of carbon tax acceptance (e.g. Kallbekken & Sælen, 2011; Brannlund & Persson, 2012; Gevrek & Uyduranoglu, 2015). When asked about the problems associated with the Tax & Dividend, the main response is that the tax would penalize rural households (47%). Interestingly, this concern comes before the threat that the tax could penalize the poorest (sixth position with 29%), although more people report the poorest as a category of people expected to lose. The second and third concerns are that the policy is simply a pretext to increase taxes (43%) — a worry documented by Dresner et al. (2006a) and Klok et al. (2006) — and that it would be ineffective to reduce pollution (37%). Related to this last point is the perceived lack of alternatives, seen as insufficient or too expensive (31%). This problem has been previously stressed by Kallbekken & Aasen (2010) in a focus group study : people do not see the point of taxing fossil fuels if they cannot substitute for other technologies. This last reason is stated as frequently as concerns over the impact on one's own purchasing power (fourth with 31%). As shown in Douenne & Fabre (2019b), self-interest largely affects acceptance of the Tax & Dividend, but this concern could sound too egoistic when stated in a direct way. While previous studies have pointed out concerns over the negative impact of carbon taxation on the economy (e.g. Thalmann, 2004; Carattini et al., 2017), this problem comes last (14%) and does not seem to represent an important obstacle for public support in the current context.

Respondents are suggested to pick at most three answers among both problems and benefits. On average, respondents pick 2.36 problems — and 53% pick at least 3 — against 1.14 benefits, excluding the most popular : "None of these reasons" (44%). This option comes far ahead of the second and third, "fight climate change" (30%) and "reduces negative impact of pollution on health" (27%). Still, environmental benefits are much more cited than economic ones. This result is likely due to people's pessimism about the outcome of the policy, but it might also reflect the limited importance given to economic consequences of the carbon tax, as already suggested by problems commonly cited.

(a) Benefits



(b) Problems

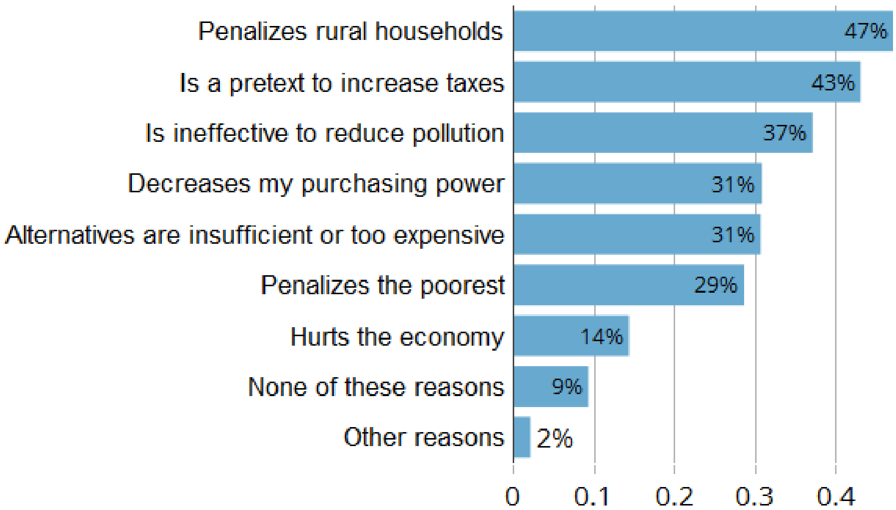


FIGURE 3.4.3 – Perceived benefits and problems from Tax & Dividend

3.4.4 Consumption and mobility constraints

The perceived problems identified above suggest a rationale for people's opposition towards carbon taxation : if people think the tax is ineffective, because their consumption is constrained and affordable alternatives are lacking, then taxing carbon can be perceived as a pretext to increase taxes.

3.4.4.1 Perceived elasticities

In order to understand to what extent people feel constrained with respect to their energy consumption, we elicit their subjective price elasticity for transport and domestic energies. We adopt the phrasing of Baranzini & Carattini (2017) and ask the expected decrease in energy consumption that would follow an increase in prices. To avoid dealing with small percentages, which people usually find more difficult to compare, we ask for the reaction to a 30% increase in the price of heating (or equivalently, an increase of 0.50€ per liter in fuel prices). Although sufficiently high to foster a significant response on demand, these changes are realistic in the medium run, and should not lead people to report long-term elasticities. Respondents may select their answer among 5 brackets. They are asked to estimate their own reaction as well as that of French people. Figure 3.4.4 presents the results.

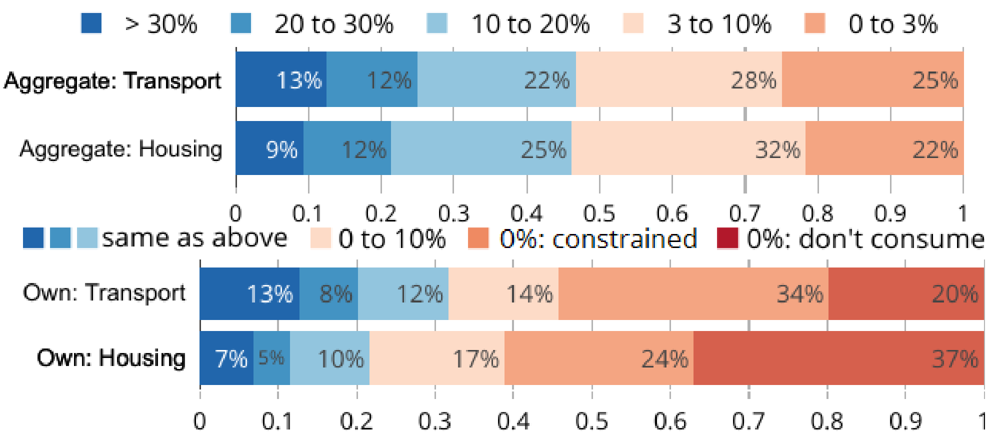


FIGURE 3.4.4 – Perceived aggregate and own elasticities.

54% (resp. 61%) of respondents consider that such an increase in prices would not lead them to reduce their transport (resp. domestic) energy consumption. This expected inelastic behavior is mainly due to mobility constraints for transport (64% of cases) while it mostly reflects a non-fossil heating type for housing (61%). Excluding people reporting inelastic behavior because of insignificant initial consumption, about 40% of people feel constrained and expect to not lower their consumption following price increases. Still, respondents perceive transport fuel price elasticity of French people at -0.45 on average, and their own elasticity at a consistent

-0.36 (after re-weighting by fuel expenditures). Concerning housing energy, aggregate and personal subjective elasticities are respectively -0.43 and -0.33. Overall, these subjective elasticities compare well to the ones found in the literature for French households, although they are slightly over-estimated (in absolute value) for housing.[5]

3.4.4.2 Mobility and public transport

To assess the level of dependence on automobiles, which we include as a determinant for preferences in Section 3.6, we study mobility habits and access to public transport. Figure 3.4.5 indicates that 65% of employed people drive to work, and that car usage is even more common for grocery shopping or leisure activities. This figure is confirmed by the national transport survey ENTD (2008) conducted by Insee and analyzed in Pappalardo et al. (2010), which reveals that a majority still uses a car for trips of 1 to 2 km. Even though 73% live within a 10 minute walk to a public transit stop (Figure 3.4.6), coverage and frequency of public transport is often too low (Figure 3.4.7) to compete with the speed, comfort, and flexibility of automobiles. Indeed, 58% of those who commute by car declare that they could neither substitute it with public transport nor walking or cycling, and only 15% could use one of these alternative without major difficulties (Figure 3.4.8). Further evidence indicates that the lack of alternatives is a main factor for car usage, besides apparent taste for a vehicle that remains a symbol of freedom. Figure 3.4.9 shows that 52% of respondents state that supply of public transport where they live is "insufficient" or "decent, but should be increased", while 40% find it "satisfactory" or "limited, but sufficient". From this perspective, "green public investments and carbon taxes appear to be complementary, and in the timing of climate policy it would be justified to carry out the former before implementing the latter", as Bureau et al. (2019) suggest. Alongside an increase in the supply of alternatives, climate policies could also address the demand for mobility, e.g. by revitalizing town centers and limiting urban sprawl.

5. For transports, estimates from the literature lie around -0.4 (Clerc & Marcus, 2009; Bureau, 2011; Douenne, forthcoming). For housing, the values are lower, typically around -0.2 (Douenne, forthcoming; Clerc & Marcus, 2009).

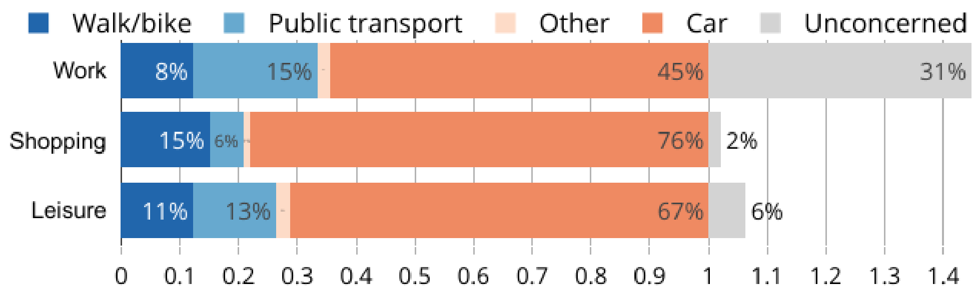


FIGURE 3.4.5 – Mode of transportation by activity.

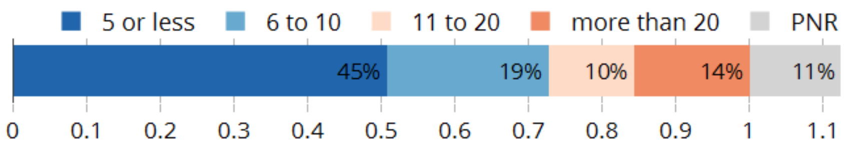


FIGURE 3.4.6 – Walking distance to the nearest stop, in minutes.

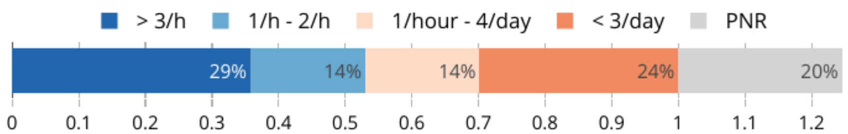


FIGURE 3.4.7 – Frequency of public transport at the nearest stop.

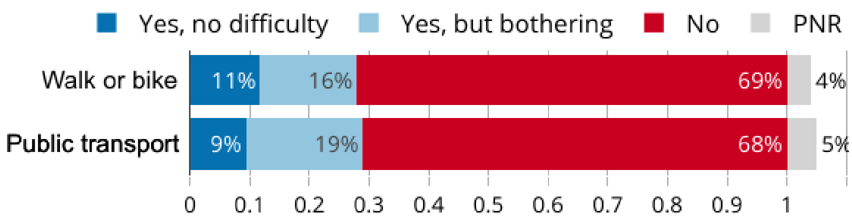


FIGURE 3.4.8 – Among those who commute to work by car, possibility to change the transportation mode, depending on the alternative.

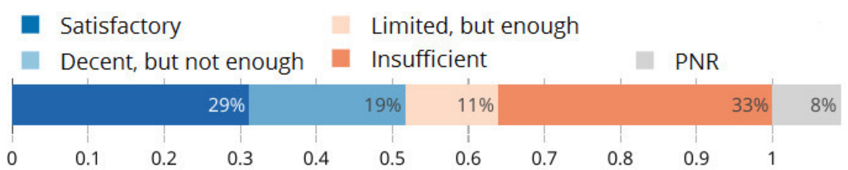


FIGURE 3.4.9 – Supply of public transport where the respondent lives.

3.5 Attitudes over Other Policies

The previous section has shown that our Tax & Dividend was largely rejected by French people. As climate policies are urgently needed, it appears necessary to assess whether other designs and instruments would be met with a higher support. This section first examines public opinion about several alternative uses for the carbon tax revenue and then turns to other environmental and climate policies.

3.5.1 Preferred Revenue Recycling

We asked respondents to what extent they would accept an increase in the carbon tax for different uses of the revenue. As the exact cost of the tax was not specified, the benefits of the revenue recycling were made relatively more salient, which explains higher acceptance rates compared to our Tax & Dividend. Still, this question enables to compare answers relative to one another.

3.5.1.1 Investments in energy transition

Figure 3.5.1 reports people's responses to each proposed scenario. Overall, the preferred revenue recyclings are investments in the energy transition. This result is consistent with various papers showing that earmarking the revenue of the tax for environmental purposes largely increases public support (for a review of the literature, see for instance Kallbekken & Aasen, 2010; Carattini et al., 2018). As people tend to see carbon taxation as effective only if it finances green investments (Sælen & Kallbekken, 2011), these policies legitimize the implementation of a tax and increase its acceptance. In addition, the large approval for a policy investing in non-polluting transport can be explained by people's desire for mobility alternatives, the lack of which was identified as an important problem with our Tax & Dividend (see section 3.4).

3.5.1.2 Transfers to households

While previous literature has shown that distributive concerns matter for carbon tax approval, the common tool proposed by economists to address this issue — lump-sum transfers — is not met with resounding support. Out of the nine proposed mechanisms, the standard flat

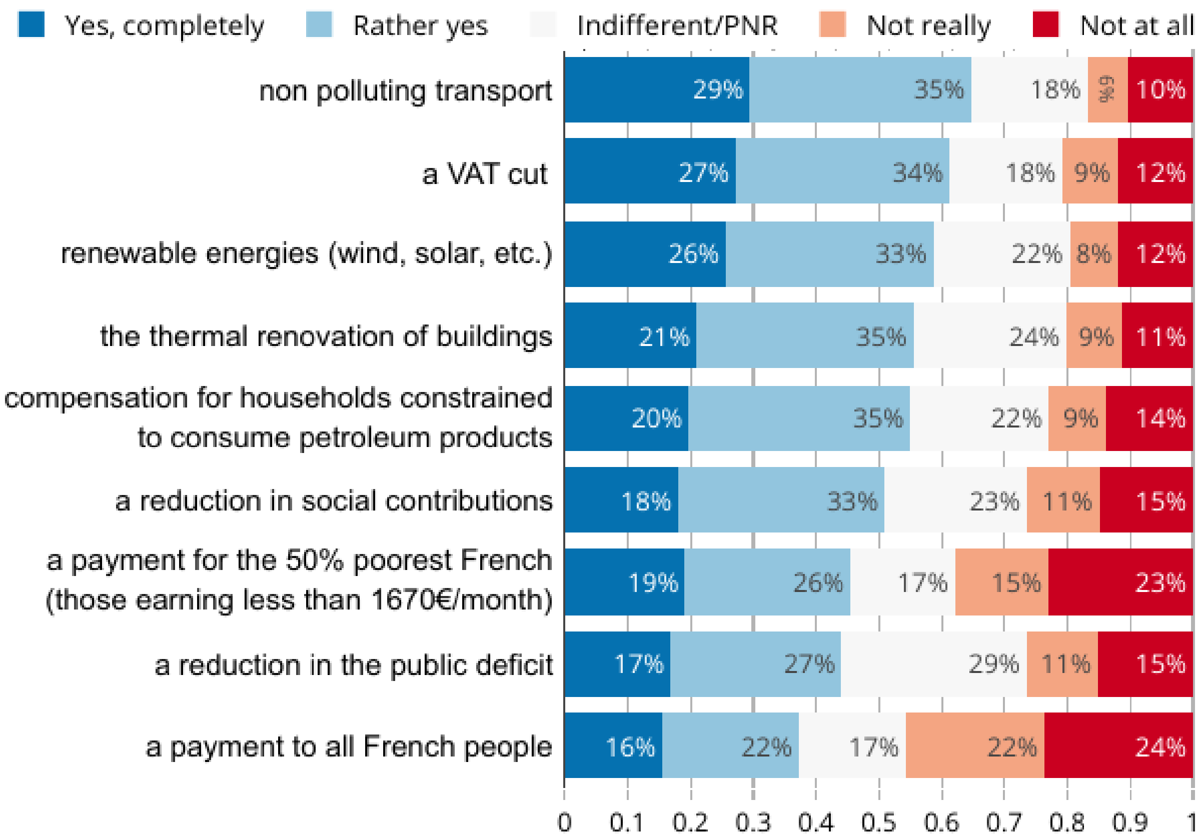


Figure 3.5.1 – Approval of a carbon tax if its revenue finances...

recycling comes last (with 37% approval), and a transfer targeted to the bottom 50% comes seventh (46%). Consistent with our previous finding that people are concerned that the carbon tax may penalize rural and peri-urban households, the preferred "lump-sum" transfer is the one targeted to people constrained with respect to their consumption of petroleum products (fifth with 55% approval). These results echo the findings of Kallbekken et al. (2011) who showed that people tend to prefer more narrowly targeted revenue recycling, possibly because of distributional concerns. The lower support for transfers is the only result that departs from the preferred revenue recycling in Germany and in the U.S., documented by Beiser-McGrath & Bernauer (2019).

The relatively low support for compensation mechanisms should however not be understood as a lack of concern about purchasing power or distributive effects. As shown in section 3.4, the distributive properties of lump-sum transfers are not well understood. Perhaps surprisingly, the second preferred mechanism for revenue recycling is a reduction in the VAT rate (61% approval). The main rationales for this support are the benefits to one's purchasing power and the perceived distributive effects. As the VAT is known to be a regressive tax, people may perceive it fair to compensate an increase in the regressive carbon tax with a decrease in the VAT. Although such a mechanism would be less favorable to poorer households — who spend less in VAT in absolute value, and would therefore receive less than from a uniform transfer — it may not be perceived as such.

3.5.1.3 Double dividend and public deficit

The last two options propose to use the carbon tax revenue to reduce social contributions, or the public deficit. These mechanisms come respectively in sixth and eighth position with 51% and 44% of approval. These results can be linked to the low level of concern regarding the impact of a carbon tax on the economy documented in section 3.4. They are also consistent with previous focus group studies (e.g. Kallbekken & Aasen, 2010), including in France where Deroubaix & Lévèque (2006) found that people did not understand why the revenue of an environmental tax reform should be used to tackle unemployment.

3.5.2 Other Instruments

Under a binding acceptability constraint, alternative instruments become relevant, even if Pigouvian taxes may be more cost-effective (e.g. Goulder & Parry, 2008). To elicit people's preferred environmental policies, we ask respondents whether they would support eight different propositions. To make these questions easier to answer, the exact mechanisms and their associated costs and benefits are unspecified. The answers reported should therefore be taken cautiously as people could change their mind once faced with clear trade-offs. Still, this exercise is informative about people's first reactions to different proposals.

3.5.2.1 Other Pigouvian taxes

Figure 3.5.2 shows that among the eight options, the most strongly supported is a tax on kerosene (70% of "Yes" including 41% of "Yes, completely"). The main rationale could be a broadly perceived effectiveness of the tax if people view aviation as an important source of emissions, and the distributive effect of such policy since richer people fly more. [6] In sharp contrast,

6. In France in 2008, people in the top income decile travelled by plane about seven times more than the bottom 50% of the income distribution (Pappalardo et al., 2010). Furthermore, kerosene's emissions are taxed only through

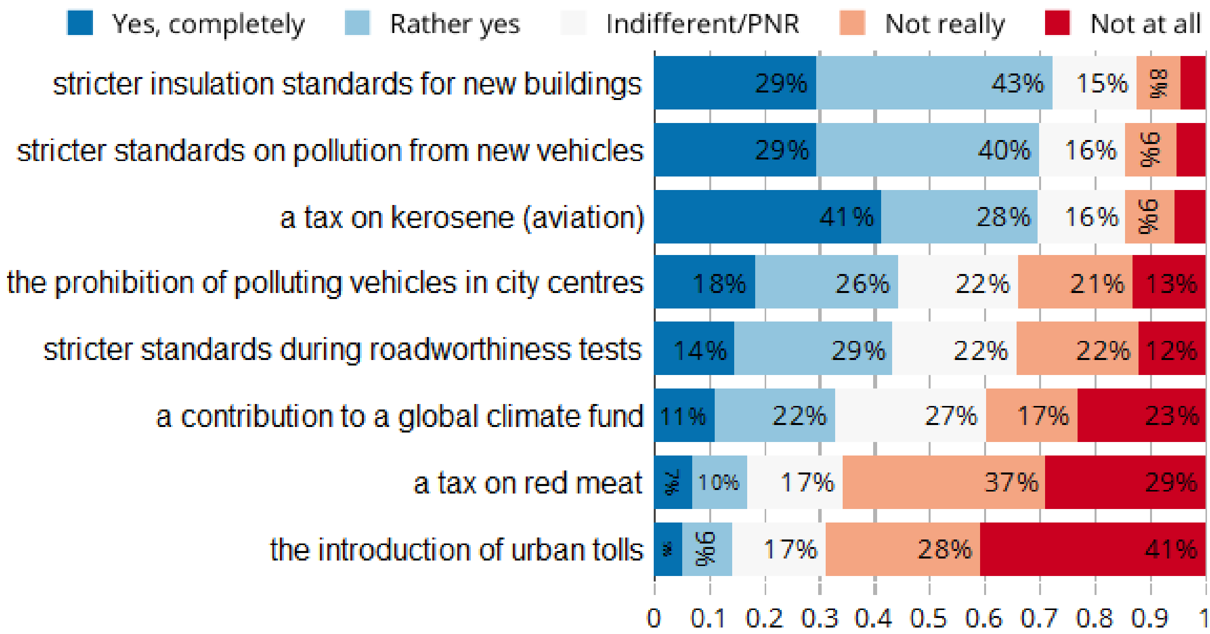


Figure 3.5.2 – Approval of different climate policies.

only 17% of our survey respondents approve a tax on red meat, a policy ranked second-to-last. One could explain this lower acceptance rate by the belief that such policy would be ineffective, as we have shown in section 3.3 that less than half of respondents know that beef has a high carbon footprint. Additional reasons for its rejection could be the perceived negative impact on purchasing power, and the feeling that the policy is too coercive and targets a behavior difficult to change (de Groot & Schuitema, 2012). Overall, this evidence confirms that people are not opposed to Pigouvian taxes *per se*, and that acceptance varies significantly depending on the target and the perceived outcome of the instrument.

3.5.2.2 Norms

Among all proposed instruments, the two most approved are norms. 72% and 70% of respondents declared being in favor of stricter standards for the insulation of new buildings and for the pollution of new vehicles, respectively. It is unclear to what extent people are aware of the "hidden costs" of such policies. For instance, fuel economy standards in the US have been estimated to be three to six times more costly than a tax on gasoline for similar abatement levels (Jacobsen, 2013), and as possibly more regressive (Jacobsen, 2013; Davis & Knittel, 2019; Le-

the EU-ETS, hence at a far lower rate than diesel and gasoline. This discrepancy has been highlighted in the public debate.

vinson, 2019). The exact properties of these instruments are of course specific to their design, but it is likely that their popularity partly reflects the underestimation of their costs.

For urban transport policies as well, standards are preferred to price instruments. While the prohibition of polluting vehicles in city centers comes fourth on the list of preferred options with 44% approval, the introduction of urban tolls comes last with only 14%. In a survey on urban road pricing, Jones (1998) identifies the main deterrent for these mechanisms. While some are specific to congestion charges, the other perceived problems are very much alike those identified for our Tax & Dividend : ineffectiveness, unfairness and the feeling that it is just another tax.

3.5.2.3 Diesel taxation

The strong opposition of the Yellow Vests against energy taxes did not only lead the government to reverse the planned carbon tax trajectory. The additional tax increases initially scheduled for diesel — to catch-up with the currently higher rates imposed on gasoline despite diesel's high social cost from air pollution — have also been abandoned.[7] In our survey, we ask respondents whether they would therefore accept an increase in diesel tax to catch up with that of gasoline. As illustrated by Figure 3.5.3, 59% of respondents answer they would not, while 29% say they would (12% "PNR"). Among the 57% of households who own a diesel vehicle, the opposition augments to 80%. The geographic difference is also striking as 73% of rural households would be opposed, vs. only 40% of those living in the Paris agglomeration. As shown in our online Appendix 3.1, these two determinants appear as the most important divides with respect to diesel taxation.

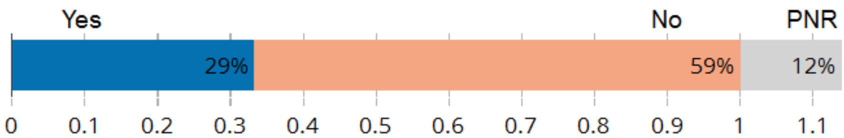


FIGURE 3.5.3 – Approval of a catching-up of the diesel tax.

7. Three increases of +0.026€/L were initially scheduled for January 2019, 2020 and 2021.

3.6 Determinants of Attitudes

To understand what factors foster environmentally-friendly attitudes, we explore the socio-demographic determinants of attitudes over CC, the correlations between knowledge and perception of CC, and how these attitudes over CC as well as socio-demographics shape preferences for policies.

3.6.1 Attitudes over climate change

Table 3.6.1 shows the main socio-demographic determinants of different attitudes towards CC : the knowledge that CC is anthropogenic (columns 1-3), an index of knowledge about CC (4) and the perception that CC is "disastrous" or "cataclysmic" (5-6). To build the index of knowledge, we aggregate different variables corresponding to the different kinds of knowledge about CC identified by Kiel & Rost (2002) (see also Hoppe et al., 2018, for a summary).

We first compute a score for the question asking the emission target p.c. required to limit CC (see section 3.3.1). Denoting t as the respondent's answer (from 0 to 10 tCO_2/yr), we define the score as :

$$\text{score emission target} = \begin{cases} 3 & \text{if } t \leq 2 \\ 2 & \text{if } t \in [3;4] \\ 1 & \text{if } t \in [5;6] \\ 0 & \text{if } t \geq 7 \end{cases} \tag{3.1}$$

and we then aggregate this score with other answers :

$$\begin{aligned} \text{knowledge} = 3 \cdot \text{CC anthropogenic} - 2 \cdot \text{CC doesn't exist} \\ + \text{ score factors} + \text{score emission target} \end{aligned} \tag{3.2}$$

where "score factors" is the sum of correct answers to factors of CC (see Figure 3.3.2), and the two first variables in the formula are dummies. The relative weights of the variables correspond to the loadings of a one-factor analysis, ensuring that our index captures the most determinant elements of knowledge.[8] The original index ranges from -2 (no respondent) to $+13$ (22 respondents), and has quartiles of 6, 8 and 9. In the regressions, we normalize this index by subtracting the mean (7.6) and dividing by the standard deviation (2.5). Finally, we run OLS regressions of the three attitudes over CC on various socio-demographics, household characteristics, and political orientation. We report only the most relevant variables, but describe the entire list of covariates in Appendix 3.C.1. We confirm that logistic regressions yield similar results (see online Appendix 5).

The best predictors of attitudes over CC corresponds to political orientation, and in particular identifying as an ecologist, one's positioning towards the Yellow Vests, and left-right leaning. Political orientation shapes attitudes in a consistent manner : being ecologist, more left-wing or less supportive of the Yellow Vests is always associated with higher "concern over CC", i.e. better knowledge and higher pessimism. Interest into politics (measured on a scale "almost not"/"a little"/"a lot") also leads to higher concern, but to a lesser extent. Two observations on the left-right leaning deserve comment. First, the 40% of people indeterminate relative to this spectrum (see Appendix 3.E for the descriptive statistics) have attitudes close to the center-right. Second, the variations predicted in the dependent variables are as high across the Yellow Vests positionings as across the traditional left-right spectrum. For instance, knowledge about CC is *ceteris paribus* lower by 0.50 standard deviation (s.d.) for people part of the movement than for those who oppose it, which is comparable to the spread of 0.41 s.d. between extreme-right and extreme-left people (4).

Two socio-demographics are also consistently related to attitudes over CC : age and level of education. On average, the younger and the more educated one is, the more one is concerned by CC. People aged 18-24 may appear to have slightly lower knowledge and lower pessimism than people of prime age *ceteris paribus*, in columns (1,4,5) ; but this is because their concern is mostly captured by the employment status modality "student", not shown in the table. Overall, the generation with the least concern is undeniably those aged over 65. For instance, without any control, they are 20 percentage points (p.p.) less likely to believe that CC is anthropogenic than young adults (2) — though most of this effect is explained by a lower level of education (1). Another finding is that men have a higher knowledge than women by 0.16 s.d. *ceteris paribus* (4),

8. See online Appendix 4 for more details.

TABLE 3.6.1 – Determinants of attitudes towards climate change (CC).

	CC is anthropogenic			Knowledge about CC	CC is disastrous	
	(1)	(2)	(3)	(4)	(5)	(6)
Interest in politics (0 to 2)	0.032**			0.137***	0.051***	
	(0.013)			(0.028)	(0.014)	
Ecologist	0.135***			0.404***	0.192***	
	(0.024)			(0.053)	(0.027)	
Yellow Vests : PNR	−0.098***			−0.142**	−0.093***	
	(0.033)			(0.071)	(0.036)	
Yellow Vests : understands	−0.038*			−0.100**	−0.051**	
	(0.022)			(0.048)	(0.024)	
Yellow Vests : supports	−0.098***			−0.223***	−0.061**	
	(0.024)			(0.051)	(0.026)	
Yellow Vests : is part	−0.207***			−0.498***	−0.105**	
	(0.043)			(0.093)	(0.047)	
Left-right : Extreme-left	0.111**		0.109	0.295**	0.075	0.005
	(0.056)		(0.077)	(0.122)	(0.062)	(0.084)
Left-right : Left	0.074***		0.070	0.137**	0.099***	−0.025
	(0.027)		(0.046)	(0.059)	(0.030)	(0.051)
Left-right : Center	0.013		0.039	0.093	0.021	−0.089*
	(0.030)		(0.044)	(0.065)	(0.033)	(0.048)
Left-right : Right	−0.029		−0.017	−0.039	−0.023	−0.143***
	(0.029)		(0.045)	(0.062)	(0.032)	(0.049)
Left-right : Extreme-right	−0.014		−0.019	−0.117	0.025	−0.086
	(0.034)		(0.055)	(0.074)	(0.037)	(0.060)
Diploma : *CAP* or *BEP*	0.040*		0.033	−0.004	−0.014	−0.010
	(0.022)		(0.023)	(0.049)	(0.025)	(0.025)
Diploma : *Baccalauréat*	0.065**		0.115***	0.145**	0.030	0.133***
	(0.027)		(0.028)	(0.058)	(0.029)	(0.031)
Diploma : Higher	0.086***		0.159***	0.266***	0.096***	0.240***
	(0.027)		(0.027)	(0.059)	(0.030)	(0.030)
Diploma × Left-right			−0.005			−0.005
			(0.008)			(0.009)
Diploma × Left-right : Indeterminate			0.013			−0.027*
			(0.014)			(0.015)
Age : 25 – 34	0.050	−0.030		0.128	0.021	
	(0.041)	(0.032)		(0.089)	(0.045)	
Age : 35 – 49	0.002	−0.088***		0.092	0.032	
	(0.041)	(0.029)		(0.089)	(0.045)	
Age : 50 – 64	0.009	−0.092***		0.069	−0.032	
	(0.044)	(0.029)		(0.096)	(0.049)	
Age : ≥ 65	−0.106**	−0.197***		−0.052	−0.092	
	(0.053)	(0.029)		(0.114)	(0.058)	
Income (k€/month)	−0.008			−0.018	−0.012	
	(0.008)			(0.017)	(0.009)	
Sex : Male	−0.023			0.156***	−0.004	
	(0.018)			(0.039)	(0.020)	
Size of town (1 to 5)	0.004			−0.003	0.006	
	(0.008)			(0.017)	(0.009)	
Frequency of public transit	0.016**			0.045***	0.007	
	(0.007)			(0.016)	(0.008)	
Additional covariates	✓			✓	✓	
Observations	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.104	0.021	0.037	0.156	0.118	0.048

*p<0.1 ; **p<0.05 ; ***p<0.01

NOTE : Standard errors are reported in parentheses. Interaction term is computed using numeric variables. Omitted modalities are : *Yellow Vests : opposes*, *Left-right : Indeterminate*, *Diploma : Brevet or no diploma*, *Age : 18 – 24*. Additional covariates are defined in 3.C.1.

but their perception of the severity of CC is virtually the same (5). Finally, other characteristics have smaller or even insignificant effects.

Although the determinants we find are broadly consistent with those elicited in the literature (Upham et al., 2009; Whitmarsh, 2011; ADEME, 2018),[9] we do not encounter the political polarity which characterizes the United States. Indeed, Kahan et al. (2012) argue that American people "tend to form perceptions of societal risks that cohere with values characteristic of groups with which they identify" (this is the cultural cognition thesis), rather than through an assessment of the scientific evidence they encounter (the science comprehension thesis). It is crucial to know whether people neglect climate science in such a way, as this would mean that a media campaign would have little effect on people's assimilation of climate science. Kahan et al. (2012) and McCright & Dunlap (2011) provide evidence for cultural cognition by showing that education has little effect on perceived risk or knowledge about CC, while the interaction between education and political orientation has a significant effect.[10] We assess whether such interaction appears in the French context, by studying the interaction between the higher degree obtained and the left-right political leaning (columns 4, 6). We find no significant interaction, and obtain the same nil result when replacing the traditional left-right scale by the Yellow Vests positioning, and/or the higher degree by knowledge about CC (see online Appendix 6). This lack of evidence suggests that the public debate over CC is less polarized in France than in the US,[11] and that the knowledge and perception of many French people could change with better access to information over CC.

Figure 3.6.1 gives a sense of the shift in the perception and support for climate policies that could follow an information campaign, as it shows the correlations between attitudes over CC, climate policies, and socio-demographics. Knowledge is highly correlated with the perceived gravity of CC (correlation of 0.43), and both of these variables are in turn well correlated with the readiness to adopt an ecological lifestyle and to the number of climate policies (of Figure 3.5.2) supported (correlations around 0.3). The acceptance of our Tax & Dividend is less corre-

9. See also Capstick et al. (2015) for trends in attitudes.
10. Funk & Kennedy (2016) also report that Republicans are equally distrustful of climate scientists' integrity whatever their level of education, while the distrust vanishes for Democrats with higher degrees. The mechanism of the interaction is documented by Ehret et al. (2018) and Van Boven et al. (2018) : people form beliefs through partisan cues, by adopting views expressed by political figures of the party they identify and rejecting positions from the other party.
11. A finding reminiscent of Ziegler (2017), who studies Germany.

lated with attitudes (at 0.1-0.2), as the support for this policy is already low. Still, the positive correlation between knowledge and support for other climate policies is an encouraging prospect for an information campaign about CC and even more so since we did not find evidence that partisanship would lead to the dismissal of scientific discourse. Finally, as previously seen, diploma and age are quite correlated with attitudes, though these correlations are below those between attitudes over CC and over policies, at 0 to 0.2.

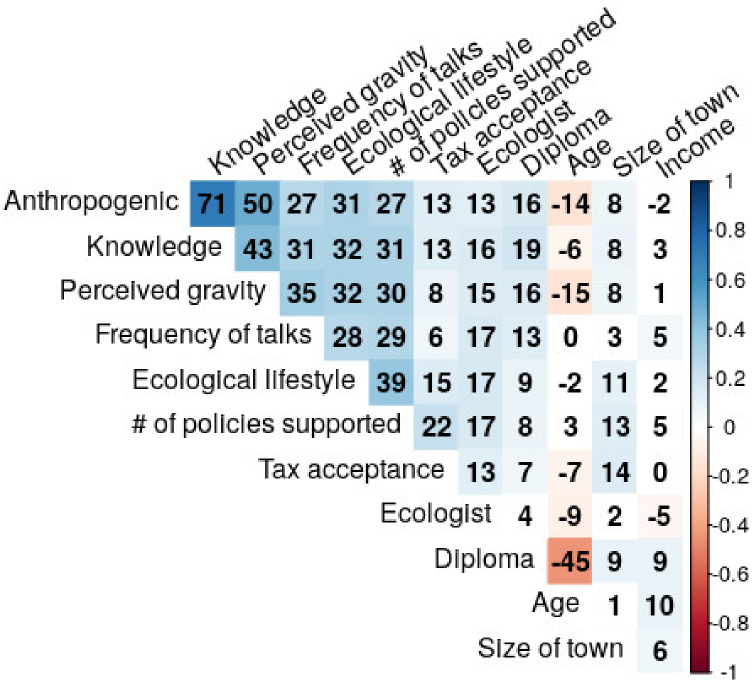


FIGURE 3.6.1 – Correlations between attitudes over climate change, climate policies and socio-demographics (in %).

3.6.2 Attitudes over policies

To better understand the heterogeneity in people's support, we regress several indicators of attitudes towards climate policies on respondents' characteristics. Table 3.6.2 reports the results for the acceptance of our Tax & Dividend (columns 1-2) and the readiness to adopt an ecological lifestyle (6) in the case that the richest were contributing, efforts were shared globally, and alternatives were developed. We also use the eight policies proposed in Figure 3.5.2 in our dependent variables : column 3 studies the share of policies approved while column 4 features the preference for norms vs. taxes within the policies. Similarly, column 5 uses six measures of Figure 3.5.1 to define an index of preference for earmarking vs. transfers. Indexes for these preferences are constructed as follows :

$$\text{Norms vs. taxes} = \sum_{p \in \text{norms}} \text{score}_p - \sum_{p \in \text{taxes}} \text{score}_p \quad (3.3)$$

where the score of each measure corresponds to a grade between -2 (for a "Not at all" answer) and 2 (for "Yes, completely"). We proceed similarly for earmarking vs. transfers, and describe the categorization of measures in Appendix 3.C.2. Again, we normalize these two indexes by subtracting the mean (2.8 for norms vs. taxes, 1.4 for earmarking vs. transfers) and dividing by the standard deviation (3.3 and 3.1 respectively). Tables 3.2 and 3.3 in online Appendix provide the analysis of the determinants of acceptance for each of the eight policies and nine revenue recycling. The results are overall very similar to those provided by the more synthetic indicators presented here.

As suggested by the correlation matrix of section 3.6.1, knowledge about CC and the conviction that it would be disastrous positively affect the approval of climate policies, *ceteris paribus*. Excluding the (endogenous) variables describing political orientation, an increase in knowledge by 1 s.d. would induce a lower likelihood to reject Tax & Dividend by 5 p.p. (column 2). The effect of these variables is even stronger when considering the share of policies approved : controlling for socio-demographics, an increase in knowledge by 1 s.d. is associated with an additional approval of 6 p.p. while the conviction that CC is disastrous increases it by 9 p.p. (see online Appendix 3.4). Beyond the strong correlation we previously found, these results confirm that increasing climate awareness could significantly increase the support for climate policies.

Besides attitudes over CC, the two most critical determinants appear to be one's affiliation as an ecologist and one's position towards the Yellow Vests. All else equal, ecologists are more likely to accept Tax & Dividend by 13 p.p., and more willing to approve other environmental policies by about 8 p.p. Conversely, holding other variables constant, people supporting the Yellow Vests are 22 p.p. more likely to reject Tax & Dividend relative to those opposed to the movement. As shown in column 3, higher affinity with the Yellow Vests is also associated with less support for other climate policies. Ecologists (resp. the Yellow Vests supporters) being more (resp. less) favorable to environmental policies and spending, their relative preference

Table 3.6.2 – Determinants of attitudes towards climate policies

	Acceptance of Tax & dividend (1)	(2)	Share of policies approved (3)	Norms vs. taxes (4)	Earmarking vs. transfers (5)	Ecological lifestyle (6)
Knowledge about CC	0.029***	0.048***	0.044***	0.024	0.131***	0.103***
	(0.009)	(0.009)	(0.005)	(0.020)	(0.020)	(0.009)
CC is disastrous	0.022	0.037**	0.081***	0.125***	0.156***	0.142***
	(0.018)	(0.018)	(0.010)	(0.040)	(0.039)	(0.018)
Interest in politics (0 to 2)	−0.019		0.034***	−0.010	0.053*	0.026**
	(0.013)		(0.007)	(0.029)	(0.028)	(0.013)
Ecologist	0.126***		0.082***	−0.134**	0.249***	0.149***
	(0.024)		(0.013)	(0.056)	(0.054)	(0.025)
Yellow Vests : PNR	−0.021		−0.052***	0.007	−0.110	−0.079**
	(0.032)		(0.018)	(0.073)	(0.071)	(0.033)
Yellow Vests : understands	−0.144***		−0.029**	−0.056	−0.091*	−0.013
	(0.022)		(0.012)	(0.050)	(0.049)	(0.022)
Yellow Vests : supports	−0.222***		−0.048***	−0.131**	−0.142***	−0.023
	(0.023)		(0.013)	(0.053)	(0.052)	(0.024)
Yellow Vests : is part	−0.214***		−0.084***	−0.252***	−0.175*	−0.037
	(0.043)		(0.023)	(0.097)	(0.095)	(0.043)
Left-right : Extreme-left	−0.040		0.025	−0.285**	0.167	0.047
	(0.056)		(0.031)	(0.127)	(0.124)	(0.056)
Left-right : Left	0.072***		−0.005	−0.137**	0.002	0.028
	(0.027)		(0.015)	(0.061)	(0.060)	(0.027)
Left-right : Center	0.051*		0.011	−0.051	0.051	0.095***
	(0.030)		(0.016)	(0.068)	(0.066)	(0.030)
Left-right : Right	−0.022		0.008	0.030	0.064	0.005
	(0.028)		(0.016)	(0.065)	(0.063)	(0.029)
Left-right : Extreme-right	−0.041		−0.028	0.055	0.009	0.014
	(0.034)		(0.018)	(0.077)	(0.075)	(0.034)
Diploma (1 to 4)	−0.006	−0.001	0.005	0.006	0.017	−0.008
	(0.009)	(0.008)	(0.005)	(0.020)	(0.020)	(0.009)
Age : 25 – 34	−0.047	−0.099***	−0.023	0.038	−0.159*	0.032
	(0.041)	(0.032)	(0.022)	(0.093)	(0.090)	(0.041)
Age : 35 – 49	−0.047	−0.089***	−0.017	0.189**	−0.002	0.039
	(0.040)	(0.030)	(0.022)	(0.092)	(0.089)	(0.041)
Age : 50 – 64	−0.054	−0.114***	−0.010	0.322***	−0.058	0.049
	(0.044)	(0.031)	(0.024)	(0.100)	(0.097)	(0.044)
Age : ≥ 65	−0.066	−0.100***	−0.009	0.370***	−0.056	0.008
	(0.052)	(0.032)	(0.028)	(0.118)	(0.115)	(0.052)
Income (k€/month)	0.006	0.001	0.009**	0.014	0.031*	−0.004
	(0.008)	(0.005)	(0.004)	(0.018)	(0.017)	(0.008)
Sex : Male	−0.053***	−0.074***	−0.017*	−0.028	−0.004	−0.063***
	(0.018)	(0.017)	(0.010)	(0.040)	(0.039)	(0.018)
Size of town (1 to 5)	0.019**	0.033***	0.0002	0.009	−0.003	−0.003
	(0.008)	(0.007)	(0.004)	(0.018)	(0.017)	(0.008)
Frequency of public transit	−0.003	0.014**	−0.003	0.046***	0.021	0.024***
	(0.007)	(0.006)	(0.004)	(0.017)	(0.016)	(0.007)
Additional covariates	✓		✓	✓	✓	✓
Observations	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.150	0.051	0.226	0.081	0.121	0.202

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in 3.C.1.

for earmarking vs. transfers is higher (resp. lower) than average, while for both groups the relative preference for norms vs. taxes is lower than average. Also, ecologists' attitudes towards environmental policies translate into a higher willingness to adopt an ecological lifestyle (by 15 p.p.), but the opposite does not hold true for the Yellow Vests. Although this could signal some warm glow, [12] it also suggests that their strong rejection of environmental policies does not simply reflect lower concerns about the environment. Rather, the conditions of fairness embedded in our question could be critical for Yellow Vests to accept sacrifices. Their rejection could also reflect a deeper rejection of policies in general, due to a high distrust in the government — documented in Algan et al. (2019). This interpretation echoes the recent findings of Rafaty (2018), who shows that perceptions of corruption and political distrust negatively affect the stringency of climate policies. Finally, although the heterogeneity in responses is significant between these two groups, the ranking of the preferred option remains consistent : on average, both ecologists and supporters of the Yellow Vests favor norms over taxes and earmarking over transfers.

A parallel message from Table 3.6.2 is that the standard left-right spectrum is not the most relevant to understand attitudes towards environmental policies. None of our five left-right dummy variables are significantly correlated with the share of policies approved, and overall, attitudes vary much less along the left-right spectrum than along the Yellow Vests cleavage. That being said, Tax & Dividend is still significantly more supported by people from the left (+7 p.p.) and the center (+5 p.p.) than by those indeterminate. This is in line with the literature (see e.g. Bornstein & Lanz 2008; McCright et al. 2013 or Drews & van den Bergh 2016 for a review). Without controlling for other variables, we find that people that are most likely to accept the Tax & Dividend in France are the ones affiliated with the center (+9 p.p. relative to "Indeterminate"), and the least likely are those on the extreme-right (-15 p.p., see online Appendix 3.4), which may be driven by their respective support or rejection of the current government who tried to increase the carbon tax. Our results also show that people from the extreme-left and the center are the most likely to approve other environmental policies (+7 p.p.), while the least likely are those on the extreme-right (-6 p.p.). Still, these differences become small and not statistically significant when covariates are included.

Besides political attitudes, we also observe heterogeneity in people's responses along socio-

12. Here, "warm glow" refers to one's unintentional strategy to overestimate their virtue in order to derive satisfaction.

demographic lines. As in attitudes over CC, age plays a role, as 18-24 are about 10 p.p. more likely to accept the Tax & Dividend (column 2). Still, controlling for knowledge, political attitudes and other variables, this effect is reduced by half. Similarly, more educated people tend to be more open to environmental policies (as previously found by Thalmann, 2004), but this effect becomes insignificant once age dummies are included as covariates. Furthermore, we find little effect of income on attitudes towards climate policies, a result that confirms that of Thalmann (2004) in Switzerland. Using our full set of controls, the most significant variables differ from the main factors of attitudes over CC : these significant variables are size of town (city dwellers being more favorable to environmental policies, as in Thalmann, 2004), and sex (males being less favorable). Although men have a higher knowledge about CC than women on average, this does not translate into higher pessimism (see section 3.6.1), and it even coincides with lower support for climate policies. This phenomenon is consistent with the findings of Stern et al. (1993) and Hampel et al. (1996) that women are more attentive to links between the environment and things they value, even if they share the same values and beliefs as men. Difference in perception of CC's impact on oneself could explain women's higher support for climate policies, even given a lower factual knowledge.

3.7 Conclusion

Despite a social movement against the carbon tax, French people appear mostly aware and concerned about climate change. Their rejection should therefore not be taken as a low willingness to act for the environment, but rather as a perceived inadequacy between current carbon taxation and the fight for the climate. Our results identify several barriers — distributive concerns, inefficacy and lack of alternatives — that could be partly alleviated with specific complementary policies. In particular, French people favor investments in green infrastructures that provide them with alternatives and foster the energy transition. They also appear willing to accept certain norms as well as Pigouvian taxes if these target specific behaviors (or populations) such as air travel. The heterogeneity in people's attitudes is significant, but the relative ranking of the different policy options are in general consistent across groups of population, suggesting the following paths towards a successful ecological transition.

First and foremost, a massive and long-lasting information campaign could be launched to improve knowledge about climate change and climate policies. Indeed, higher knowledge is clearly associated with higher concern for CC and higher support for climate policies. Second, as people mostly favor policies that provide alternatives to fossil fuels, the government could develop such policies as a substitute to a carbon tax : investments, subsidies, and regulations in favor of public transport, cleaner vehicles and thermal insulation, etc. Third, a tax and dividend restricted to kerosene could serve as a learning example as kerosene taxation is popular. [13] Last but not least, a more cost-effective carbon tax should later complement these policies, as people get convinced by the objective of carbon neutrality and by the government's commitment towards this goal.

But to successfully introduce a carbon tax, it is important to build public trust in politicians (Harring & Jagers, 2013; Rafaty, 2018) and to correct the inequities of the tax. As such, it is no surprise if political trust is among the highest in the country that first introduced a carbon tax, Sweden (Klenert et al., 2018). It is no coincidence either that the 1991 Swedish tax was part of a comprehensive restructuring of the tax system, the popular "reform of the century", resulting from a dialogue with all stakeholders (Sterner, 2014).

The French government is willing to build such a democratic consensus, as it has just launched an assembly to tackle climate change composed of 150 citizens randomly drawn. Nevertheless, it will remain challenging to reintroduce a carbon tax in the short-run, since French people's beliefs about carbon taxation are largely biased, and these biases are well anchored (as shown in our companion paper, Douenne & Fabre 2019b). In a nutshell, market imperfections, distributive effects and political acceptability concerns all call for a combination of different types of climate policies rather than a single price signal (Stern & Stiglitz, 2017; Stiglitz, 2019). The French context seems to call for a focus on the other policies to make the carbon tax politically acceptable.

13. Murray & Rivers (2015) document an increase in the support of the carbon tax following its implementation in British Columbia.

3.A Raw data

See Appendix 2.A which presents the raw data of the same survey.

3.B Sources on GHG emissions

3.B.1 Carbon footprints

Plane vs. train Given that French electricity mix is decarbonized at 93% [14], the carbon footprint of highspeed train is actually more than 20 times lower than that of an interior flight of the same distance. Hence, we chose Bordeaux - Nice as our case study as the train connection makes a big detour by Paris. Thus, we obtain an emission of 10 kg of CO_2 by train as compared to 180 kg by plane. Our source for train is the French railroad company, SNCF, and is consistent with data aggregated by the official agency ADEME. For the flight, our source is a carbon footprint calculator. Another calculator provides almost the same result, so we preferred this figure rather than a higher figure from a third calculator.

Nuclear vs. wind AR5 from IPCC and Pehl et al. (2017) show that nuclear power plants and wind turbines have similar carbon footprint, at 10 gCO_2eq/kWh (for comparison, it is 500 for gas combined cycle).

Beef vs. pasta Poore & Nemecek (2018) show that median beef carbon footprint is 60 $kgCO_2$eq/kg (more precisely, 30 $kgCO_2$eq per 100g of protein and 200g of protein per kg) ; while the carbon footprint of wheat pasta is 1.3 $kgCO_2$eq/kg (0.5 $kgCO_2$eq per 1000 kcal of protein and 2695 kcal per kg). Given that a beef steak weighs 100-125g, its carbon footprint is twenty times that of two servings of pasta of 125g each.

3.B.2 Current and target emissions

French consumption-based yearly GHG emissions amounted in 2014 to 712 $MtCO_2$eq, i.e. 10.8 tCO_2eq p.c., and are roughly stable in recent years (CGDD, 2019). To stop climate change

14. Cf. RTE - Bilan électrique 2018 (p. 32).

and stabilize the GHG concentration in the atmosphere, it is required to meet zero net emissions. To meet the Paris agreement, France National Low-Carbon Strategy aims to achieve carbon (i.e. GHG) neutrality by 2050 (CGDD, 2015). Given carbon sinks estimated at 85 Mt_2eq for 2050 (mainly forest and soil), this strategy requires to reach gross emissions of about 1 tCO_2eq p.c. at this date. Admittedly, less stringent scenarios may still allow to keep global warming below +2°C in 2100 with good probability — even considering the same burden share for France — by relying more heavily on net negative emissions after 2070 through carbon capture and storage. For this reason, we consider a range of answers as correct for the French target emission in 2050 : from 0 to 2 tCO_2eq p.c.

3.C Details on main regressions

3.C.1 Control variables

Our regression Tables 3.6.1 and 3.6.2 display only the most relevant variables, but — when specified — the following additional covariates are included as controls :

Socio-demographics : *respondent's income ; household's income ; employment status* (9 categories) ; *socio-professional category* (8 categories) ; *region of France* (10 categories) ; *household size ; number of people above 14 ; number of adults ; single ; number of c.u. ; smokes ; favored medium for news* (5 categories).

Political orientation : *conservative ; liberal ; humanist ; patriot ; apolitical.*

Energy and exposure to policies : *heating energy : gaz ; heating energy : domestic fuel ; accomodation size ; annual distance travelled by car ; fuel economy ; type of fuel : diesel ; type of fuel : gasoline ; number of vehicles ; simulated net gain from Tax & Dividend ; opinion on public transports ; mode of commuting transport.*

3.C.2 Measures for relative preferences

We constructed the two indexes of section 3.6.2 using the following measures :

Norms : *insulation standards ; pollution standards ; roadworthiness standards ; prohibition of polluting vehicles.*

Taxes : *kerosene ; red meat ; urban tolls ; climate fund.*

Earmarking : *renovation ; renewables ; non polluting transport.*

Transfers : *to bottom half ; to all ; to constrained households.*

3.D Questionnaire

Hereafter, we only describe questions of the survey that are used in the present chapter. The other questions are described and analyzed in our companion paper (Douenne & Fabre, 2019b). The corresponding questionnaire can be found in Appendix 2.G of this thesis. Words that appear in bold were actually in both bold and underlined in the respondents' questionnaire.

Socio-demographics

1. What is your postal code ?
2. What is your gender (in the sense of civil status) ?
   Female ; Male
3. What is your age group ?
   18 to 24 years old ; 25 to 34 years old ; 35 to 49 years old ; 50 to 64 years old ; 65 years old or more
4. What is your employment status ?
   Permanent ; Temporary contract ; Unemployed ; Student ; Retired ; Other active ; Inactive
5. What is your socio-professional category ? (Remember that the unemployed are active workers).
   Farmer ; Craftsperson, merchant ; Independent ; Executive ; Intermediate occupation ; Employee ; Worker ; Retired ; Other Inactive
6. What is your highest degree ?
   No diploma ; Brevet des collèges ; CAP or BEP [secondary] ; Baccalaureate ; Bac +2 (BTS, DUT,

DEUG, schools of health and social training...) ; *Bac +3* (*licence...*) [*bachelor*] ; *Bac +5 or more* (*master, engineering or business school, doctorate, medicine, master, DEA, DESS...*)

7. How many people live in your household ? Household includes : you, your family members who live with you, and your dependents.
8. What is your net **monthly** income (in euros) ? **All income** (before withholding tax) is included here : salaries, pensions, allowances, APL [housing allowance], land income, etc.
9. What is the net **monthly** income (in euros) **of your household** ? **All income** (before withholding tax) is included here : salaries, pensions, allowances, APL [housing allowance], land income, etc.
10. In your household how many people are 14 years old or older (**including yourself**) ?
11. In your household, how many people are over the age of majority (**including yourself**) ?

Energy characteristics

12. What is the surface area of your home ? (in m^2)
13. What is the heating system in your home ?
    Individual heating ; Collective heating ; PNR (*Don't know, don't say*)
14. What is the main heating energy source in your home ?
    Electricity Town gas ; Butane, propane, tank gas ; Heating oil ; Wood, solar, geothermal, aerothermal (*heat pump*) *; Other ; PNR* (*Don't know, don't say*)
15. How many motor vehicles does your household have ?
    None ; One ; Two or more
16. [Without a vehicle] How many kilometers have you driven in the last 12 months ?
17. [One vehicle] What type of fuel do you use for this vehicle ?
    Electric or hybrid ; Diesel ; Gasoline ; Other
18. [One vehicle] What is the average fuel economy of your vehicle ? (in Liters per 100 km)
19. [One vehicle] How many kilometers have you driven with your vehicle in the last 12 months ?
20. [At least two vehicles] What type of fuel do you use for your main vehicle ?
    Electric or hybrid ; Diesel ; Gasoline ; Other

21. [At least two vehicles] What type of fuel do you use for your second vehicle ?
   Electric or hybrid ; Diesel ; Gasoline ; Other

22. [At least two vehicles] What is the average fuel economy of all your vehicles ? (in Liters per 100 km)

23. [At least two vehicles] How many kilometers have you driven with all your vehicles in the last 12 months ?

Partial reforms [transport / housing] (...)

24. If fuel prices increased by 50 cents per liter, by how much would **your household** reduce its fuel consumption ?
   0% - [I already consume almost none / I am already not consuming] ; 0% - [I am constrained on all my trips / I will not reduce it] ; From 0% to 10% ; From 10% to 20% ; From 20% to 30% ; More than 30% - [I would change my travel habits significantly / I would change my consumption significantly]

25. In your opinion, if [fuel prices increased by 50 cents per liter / gas and heating oil prices increased by 30%], by how much would **French people** reduce their consumption on average ?
   From 0% to 3% ; From 3% to 10% ; From 3% to 10% ; From 10% to 20% ; From 20% to 30% ; More than 30%

Tax & Dividend : initial

26. The government is studying an increase in the carbon tax, whose revenues would be redistributed to all households, regardless of their income. This would imply :
   — an increase in the price of gasoline by 11 cents per liter and diesel by 13 cents per liter ;
   — an increase of 13% in the price of gas, and 15% in the price of heating oil ;
   — an annual payment of 110€ to each adult, or 220€ per year for a couple.

   (...)

27. [[empty] / Scientists agree that a carbon tax would be effective in reducing pollution.] Do you think that such a measure would reduce pollution and fight climate change ?
   Yes ; No ; PNR (Don't know, don't say)

28. In your opinion, which categories would lose [[blank] / purchasing power] with such a measure ? (Several answers possible)
No one ; The poorest ; The middle classes ; The richest ; All French people ; Rural or peri-urban people ; Some French people, but not a particular income category ; PNR (*Don't know, don't say*)

29. In your opinion, what categories would gain purchasing power with such a measure ? (Several answers possible)
No one ; The poorest ; The middle classes ; The richest ; All French people ; Urban dwellers ; Some French people, but not a particular income category ; PNR (*Don't know, don't say*)

Tax & Dividend : after knowledge We always consider the same measure. (...)

30. Why do you think this measure is beneficial ? (Maximum three responses)
Contributes to the fight climate change ; Reduces the harmful effects of pollution on health ; Reduces traffic congestion ; Increases my purchasing power ; Increases the purchasing power of the poorest ; Fosters France's independence from fossil energy imports ; Prepares the economy for tomorrow's challenges ; For none of these reasons ; Other (*specify*) *:*

31. Why do you think this measure is unwanted ? (Maximum three answers)
Is ineffective in reducing pollution ; Alternatives are insufficient or too expensive ; Penalizes rural areas ; Decreases my purchasing power ; Decreases the purchasing power of some modest households ; Harms the economy and employment ; Is a pretext for raising taxes ; For none of these reasons ; Other (*specify*) *:*

(...)

Attitudes over other policies

32. In which cases would you be in favor of increasing the carbon tax ? I would be in favor if the tax revenues were used to finance...
    (a) a payment to the 50% poorest French people (those earning less than 1670€ per month)
    (b) a payment to all French people
    (c) a compensation for households forced to consume petroleum products
    (d) a decrease in social contributions

(e) a decrease in VAT

(f) a decrease in the public deficit

(g) the thermal renovation of buildings

(h) renewable energy (wind, solar, etc.)

(i) clean transport

Yes, absolutely ; Yes, rather ; Indifferent or Don't know ; No, not really ; No, not at all

33. Please select "A little" (test to check that you are attentive).

    Not at all ; A little ; A lot ; Completely ; PNR (Don't know, don't say)

34. Would you support the following environmental policies ?

    (a) A tax on kerosene (aviation)

    (b) A tax on red meat

    (c) Stricter standards on the insulation of new buildings

    (d) Stricter standards on the pollution of new vehicles

    (e) Stricter standards on pollution during roadworthiness tests

    (f) The prohibition of polluting vehicles in city centers

    (g) The introduction of urban tolls

    (h) A contribution to a global climate fund

Yes, absolutely ; Yes, rather ; Indifferent or Don't know ; No, not really ; No, not at all

35. For historical reasons, diesel is taxed less than gasoline. Would you be in favor of raising taxes on diesel to catch up with the level of taxation on gasoline ?

    Yes ; No ; PNR (Don't know, don't say)

Attitudes over climate change

36. How often do you talk about climate change ?

    Several times a month ; Several times a year ; Almost never ; PNR (Don't know, don't say)

37. In your opinion, climate change...

    is not a reality ; is mainly due to natural climate variability ; is mainly due to human activity ; PNR (Don't know, don't say).

38. Which of the following elements contribute to global warming ? (Several answers possible)

    CO_2 ; Methane ; Oxygen ; Particulate matter

39. In your opinion, which of the following statements are true ? (Several answers possible).

    Consuming one beef steak emits about 20 times more greenhouse gases than eating two servings of pasta. ; Electricity produced by nuclear power emits about 20 times more greenhouse gases than electricity produced by wind turbines. ; A seat in a Bordeaux - Nice journey emits about 20 times more greenhouse gases by plane than by high speed train.

40. In your opinion, how would the effects of climate change be, if humanity did nothing to limit it ?

    Insignificant, or even beneficial ; Small, because humans would be able to live with it ; Grave, because there would be more natural disasters ; Disastrous, lifestyles would be largely altered ; Cataclysmic, humankind would disappear ; PNR(Don't know, don't say)

41. In which of these two regions do you think will climate change have the worst consequences ?

    The European Union ; India ; As much in both

42. In your opinion, in France, which generations will be seriously affected by climate change ? (Several answers possible)

    People born in the 1960s ; People born in the 1990s ; People born in the 2020s ; People born in the 2050s ; None of the four

43. In your opinion, who is responsible for climate change ? (Several possible choices)

    Each of us ; The richest ; Governments ; Some foreign countries ; Past generations ; Natural causes

44. Currently, each French person emits on average the equivalent of 10 tons of CO_2 per year.

    In your opinion, how much must this figure be reduced to by 2050 in order to hope to contain global warming to +2°C in 2100 (if all countries did the same) ? In 2050, we should emit at most...

    0 ; 1 ; 2 ; 3 ; 4 ; 5 ; 6 ; 7 ; 8 ; 9 ; 10 tons

45. Has climate change had or will it have an influence on your decision to make a child (or children) ?

    Yes ; No ; PNR (Don't know, don't say)

46. [If *Yes*] Why does climate change influence your decision to have a child (or children)? (Several answers possible).

    Because I don't want my child to live in a devastated world.; Because each additional human being aggravates climate change.

47. Would you be willing to change your lifestyle to fight climate change? (Several answers possible)

    Yes, if policies went in this direction; Yes, if I had the financial means; Yes, if everyone did the same; No, only the richest people have to change their way of life; No, it is against my personal interest; No, I think climate change is not a real problem; I have already adopted a sustainable way of life; I try, but I have trouble changing my habits

48. Assuming that all states in the world agree to firmly fight climate change, notably through a transition to renewable energy, by making the richest contribute, and imagining that France would expand the supply of non-polluting transport very widely; would you be willing to adopt an ecological lifestyle (i.e. eat little red meat and ensure to use almost no gasoline, diesel or kerosene)?

    Yes; No; PNR (Don't know, don't say)

Access to public transport and mobility habits

49. How many minutes walk is it to the nearest public transit stop? (To simplify, you can use the conversion 1 km = 10 min walk).

    in min :; PNR (Don't know, don't say)

50. How often does the nearest public transport pass? (excluding school buses)

    Less than three times a day; Between four times a day and once an hour; Once or twice an hour; More than three times an hour; PNR (Don't know, don't say)

51. What do you think about the availability of public transport where you live? It is...

    Satisfactory; Suitable, but should be increased; Limited, but sufficient; Insufficient; PNR (Don't know, don't say)

52. What mode of transportation do you mainly use for each of the following trips?

    (a) Home - work (or studies)

    (b) Grocery shopping

(c) Leisure (excluding holidays)

Car ; Public transport ; Walking or cycling ; Two-wheeled vehicle ; Carpooling ; Not concerned

53. [If *Car* selected for Work] Would it be possible for you, without changing your home or workplace, to travel from home to work using public transport ?

    Yes, it would not be very difficult for me ; Yes, but it would bother me ; No ; PNR (*Don't know, don't say*)

54. [If *Car* selected for Work] Would it be possible for you, without changing your home or workplace, to travel from home to work by walking or cycling ?

    Yes, it would not be very difficult for me ; Yes, but it would bother me ; No ; PNR (*Don't know, don't say*)

Politics and media

55. How much are you interested in politics ?

    Almost not ; A little ; A lot

56. How would you define yourself ? (Several answers possible)

    Extreme left ; Left ; Center ; Right ; Extreme right ; Liberal ; Conservative ; Humanist ; Patriot ; Apolitical ; Ecologist

57. How do you keep yourself informed of current events ? Mainly through...

    Television ; Press (*written or online*) *; Social networks ; Radio ; Other*

58. What do you think of the Yellow Vests ? (Several answers possible)

    I am part of them ; I support them ; I understand them ; I oppose them ; PNR (*Don't know, don't say*)

Open field

59. The survey is nearing completion. You can now enter any comments, comments or suggestions in the field below.

3.E Who are the Yellow Vests

TABLE E.1 – Positioning towards Yellow Vests, per category.

	Opposed	Understands	Supports	Is part	PNR
Extreme-left (2%)	6%	26%	51%	12%	5%
Left (20%)	17%	36%	36%	5%	7%
Center (13%)	49%	30%	15%	2%	6%
Right (16%)	40%	32%	20%	3%	6%
Extreme-right (9%)	11%	28%	47%	10%	5%
Indeterminate (40%)	19%	32%	30%	4%	13%
Liberal (5%)	48%	26%	18%	2%	6%
Conservative (2%)	22%	28%	30%	10%	11%
Humanist (11%)	21%	35%	29%	5%	10%
Patriot (8%)	21%	27%	39%	7%	6%
Apolitical (21%)	21%	31%	32%	4%	12%
Ecologist (15%)	17%	39%	27%	5%	12%
Rural (21%)	20%	31%	34%	6%	9%
<20k (17%)	24%	28%	34%	6%	9%
20-100k (14%)	22%	33%	32%	4%	9%
>100k (31%)	29%	34%	26%	3%	8%
Paris (17%)	28%	33%	25%	4%	11%
No diploma or *Brevet* (30%)	21%	29%	34%	5%	10%
CAP or *BEP* (24%)	23%	28%	36%	6%	7%
Baccalauréat (17%)	22%	35%	29%	4%	11%
Higher (29%)	32%	21%	36%	3%	8%
Age : 18–24 (12%)	23%	34%	27%	4%	12%
Age : 25–34 (15%)	21%	33%	28%	7%	11%
Age : 35–49 (24%)	25%	32%	29%	5%	9%
Age : 50–64 (24%)	21%	32%	36%	4%	7%
Age : $\geq$ 65 (25%)	32%	30%	28%	3%	7%
Income decile : 1	25%	33%	26%	3%	14%
Income decile : 2	18%	31%	35%	5%	11%
Income decile : 3	17%	31%	32%	7%	12%
Income decile : 4	15%	33%	37%	6%	9%
Income decile : 5	21%	29%	36%	5%	8%
Income decile : 6	26%	33%	29%	6%	7%
Income decile : 7	25%	36%	28%	4%	7%
Income decile : 8	31%	31%	28%	3%	8%
Income decile : 9	39%	32%	20%	3%	6%
Income decile : 10	47%	29%	15%	3%	6%
Female (52%)	21%	34%	29%	5%	12%
Male (48%)	29%	30%	31%	5%	6%
Average	*25%*	*32%*	*30%*	*5%*	*9%*

NOTE : The percentages in parenthesis express the weighted share of each category from our sample.

Online Appendix

3.F Supplementary material

This section corresponds to the online appendix of the paper titled "French Attitudes on Climate Change, Carbon Taxation and other Climate Policies". It presents additional results, robustness tests, and supplementary material, e.g. to detail the construction of the knowledge index.

3.F.1 Additional results on attitudes over climate change

3.F.1.1 Perceptions

The looming threat of CC already seems to impact people's behavior. Indeed, 20% say the CC "has had or will have an influence in their decision to have a child". Among them, 37% justify it "because each additional human aggravates climate change", and 86% because they "don't want [their] child to live in a devastated world". This result echoes a survey from ADEME (2018) which shows that 63% of French people think that "living conditions will be extremely harsh" in France in 50 years and that 57% do not think CC "will be limited to acceptable levels by the end of the century". Such concern is not limited to France, as Funk & Kennedy (2016) document that 75% of American are concerned by CC. Nor is it recent, as Eurobarometer surveys cited by Whitmarsh & Capstick (2018) found that more than three-quarters of respondents were already worried about climate change in 1988, rising to almost nine in ten by 1992.

Despite — or perhaps due to — widespread hopelessness, 34% almost never talk about CC (Figure 3.F.1). 27% talk about CC several times per month, which can give a sense of the share of people who regularly engage in long-term thinking. The relatively low amount of discussion around an issue largely perceived as a serious threat may be understood as a way to flee from one's moral duty and to protect one's lifestyle. Indeed, as a recent literature has shown, people tend to discard information perceived as bad news and display what Sharot et al. (2011) call "unrealistic optimism in front of reality". Whitmarsh & Capstick (2018) relate another strategy of avoidance : the general tendency to discount one's own contribution to causing CC and identify causes of CC primarily with other people or countries.

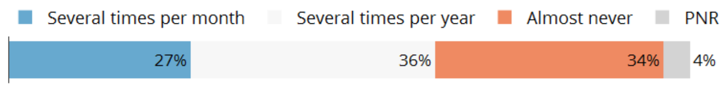


FIGURE 3.F.1 – Frequency at which respondents talk about climate change.

One can wonder if this blindness to the causes is mirrored by a sentiment that oneself will not be impacted. This does not seem to be the case on a spatial dimension. Indeed, Figure 3.F.2 shows that although five times more people (correctly [15]) believe that India will face more serious climate impacts than the European Union, 65% still think that both regions will face as much damage. Yet, the evidence is mild regarding the time dimension, as 45% of American think that "global warming will pose a serious threat to [them] or [their] way of life in [their] lifetime" (Gallup, 2019) while 62% of French people think that the first generation seriously affected by CC is yet to be born (Figure 3.F.3). [16] Interestingly, a delay of one generation as the first (perceived as) affected by CC is significantly associated with a lower knowledge index by 0.1 standard deviation. This finding may indicate that learning is partly motivated by perceived personal prejudice.

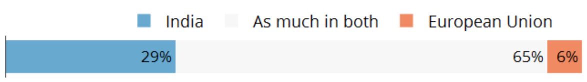


FIGURE 3.F.2 – Perceived region where climate change impacts will be the most serious.

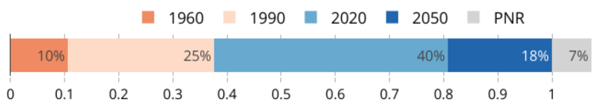


FIGURE 3.F.3 – Perceived date of birth of first generation severely affected by CC.

3.F.1.2 The Reaction Needed

Kallbekken & Aasen (2010) report that "a poll of 22,000 respondents from 21 countries found that 83% say it will be necessary to make lifestyle and behavioural changes to reduce emissions of greenhouse gases (Globescan and PIPA, 2007)." Other French representative surveys find similar results for the reaction needed and indicate which efforts people are most ready to make. BVA (2011) indicates that, to save energy, 76% plan to "change their consumption habits" and 61% plan works in their accomodation. In the U.S., 52% already think they "do a good job at protecting the environment" Gallup (2019). However, ADEME (2018) shows that the efforts people are making or could easily make are also the least efficient to reduce GhG

15. See e.g. vulnerability indexes (Climate Vulnerable Forum, 2012; Guillaumont, 2015; Closset et al., 2018).
16. We assume here that both countries are comparable.

emissions : most people cite waste sorting (89%) or buying seasonal vegetables (87%), but fewer mention walking or cycling (55%) or using public transport (49%) instead of driving.

Logically, 62% thus think that "only legislative constraint is effective in making a successful transition and forcing everyone to change their consumption habits" (OpinionWay, 2019). The extent to which people support such legislation is documented by Bréchon et al. (2019) : 50% favour the protection of the environment at the expense of the economy and employment. In the U.S., Gallup surveys show that this prioritization depends largely on the economic conditions, in accordance with Brulle et al. (2012) and Shum (2012) : the figure is 65% in 2019 but was 38% in 2010.

3.F.2 Test different wording for winners and losers

TABLE F.1 – Effect of defining winners/losers in terms of purchasing power

	Dependent variable :			
	Poors expected to win	City dwellers expected to win	Rich expected to lose	Rural expected to lose
	(1)	(2)	(3)	(4)
Constant	0.058***	0.207***	0.009***	0.352***
	(0.007)	(0.010)	(0.003)	(0.012)
In purchasing power	0.045***	−0.029**	0.015***	−0.014
	(0.010)	(0.014)	(0.005)	(0.017)
Observations	3,002	3,002	3,002	3,002
R^2	0.007	0.001	0.003	0.0002

*p<0.1 ; **p<0.05 ; ***p<0.01

3.F.3 Additional specifications for determinants of attitudes

Table F.2 – Determinants of attitudes towards diesel taxation

	Acceptance increase in diesel taxation			
	(1)	(2)	(3)	(4)
Knowledge on CC	0.046***			
	(0.008)			
Ecologist	0.082***			
	(0.023)			
Yellow Vests : PNR	−0.041		−0.068**	
	(0.030)		(0.034)	
Yellow Vests : understands	−0.099***		−0.134***	
	(0.021)		(0.023)	
Yellow Vests : supports	−0.188***		−0.289***	
	(0.022)		(0.024)	
Yellow Vests : is part	−0.163***		−0.300***	
	(0.040)		(0.045)	
Left-right : Extreme-left	0.082			0.076
	(0.052)			(0.060)
Left-right : Left	0.033			0.025
	(0.025)			(0.024)
Left-right : Center	0.016			0.081***
	(0.028)			(0.029)
Left-right : Right	−0.045*			−0.060**
	(0.027)			(0.026)
Left-right : Extreme-right	−0.030			−0.180***
	(0.031)			(0.033)
Size of town : -20k	−0.001	0.002		
	(0.025)	(0.025)		
Size of town : 20-100k	0.013	0.016		
	(0.027)	(0.027)		
Size of town : +100k	0.068***	0.106***		
	(0.025)	(0.022)		
Size of town : Paris	0.083**	0.143***		
	(0.041)	(0.026)		
Diesel	−0.371***	−0.474***		
	(0.023)	(0.016)		
Gasoline	0.153***			
	(0.022)			
Number vehicles	−0.022			
	(0.019)			
Frequency of public transit	0.001			
	(0.007)			
Additional covariates	✓			
Observations	3,002	3,002	3,002	3,002
R^2	0.357	0.271	0.054	0.018

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in Appendix C.

Table F.3 – Determinants of attitudes towards carbon tax revenue recycling

	Non-polluting transports (1)	VAT cut (2)	Renewable energies (3)	Renovation of buildings (4)	Transfer constrained hh. (5)	Reduction soc. contri. (6)	Transfer poor hh. (7)	Reduction pub. deficit (8)	Transfer all hh. (9)
Knowledge on CC	0.127***	−0.050*	0.132***	0.099***	0.051*	−0.064**	−0.027	−0.009	−0.074**
	(0.025)	(0.026)	(0.025)	(0.025)	(0.026)	(0.026)	(0.029)	(0.026)	(0.029)
CC is disastrous	0.298***	0.085	0.275***	0.247***	0.151***	0.109**	0.102*	0.105**	0.078
	(0.049)	(0.052)	(0.050)	(0.049)	(0.052)	(0.053)	(0.057)	(0.052)	(0.057)
Interest in politics (0 to 2)	0.031	−0.115***	−0.003	−0.008	−0.006	−0.096**	−0.073*	−0.079**	−0.068*
	(0.035)	(0.038)	(0.036)	(0.036)	(0.038)	(0.038)	(0.041)	(0.038)	(0.041)
Ecologist	0.310***	−0.036	0.436***	0.262***	0.055	−0.085	0.183**	−0.024	−0.012
	(0.068)	(0.073)	(0.069)	(0.068)	(0.072)	(0.073)	(0.078)	(0.072)	(0.079)
Yellow Vests : PNR	−0.156*	−0.041	−0.256***	−0.171*	−0.140	−0.189**	0.032	−0.318***	−0.129
	(0.089)	(0.096)	(0.091)	(0.090)	(0.095)	(0.096)	(0.104)	(0.095)	(0.104)
Yellow Vests : understands	−0.039	0.262***	−0.106*	−0.016	0.091	0.007	0.127*	−0.096	−0.094
	(0.061)	(0.066)	(0.062)	(0.061)	(0.065)	(0.066)	(0.071)	(0.065)	(0.071)
Yellow Vests : supports	−0.271***	0.141**	−0.346***	−0.243***	−0.098	−0.166**	−0.043	−0.321***	−0.277***
	(0.065)	(0.070)	(0.066)	(0.065)	(0.069)	(0.070)	(0.076)	(0.069)	(0.076)
Yellow Vests : is part	−0.306***	0.272**	−0.370***	−0.211*	0.022	−0.112	−0.023	−0.297**	−0.345**
	(0.118)	(0.127)	(0.120)	(0.119)	(0.126)	(0.127)	(0.137)	(0.125)	(0.137)
Left-right : Extreme-left	0.066	0.162	0.066	0.223	0.043	−0.195	0.180	−0.216	−0.399**
	(0.154)	(0.166)	(0.157)	(0.155)	(0.164)	(0.166)	(0.179)	(0.164)	(0.179)
Left-right : Left	0.085	−0.079	0.145*	0.089	0.074	−0.097	0.301***	−0.099	−0.065
	(0.074)	(0.080)	(0.076)	(0.075)	(0.079)	(0.080)	(0.086)	(0.079)	(0.087)
Left-right : Center	0.038	−0.162*	0.021	0.137*	0.083	−0.093	0.054	0.105	−0.100
	(0.082)	(0.088)	(0.084)	(0.083)	(0.087)	(0.089)	(0.095)	(0.087)	(0.096)
Left-right : Right	0.048	−0.013	0.058	0.084	0.072	0.090	−0.134	0.160*	0.051
	(0.079)	(0.085)	(0.080)	(0.079)	(0.084)	(0.085)	(0.092)	(0.084)	(0.092)
Left-right : Extreme-right	−0.212**	−0.041	−0.106	−0.147	−0.186*	−0.013	−0.209*	−0.172*	−0.095
	(0.093)	(0.100)	(0.095)	(0.094)	(0.099)	(0.100)	(0.108)	(0.099)	(0.108)
Diploma (1 to 4)	−0.014	−0.027	0.016	0.002	−0.014	−0.047*	−0.046	−0.021	0.011
	(0.025)	(0.026)	(0.025)	(0.025)	(0.026)	(0.027)	(0.029)	(0.026)	(0.029)
Age : 25 – 34	−0.285**	−0.105	−0.270**	−0.101	−0.096	−0.120	−0.308**	−0.261**	0.244*
	(0.113)	(0.121)	(0.115)	(0.113)	(0.120)	(0.121)	(0.131)	(0.120)	(0.131)
Age : 35 – 49	−0.167	−0.083	−0.109	0.057	−0.023	0.014	−0.283**	−0.202*	0.096
	(0.112)	(0.120)	(0.114)	(0.112)	(0.119)	(0.120)	(0.130)	(0.119)	(0.130)
Age : 50 – 64	−0.015	0.032	−0.038	0.122	0.178	0.166	−0.053	−0.176	0.129
	(0.121)	(0.130)	(0.124)	(0.122)	(0.129)	(0.131)	(0.141)	(0.129)	(0.141)
Age : $\geq$ 65	−0.010	−0.034	−0.034	0.217	0.215	0.130	0.028	−0.140	0.111
	(0.143)	(0.154)	(0.146)	(0.144)	(0.152)	(0.154)	(0.166)	(0.152)	(0.166)
Income (k€/month)	0.025	−0.016	0.014	0.013	−0.014	−0.002	−0.084***	0.008	0.054**
	(0.022)	(0.023)	(0.022)	(0.022)	(0.023)	(0.023)	(0.025)	(0.023)	(0.025)
Sex : Male	−0.151***	−0.183***	−0.183***	−0.132***	−0.190***	−0.221***	−0.161***	−0.132**	−0.108*
	(0.049)	(0.053)	(0.050)	(0.049)	(0.052)	(0.053)	(0.057)	(0.052)	(0.057)
Size of town (1 to 5)	−0.007	0.005	0.004	0.003	−0.012	0.019	0.029	0.016	−0.007
	(0.021)	(0.023)	(0.022)	(0.021)	(0.023)	(0.023)	(0.025)	(0.023)	(0.025)
Frequency of public transit	0.025	−0.026	−0.006	0.0001	−0.012	−0.015	−0.019	−0.029	−0.014
	(0.020)	(0.022)	(0.021)	(0.021)	(0.022)	(0.022)	(0.024)	(0.022)	(0.024)
Additional covariates	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	3,002	3,002	3,002	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.125	0.066	0.129	0.095	0.060	0.058	0.120	0.053	0.064

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in Appendix C.

Table F.4 – Determinants of attitudes towards specific climate policies

	Norms for buildings (1)	Norms for new vehicles (2)	Tax on kerosene (3)	Prohibition pol. vehicles (4)	Norms for old vehicles (5)	Contribution climate fund (6)	Tax on red meat (7)	Urban tolls (8)
Knowledge on CC	0.155***	0.186***	0.130***	0.118***	0.100***	0.187***	0.118***	0.027
	(0.022)	(0.022)	(0.024)	(0.025)	(0.024)	(0.025)	(0.023)	(0.023)
CC is disastrous	0.175***	0.360***	0.105**	0.246***	0.252***	0.271***	0.160***	0.092**
	(0.043)	(0.043)	(0.047)	(0.050)	(0.047)	(0.050)	(0.046)	(0.046)
Interest in politics (0 to 2)	0.117***	0.115***	0.245***	0.022	0.003	0.041	−0.022	0.027
	(0.031)	(0.031)	(0.034)	(0.036)	(0.034)	(0.036)	(0.033)	(0.033)
Ecologist	0.141**	0.160***	0.263***	0.317***	0.233***	0.288***	0.480***	0.267***
	(0.059)	(0.059)	(0.065)	(0.069)	(0.066)	(0.069)	(0.063)	(0.064)
Yellow Vests : PNR	−0.151*	−0.084	−0.203**	−0.104	−0.127	−0.086	0.012	−0.213**
	(0.078)	(0.078)	(0.086)	(0.091)	(0.087)	(0.091)	(0.083)	(0.084)
Yellow Vests : understands	−0.005	−0.103*	0.041	−0.162***	−0.139**	−0.113*	0.069	−0.224***
	(0.053)	(0.053)	(0.059)	(0.062)	(0.059)	(0.062)	(0.057)	(0.058)
Yellow Vests : supports	−0.071	−0.178***	0.201***	−0.285***	−0.294***	−0.291***	0.059	−0.365***
	(0.057)	(0.057)	(0.062)	(0.066)	(0.063)	(0.066)	(0.061)	(0.061)
Yellow Vests : is part	−0.147	−0.447***	0.171	−0.573***	−0.456***	−0.536***	−0.107	−0.324***
	(0.104)	(0.103)	(0.113)	(0.121)	(0.115)	(0.120)	(0.111)	(0.112)
Left-right : Extreme-left	−0.076	−0.174	0.007	−0.191	−0.051	0.267*	0.199	−0.017
	(0.135)	(0.135)	(0.148)	(0.157)	(0.150)	(0.157)	(0.144)	(0.146)
Left-right : Left	0.009	−0.067	−0.070	−0.084	−0.110	0.226***	−0.007	0.056
	(0.065)	(0.065)	(0.071)	(0.076)	(0.072)	(0.076)	(0.070)	(0.070)
Left-right : Center	0.062	−0.017	0.111	−0.043	0.029	−0.047	0.028	0.110
	(0.072)	(0.072)	(0.079)	(0.084)	(0.080)	(0.084)	(0.077)	(0.078)
Left-right : Right	−0.046	−0.036	−0.048	−0.021	0.003	−0.047	−0.114	0.009
	(0.069)	(0.069)	(0.076)	(0.080)	(0.077)	(0.080)	(0.074)	(0.074)
Left-right : Extreme-right	−0.013	−0.064	0.007	−0.215**	−0.262***	−0.329***	−0.236***	−0.180**
	(0.082)	(0.082)	(0.089)	(0.095)	(0.090)	(0.095)	(0.087)	(0.088)
Diploma (1 to 4)	−0.030	−0.003	0.017	0.044*	0.015	−0.037	0.011	0.016
	(0.022)	(0.022)	(0.024)	(0.025)	(0.024)	(0.025)	(0.023)	(0.023)
Age : 25 – 34	−0.012	−0.066	0.223**	0.051	−0.015	−0.174	−0.199*	−0.016
	(0.099)	(0.099)	(0.108)	(0.115)	(0.109)	(0.115)	(0.105)	(0.106)
Age : 35 – 49	−0.014	0.087	0.319***	0.130	−0.060	−0.227**	−0.419***	−0.155
	(0.098)	(0.098)	(0.107)	(0.114)	(0.109)	(0.114)	(0.105)	(0.106)
Age : 50 – 64	0.096	0.145	0.427***	0.173	0.090	−0.368***	−0.423***	−0.199*
	(0.106)	(0.106)	(0.116)	(0.124)	(0.118)	(0.123)	(0.113)	(0.114)
Age : ≥ 65	0.080	0.123	0.447***	0.275*	0.210	−0.483***	−0.394***	−0.109
	(0.125)	(0.125)	(0.137)	(0.146)	(0.139)	(0.145)	(0.134)	(0.135)
Income (k€/month)	0.029	0.004	−0.025	0.040*	0.038*	0.039*	0.004	0.046**
	(0.019)	(0.019)	(0.021)	(0.022)	(0.021)	(0.022)	(0.020)	(0.020)
Sex : Male	−0.120***	−0.114***	0.057	−0.026	−0.132***	−0.216***	−0.136***	−0.002
	(0.043)	(0.043)	(0.047)	(0.050)	(0.047)	(0.050)	(0.046)	(0.046)
Size of town (1 to 5)	0.003	0.004	−0.041**	0.020	0.018	0.038*	0.049**	−0.029
	(0.019)	(0.019)	(0.020)	(0.022)	(0.021)	(0.022)	(0.020)	(0.020)
Frequency of public transit	0.013	0.002	−0.040**	−0.028	−0.002	−0.040*	−0.052***	−0.036*
	(0.018)	(0.018)	(0.020)	(0.021)	(0.020)	(0.021)	(0.019)	(0.019)
Additional covariates	✓	✓	✓	✓	✓	✓	✓	✓
Observations	3,002	3,002	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.086	0.165	0.117	0.164	0.176	0.173	0.147	0.118

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in Appendix C.

TABLE F.5 – Determinants of attitudes towards climate policies, additional specifications

	Share of policies	Tax & dividend	
	(1)	(2)	(3)
Knowledge on CC	0.057***		
	(0.005)		
CC is disastrous	0.090***		
	(0.010)		
Diploma (1 to 4)	0.006		
	(0.004)		
Age : 25 – 34	−0.039**		
	(0.018)		
Age : 35 – 49	−0.019		
	(0.017)		
Age : 50 – 64	0.005		
	(0.017)		
Age : ≥ 65	0.045**		
	(0.018)		
Income (k€/month)	0.003		
	(0.002)		
Sex : Male	−0.008		
	(0.009)		
Size of town (1 to 5)	0.008**		
	(0.004)		
Frequency of public transit	0.017***		
	(0.004)		
Left-right : Extreme-left		0.072**	−0.065
		(0.033)	(0.057)
Left-right : Left		0.040***	0.031
		(0.013)	(0.022)
Left-right : Center		0.071***	0.090***
		(0.015)	(0.026)
Left-right : Right		0.029**	−0.037
		(0.014)	(0.024)
Left-right : Extreme-right		−0.061***	−0.155***
		(0.018)	(0.031)
Observations	3,002	3,002	3,002
R^2	0.143	0.018	0.017

*p<0.1 ; **p<0.05 ; ***p<0.01

NOTE : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in Appendix C.

3.F.4 Construction of the knowledge index

We synthesize the different dimensions of knowledge proposed by Kiel & Rost (2002) and summarized by Hoppe et al. (2018) using our questions on the existence and anthropogenic origin of CC (corresponding to the causal knowledge), on the region most affected (effects), as well as our scores on the emission target (basic), greenhouse gases (basic) and on activities responsible for CC (action-related).

From an exploratory factor analysis (fitted using the maximum likelihood method), we find the factor which explains the highest share of common variance, and report it in Table F.6. We use the factor loadings hereby obtained to define the relative weights of the components of our index of knowledge, and we round them for readability purpose. The rounding has virtually no effect on the result, as the correlation between our index and the factor obtained is 0.999. For information, the correlations between the different components of our index, including our index itself, are reported on Figure 3.F.4.

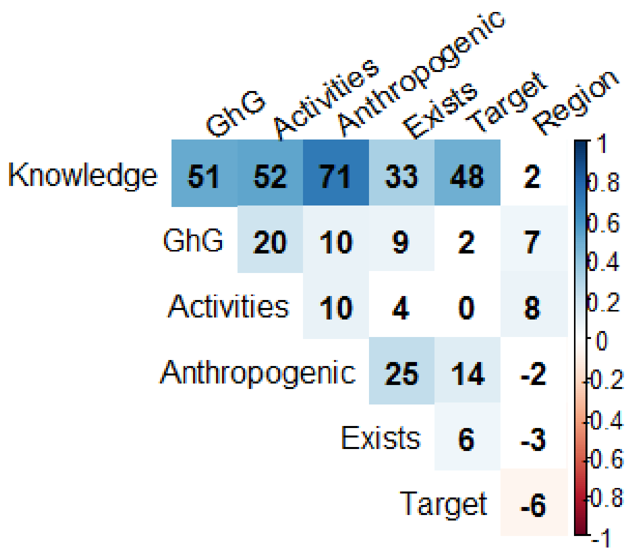


FIGURE 3.F.4 – Correlations between different variables of knowledge on CC.

Moreover, Table F.7 shows that the determinants of Tax & Dividend are robust to the choice of the *knowledge* variable : if we replace our index by any of its component, the coefficients of the other determinants are virtually unchanged. Interestingly, this analysis indicates that it is the

Table F.6 – Factor loadings and weights chosen for different dimensions of knowledge on CC

Variable	GhG	Activities	Exists	Anthropogenic	Target	Region
Loading	.212	.182	.398	.601	.200	.000
Weight	1	1	2	3	1	0

knowledge on the existence and the anthropogenic nature of CC that drives the effect of overall knowledge, justifying a higher weight for these two components. Finally, we could reproduce this robustness check for the other dependent variable of Table II, and also by replacing the independent variable *knowledge* in Table I, and we would again see that the other coefficients are essentially unaffected.

Table F.7 – Robustness of the determinants of Tax & Dividend Acceptance To Knowledge Variables

	Tax & dividend					
	(1)	(2)	(3)	(4)	(5)	(6)
Knowledge on CC	0.029***					
	(0.009)					
CC is Anthropogenic		0.068***				
		(0.019)				
CC Exists			0.115**			
			(0.051)			
Score GhG				0.002		
				(0.009)		
Score Activities					0.005	
					(0.009)	
Score Target proximity						0.015*
						(0.008)
Ecologist	0.126***	0.130***	0.135***	0.135***	0.134***	0.132***
	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Yellow Vests : PNR	−0.021	−0.019	−0.023	−0.023	−0.023	−0.024
	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)	(0.032)
Yellow Vests : understands	−0.144***	−0.144***	−0.146***	−0.146***	−0.145***	−0.146***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Yellow Vests : supports	−0.222***	−0.222***	−0.226***	−0.228***	−0.227***	−0.227***
	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.023)
Yellow Vests : is part	−0.214***	−0.215***	−0.218***	−0.226***	−0.225***	−0.225***
	(0.043)	(0.043)	(0.043)	(0.042)	(0.043)	(0.042)
Left-right : Extreme-left	−0.040	−0.038	−0.028	−0.033	−0.033	−0.037
	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)
Left-right : Left	0.072***	0.072***	0.075***	0.075***	0.074***	0.075***
	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)	(0.027)
Left-right : Center	0.051*	0.053*	0.052*	0.053*	0.053*	0.054*
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)
Left-right : Right	−0.022	−0.022	−0.023	−0.023	−0.023	−0.022
	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)	(0.028)
Left-right : Extreme-right	−0.041	−0.044	−0.046	−0.045	−0.044	−0.045
	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)	(0.034)
Sex : Male	−0.053***	−0.047***	−0.046***	−0.048***	−0.049***	−0.048***
	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Additional covariates	✓		✓	✓	✓	✓
Observations	3,002	3,002	3,002	3,002	3,002	3,002
R^2	0.150	0.151	0.149	0.147	0.147	0.148

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Standard errors are reported in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are the same as in Table II.

3.F.5 Logit regressions for determinants

TABLE F.8 – Determinants of attitudes towards climate change (CC) with logit regressions.

	CC is anthropogenic			CC is disastrous	
	(1)	(2)	(3)	(4)	(5)
Interest in politics (0 to 2)	0.034***			0.045***	
	(0.013)			(0.014)	
Ecologist	0.144***			0.186***	
	(0.021)			(0.027)	
Yellow Vests : PNR	−0.097***			−0.069**	
	(0.036)			(0.034)	
Yellow Vests : understands	−0.034			−0.040*	
	(0.023)			(0.024)	
Yellow Vests : supports	−0.101***			−0.052**	
	(0.025)			(0.025)	
Yellow Vests : is part	−0.196***			−0.079*	
	(0.047)			(0.044)	
Left-right : Extreme-left	0.121**		0.079	0.070	0.006
	(0.047)		(0.071)	(0.064)	(0.088)
Left-right : Left	0.088***		0.050	0.104***	−0.006
	(0.025)		(0.045)	(0.030)	(0.053)
Left-right : Center	0.011		0.009	0.030	−0.072
	(0.030)		(0.044)	(0.032)	(0.048)
Left-right : Right	−0.031		−0.032	−0.029	−0.138***
	(0.029)		(0.046)	(0.031)	(0.048)
Left-right : Extreme-right	−0.012		−0.025	0.023	−0.081
	(0.034)		(0.056)	(0.038)	(0.062)
Diploma : *CAP* or *BEP*	0.042**		0.039*	−0.022	−0.015
	(0.020)		(0.021)	(0.025)	(0.026)
Diploma : *Baccalauréat*	0.063***		0.111***	0.025	0.121***
	(0.024)		(0.024)	(0.029)	(0.030)
Diploma : Higher	0.093***		0.165***	0.095***	0.234***
	(0.025)		(0.024)	(0.031)	(0.030)
Diploma × Left-right			−0.010		−0.004
			(0.008)		(0.009)
Diploma × Left-right : Indeterminate			0.005		−0.024
			(0.015)		(0.016)
Age : 25 – 34	0.048	−0.040		0.018	
	(0.042)	(0.041)		(0.047)	
Age : 35 – 49	−0.008	−0.113***		0.026	
	(0.043)	(0.035)		(0.045)	
Age : 50 – 64	0.005	−0.116***		−0.036	
	(0.045)	(0.034)		(0.047)	
Age : ≥ 65	−0.095*	−0.228***		−0.087	
	(0.057)	(0.035)		(0.056)	
Income (k€/month)	−0.011			−0.010	
	(0.008)			(0.009)	
Sex : Male	−0.024			0.003	
	(0.018)			(0.019)	
Size of town (1 to 5)	0.006			0.007	
	(0.008)			(0.008)	
Frequency of public transit	0.012			0.007	
	(0.007)			(0.008)	
Additional covariates	✓			✓	
Observations	3,002	3,002	3,002	3,002	3,002
Note :				*p<0.1 ; **p<0.05 ; ***p<0.01	

NOTE : Standard errors are reported in parentheses. Interaction term is computed using numeric variables. Omitted modalities are : *Yellow Vests : opposes*, *Left-right : Indeterminate*, *Diploma : Brevet or no diploma*, *Age : 18 – 24*. Additional covariates are defined in Appendix C.

Table F.9 – Determinants of attitudes towards climate policies with logit regressions.

	Tax & dividend		Share of policies	Ecological lifestyle
	(1)	(2)	(3)	(4)
Knowledge on CC	0.029***	0.049***	0.046***	0.092***
	(0.009)	(0.009)	(0.010)	(0.010)
CC is disastrous	0.023	0.035*	0.081***	0.137***
	(0.017)	(0.018)	(0.020)	(0.018)
Interest in politics (0 to 2)	−0.019		0.032**	0.028**
	(0.013)		(0.014)	(0.013)
Ecologist	0.107***		0.077***	0.173***
	(0.025)		(0.028)	(0.023)
Yellow Vests : PNR	−0.022		−0.054	−0.087**
	(0.028)		(0.036)	(0.034)
Yellow Vests : understands	−0.117***		−0.025	−0.009
	(0.018)		(0.024)	(0.022)
Yellow Vests : supports	−0.207***		−0.050*	−0.020
	(0.019)		(0.026)	(0.024)
Yellow Vests : is part	−0.177***		−0.080*	−0.026
	(0.028)		(0.047)	(0.042)
Left-right : Extreme-left	−0.035		0.022	0.083
	(0.055)		(0.065)	(0.055)
Left-right : Left	0.070***		−0.003	0.039
	(0.027)		(0.030)	(0.027)
Left-right : Center	0.051*		0.013	0.096***
	(0.029)		(0.033)	(0.028)
Left-right : Right	−0.022		0.009	0.010
	(0.027)		(0.032)	(0.028)
Left-right : Extreme-right	−0.076**		−0.023	0.010
	(0.034)		(0.039)	(0.033)
Diploma (1 to 4)	−0.002	0.004	0.007	−0.007
	(0.009)	(0.008)	(0.010)	(0.009)
Age : 25 – 34	−0.039	−0.079***	−0.024	0.032
	(0.038)	(0.028)	(0.048)	(0.042)
Age : 35 – 49	−0.041	−0.067**	−0.015	0.051
	(0.037)	(0.026)	(0.046)	(0.040)
Age : 50 – 64	−0.043	−0.078***	−0.002	0.059
	(0.040)	(0.027)	(0.049)	(0.042)
Age : $\geq$ 65	−0.066	−0.074***	0.001	0.016
	(0.046)	(0.028)	(0.058)	(0.051)
Income (k€/month)	0.0002	0.001	0.010	−0.005
	(0.008)	(0.004)	(0.009)	(0.009)
Sex : Male	−0.051***	−0.070***	−0.027	−0.066***
	(0.017)	(0.017)	(0.020)	(0.018)
Size of town (1 to 5)	0.021***	0.035***	0.001	−0.005
	(0.008)	(0.007)	(0.009)	(0.008)
Frequency of public transit	−0.006	0.012*	−0.003	0.023***
	(0.007)	(0.006)	(0.008)	(0.008)
Additional covariates	✓		✓	✓
Observations	3,002	3,002	3,002	3,002

*p<0.1 ; **p<0.05 ; ***p<0.01

Note : Average marginal effects are reported, with standard errors in parentheses. Omitted variables are *Yellow Vests : opposes*, *Age : 18 – 24* and *Left-right : Indeterminate*. Additional covariates are defined in Appendix C.

3.F.6 Robustness for the absence of cultural cognition effect

TABLE F.10 – Robustness of the absence interaction on perceived effects between political orientation and knowledge.

	CC is disastrous		
	(1)	(2)	(3)
Constant	0.404***	0.510***	0.458***
	(0.035)	(0.056)	(0.017)
Yellow Vests : PNR	−0.049		−0.021
	(0.041)		(0.033)
Yellow Vests : understands	−0.013		0.001
	(0.034)		(0.023)
Yellow Vests : supports	−0.020		0.002
	(0.051)		(0.023)
Yellow Vests : is part	−0.049		0.024
	(0.079)		(0.044)
Left-right : Left		−0.004	
		(0.059)	
Left-right : Center		−0.071	
		(0.060)	
Left-right : Right		−0.119**	
		(0.060)	
Left-right : Extreme-right		−0.054	
		(0.063)	
Diploma : *CAP* or *BEP*	−0.029		
	(0.024)		
Diploma : *Baccalauréat*	0.109***		
	(0.027)		
Diploma : Higher	0.203***		
	(0.024)		
Knowledge CC		0.174***	0.188***
		(0.011)	(0.009)
Diploma × Yellow Vests	−0.001		
	(0.009)		
Knowledge CC × Left-right		−0.007	
		(0.009)	
Knowledge CC × Yellow Vests			0.001
			(0.010)
Observations	3,002	1,813	3,002
R^2	0.039	0.138	0.145
			*p<0.1 ; **p<0.05 ; ***p<0.01

NOTE : Standard errors are reported in parentheses. Interaction term is computed using numeric variables. Omitted modalities are : *Yellow Vests : opposes*, *Left-right : Extreme-left*, *Diploma : Brevet or no diploma*.

Chapitre 4

Disaster Risks, Disaster Strikes, and Economic Growth : The Role of Preferences [1]

1. Acknowledgments : I am grateful to Katheline Schubert for her support and helpful comments. I also thank Lucas Bretschger, Stéphane Gauthier, Christian Gollier, Fanny Henriet, Jean Imbs, Katrin Millock, Hélène Ollivier, Rick van der Ploeg, Ingmar Schumacher, Alexandra Vinogradova, Sweder van Wijnbergen, Anastasios Xepapadeas, participants at several seminars and conferences, as well as anonymous referees and editors of the *Review of Economic Dynamics*.

Abstract :

This chapter studies the role of preferences on the link between disasters, growth, and welfare. An endogenous growth model with endogenous disasters is presented in which one can derive closed-form solutions with recursive preferences. The model distinguishes disaster risks and disaster strikes and highlights the numerous mechanisms through which they may affect growth. It is shown that separating aversion to risk from the elasticity of inter-temporal substitution bears critical implications that enable to better understand these mechanisms. In a calibration of the model based on empirical evidence about disaster impacts in the U.S., it is shown that precautionary savings are unlikely to be sufficient to generate a positive link between disasters and growth at the optimum. The chapter also assesses the impact of disasters on welfare and highlights the large benefits that could be obtained by enhancing insurance coverage. As the previous results are sensitive to preference parameters, the chapter calls for a wider use of more flexible representations of preferences—such as Epstein-Zin-Weil utility—in the modeling of disasters.

4.1 Introduction

Risk is more than ever an essential concern for economic policies. The renewal of interest for the study of risk in macroeconomic models is not only the result of the 2008 economic and financial crisis but also reflects the growing concerns around environmental risks such as climate change and environmental disasters. The risk of rare catastrophic events bears critical welfare implications not only as disasters hurt when they strike but also as their anticipation may affect agents decisions. This view has been first introduced by Rietz (1988) in an attempt to explain the equity premium puzzle (Mehra & Prescott, 1985). Since, his idea that a low subjective probability of a catastrophic event may drive agents investment decisions has gained momentum with a development of new theoretical frameworks (e.g. Barro, 2006, 2009; Gabaix, 2012) supported by empirical evidences on the history of catastrophic events (e.g. Barro & Ursua, 2008). More recently, some authors have adopted similar frameworks to analyze the macroeconomic impacts of environmental disasters in endogenous growth frameworks (Ikefuji & Horii, 2012; Barro, 2015; Müller-Fürstenberger & Schumacher, 2015; Bakkensen & Barrage, 2016; Bretschger & Vinogradova, 2017; Akao & Sakamoto, 2018). As pointed out by Bakkensen & Barrage (2016), if these disasters reduce output or production means when they strike, they also affect consumption and savings decisions in an ambiguous way, resulting in potentially important long-term impacts.

In line with this literature, the objective of the present chapter is to better understand the link between environmental disasters, economic growth, and welfare. To investigate the underlying mechanisms, I propose an endogenous growth model with endogenous disasters that can be fully solved analytically. The model builds on the frameworks proposed by Müller-Fürstenberger & Schumacher (2015) and Bretschger & Vinogradova (2017), and extends these earlier works by allowing for a more general representation of individuals' preferences. In particular, the model is solved for the class of utility functions proposed by Epstein & Zin (1989) and Weil (1990), building on Kreps & Porteus (1978) non-expected utility theory. As shown by a large literature in finance (see Bansal & Yaron, 2004), by distinguishing risk aversion from the inter-temporal elasticity of substitution, these utility functions enable to better explain individuals decision in front of risk. As the objective of the chapter is to understand how disasters affect growth and welfare, allowing for this more general and flexible representation of preferences will prove critical. In particular, the chapter shows analytically that the restrictions imposed by more standard utility functions — e.g. logarithmic or time-additive power utility — bias our understanding of the mechanisms that link disasters to growth, and welfare. In a calibration of the model that matches empirical evidence on environmental disasters, the chapter also shows that these biases matter quantitatively.

In order to start from a simple benchmark, the model is first solved in the case of exogenous disasters. Several preliminary intuitions are derived in this situation. I then turn to the case of disasters whose probability can be mitigated through a policy. In the appendix the model is also solved for multiple types of disasters including catastrophes of endogenous intensity. It follows from the model that the optimal shares of output consumed, saved, and spent in risk-mitigation are all constant on the optimal path. The effects of the model's parameters are studied and in particular the role of the preference parameters are emphasized. While risk and risk aversion (RRA) drive the decision to mitigate risk, the inter-temporal elasticity of substitution (IES) plays no role in this decision. However, it appears to be critical in the risk sensitivity of the consumption/savings decision. When the risk of disasters increases, current consumption is partly transferred to the future through savings when the IES is below unity. Interestingly, if the *sign* of this effect solely depends on the IES, its *magnitude* depends on the RRA. While a low IES — i.e. high aversion to fluctuations — unambiguously leads to more precautionary savings, a high aversion to risk may increase either precautionary savings or precautionary consumption. This result shows that it is essential to depart from the standard time-additive utility function as aversion to risk and to fluctuations end up having very different effects on the optimal solution. A second result of importance is that, when introducing an instrument to mitigate disasters, an increase in risk also generates a transfer from savings to risk-mitigation spending. As a result, and contrary to what has been emphasized so far in the literature, an IES below unity is a necessary but insufficient condition to guarantee a net positive response of savings to risk.

From the law of capital accumulation, one can compute analytically the stochastic growth rate as well as the average long-run growth rate of the economy. Most interestingly, one can look at the effect of disasters on the latter. Following the terminology used by Bakkensen & Barrage (2016) I distinguish the impact of disaster *risks* from the one of disaster *strikes*. If damages from catastrophes (i.e. from strikes) reduce expected growth, their anticipation (i.e. risk) has an ambiguous effect through the sensitivity of capital accumulation to risk. For realistic parameter values — i.e. unless the crowding out of risk-mitigation spending over savings is too high — disasters foster average long-run growth if aversion to risk and to fluctuations are both large enough. Since the existence of disasters necessarily reduces welfare, there are therefore situations in which growth and welfare are inversely linked. To further examine the impact of disasters on welfare, I compute analytically the marginal rate of substitution between disaster parameters (i.e. frequency and intensity) and output, as well as a measure proposed by Lucas (1987, 2003) to assess the welfare benefits of the policy instrument relative to a business-as-usual scenario.

In order to illustrate quantitatively the analytic findings of the chapter, the model is then calibrated so as to represent the U.S. — a country among the most impacted by environmental disasters (see Shi et al., 2015) — disaggregated at the county level. Disaster parameters are proxied from the most recent study on the impact of disasters in U.S. counties over the last 80 years by Boustan et al. (2017). From this exercise, we reach three important conclusions. First, if a positive impact of disasters on long-run growth is theoretically possible in this framework, such a positive relationship can occur only for extremely large disasters and (rather implausibly) high values of aversion towards risk and fluctuations. Second, the effects of disasters on welfare appear significant, even ignoring their impacts on human lives. For instance, reducing by only 10% the likelihood of disasters would be equivalent to an increase by 0.7% of GDP in our main scenario, even though yearly expected damages on GDP are as low as 0.13%. Interestingly, holding expected damages constant but increasing disaster intensity, the welfare effects become much larger. This result stresses the role of insurance as an adaptation strategy, as the welfare gains from trading-off disaster intensity against likelihood appear important. Third and last, the two previous results are sensitive to the calibration of preferences parameters. Thus, the constraints imposed by logarithmic or power utility functions do not only affect our qualitative understanding of the effects of disasters, but they also matter quantitatively. In particular, when using high values for the elasticity of the utility to capture risk aversion, one overestimates the importance of precautionary savings and may wrongly conclude that disasters positively affect growth. When using lower values to better match the IES, one instead underestimates the impact of disasters on welfare, and the level of optimal mitigation policies.

This chapter contributes to two strands of the literature. First, it provides a novel framework to study the effect of environmental disasters on economic growth. Improving our understanding of the mechanisms underlying this link in a first-best setting is critical not only from a theoretical point of view but also as to guide future empirical research on this issue. Indeed, the empirical literature on the link between disasters and growth points towards contrasted evidence. Skidmore & Toya (2002) conclude that higher frequencies of climatic disasters may foster growth, possibly through an effect on human capital accumulation and technology. While Cavallo et al. (2013) find no significant impact of disasters on short and long-run growth, Sawada et al. (2011) find significant negative effects in the short run, but positive effects in the longer term. Strobl (2011) studies hurricanes in the U.S. coastal counties and finds evidence of negative effects with very partial recovery, but the macroeconomic impact of these local catastrophes appears to be negligible. Noy (2009) also finds negative but heterogeneous impacts, with more developed countries being less exposed. More recently, Hsiang & Jina (2014) found a strong negative long-run effect of hurricanes on output and long-run growth with no evidence of a rebound effect in the twenty years following a catastrophe. Some previous theoretical works have recently attempted to understand these diverging empirical evidence. Ikefuji & Horii (2012) stress the role of human capital as a substitute for physical capital to sustain growth when physical capital pollutes. Bakkensen & Barrage (2016) try to reconcile the heterogeneous empirical findings by disentangling hurricanes *strikes* and hurricanes *risks*. They show that while the former may persistently reduce output, the second may foster growth through more accumulation due to precautionary savings. They argue that the contradictory results found in empirical studies might partly be explained by different methodologies that either capture the effect of disaster strikes or disaster risks. Akao & Sakamoto (2018) study exogenous disasters and discuss the role of human capital and technology. As Bakkensen & Barrage (2016), they emphasize the key role of the elasticity of the utility function for disaster risks to foster growth through precautionary savings. Although they do not focus directly on growth, Müller-Fürstenberger & Schumacher (2015) and Bretschger & Vinogradova (2017) both analyze the effect of risk on capital accumulation in a Ramsey type of model where risk can be mitigated through abatement activities. Their results derived in a first-best setting also support the idea that disasters may accelerate capital accumulation depending on the elasticity of the utility function. By contrast, using a more satisfactory representation of preferences towards risk, calibrated so as to match empirical evidence of disaster impacts, this chapter shows that precautionary savings are unlikely to be sufficient to generate a positive link between disasters and growth at the optimum. It remains an open question whether this positive link is a robust empirical fact, but if that is, future research will have to determine which other mechanisms or which market failures could explain it.

Second, this chapter adds to the theoretical literature on the optimal mitigation of environmental risks. In particular, it contributes to recent literature that incorporates recursive preferences into environmental models where risk matters. Previous studies have analyzed the effect of pollution (Soretz, 2007) or biodiversity losses (Augeraud-Véron et al., 2018) on fluctuations, and shown how optimal policies depended on preferences parameters. Considering larger shocks, Barro (2015) extends the previous disaster model of Barro (2009) to disentangle environmental disasters from other types of catastrophes. In a different set-up, Bansal & Ochoa (2011), Bansal et al. (2016), and Karydas & Xepapadeas (2019) examine the effect of temperature-driven disasters on market returns with non-expected utility. van der Ploeg & de Zeeuw (2017) study precautionary savings as a reaction to an endogenous climate tipping point. They characterize savings responses to the tipping depending on its impact delay and on the distance of the economy from its steady-state. However, the model does not provide closed-form solutions and does not enable to study repeated catastrophes. Other papers using numerical methods have introduced Epstein-Zin-Weil preferences in climate economy models, such as DSGE models (e.g. van den Bremer & van der Ploeg, 2018) and Integrated Assessment Models (see Crost & Traeger, 2014; Jensen & Traeger, 2014; Cai & Lontzek, 2018; Olijslagers & van Wijnbergen, 2019). To my knowledge, this chapter is the first to present a framework to study analytically the relationship between endogenous growth and endogenous disasters in which agents display recursive preferences. Both through analytical results and a calibration consistent with observed impacts of disasters, the chapter shows the importance of separating aversion towards risk and fluctuations, in order to better understand the effects of disasters on growth, welfare, and the implications for optimal policies.

The rest of the chapter is organized as follows. Section 2 presents the general framework. Section 3 considers the case of exogenous disasters as a benchmark to highlight the first intuitions of the model. Section 4 turns to endogenous disasters whose probability can be reduced through a risk-mitigation policy. Section 5 provides a calibration of the model and a quantitative assessment of the link between disasters, growth and welfare, and the importance of using non-expected utility over more restrictive representations of preferences. Section 6 concludes. Computations are reported to the appendix, where the model is also extended to multiple types of disasters including of endogenous intensity.

4.2 General framework

The model features essentially two ingredients. One is the stochastic process driving catastrophes. The other is the representation of preferences. We assume utility is derived from the consumption of a unique good C. The central planner's preferences are defined recursively as first proposed by Epstein & Zin (1989) and Weil (1990), and extended to continuous time by Svensson (1989) and Duffie & Epstein (1992). These preferences can be represented by the following utility function :

$$(1-\gamma)U_t = \left[C_t^{\frac{\varepsilon-1}{\varepsilon}} dt + e^{-\rho dt}\left((1-\gamma)\mathbb{E}U(t+dt)\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}} \tag{4.1}$$

where ρ is the pure rate of time preferences, γ the coefficient of relative risk aversion (RRA), and ε the inter-temporal elasticity of substitution (IES), so that $1/\varepsilon$ can be understood as aversion towards inter-temporal fluctuations. In the specific case where $\gamma = 1/\varepsilon$ we obtain the standard time-additive power utility function widely used in the literature. In the even more special case where this parameter tends to one, the power utility converges towards a logarithmic utility. Finally, when $\varepsilon = 1$ and γ is a free parameter, these preferences coincide with the risk-sensitive preferences of Hansen & Sargent (1995).[2] The recursive form of the function defined in equation (4.1) yields the following Hamilton Jacobi Bellman (HJB) equation :

$$(1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}} dt + e^{-\rho dt}\left((1-\gamma)\mathbb{E}V(K_{t+dt})\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}} \tag{4.2}$$

2. Although more restrictive than the EZW utility, Bommier et al. (2017) show that this latter specification has the advantage of being the only Kreps-Porteus recursive utility that permits to isolate the RRA from the IES while satisfying the criterion of first-order stochastic dominance (FSD) monotonicity. This special case of the EZW utility will be used as our main specification in the calibration.

Now, let's consider an economy facing disasters, i.e. catastrophic events that may happen with small probability and destroy part of the capital stock. As Martin & Pindyck (2015), we consider multiple types of catastrophes and keep the specification general enough so that these events may include but are not limited to environmental disasters. Although they are rare events, their effect is long lasting : once capital is destroyed, it takes time to re-build. These disasters are assumed endogenous to some risk-mitigation activities, and are taken to be uninsurable. We denote τ the share of output spent to mitigate disasters. The central planner must therefore allocate production (Y) between consumption (C), risk-mitigation activities (τY) and savings (S). Assuming there are n types of disasters and m types of risk-mitigation technologies, the law of capital accumulation is defined as :

$$dK_t = [Y_t - \sum_{j=1}^{m} \tau_{j,t} Y_t - C_t]dt + \sigma_{w,t} dz - \sum_{i=1}^{n} \sigma_{p,i,t} dq_{i,t} \tag{4.3}$$

where dz is a Wiener process scaled by $\sigma_{w,t}$, and $dq_{i,t}$ a Poisson process scaled by $\sigma_{p,i,t}$. The Wiener process models small fluctuations around the trend, while the Poisson process models rare catastrophic events. The use of the Poisson process in the modelling of agents' optimal consumption and savings decisions has been introduced by Wälde (1999) and later used in the study of natural disasters by Müller-Fürstenberger & Schumacher (2015) and Bretschger & Vinogradova (2017), and in a slightly different set-up by Ikefuji & Horii (2012). As Müller-Fürstenberger & Schumacher (2015), we will assume the Poisson process to be endogenous possibly both through its intensity and its probability, and to depend on risk-mitigation spending. The probability of a shock is assumed to be of the form $\mathbb{E}dq_{i,t} = \lambda_i f_i dt$ with λ_i a constant and f_i a function of abatement activities τ_j, $j = 1, ..., m$ to be defined. We also denote $\tilde{K}_i$ the stock of capital after a shock of the i^{th} process occurred, with $\forall i, 0 < \tilde{K}_{i,t} < K_t$, so that the size of a shock for the process i at time t is $\sigma_{p,i,t} = K_t - \tilde{K}_{i,t}$. Bretschger & Vinogradova (2017) also consider the case of an endogenous variance for the Wiener process. Although possible in this model, for the sake of simplicity we keep the Wiener process independent of risk-mitigation spending as this feature does not bear critical implications. In the next sections, $\sigma_{w,t}$ will simply be taken as proportional to the capital stock to model a geometric Brownian motion.

The objective of the central planner is to maximize its utility (4.1) subject to the stochastic law of capital accumulation (4.3). The solution method is detailed in the appendix. It makes use of useful contributions in the resolution of stochastic problems in continuous time (e.g. Merton, 1971; Wälde, 1999; Sennewald & Wälde, 2006) and how it applies to Epstein-Zin-Weil preferences in an endogenous growth model (see Epaulard & Pommeret, 2003). It is shown in the appendix that if we define :

$$X(K,C,\tau) = V_k[(1-\sum_{j=1}^{m}\tau_{j,t})Y - C] + \frac{1}{2}V_{kk}\sigma_w^2 + \sum_{i=1}^{n}\lambda_i f_i\left(V(\tilde{K}_i) - V(K)\right) \tag{4.4}$$

with $V_k = \partial V(K)/\partial K$ and $V_{kk} = \partial^2 V(K)/\partial K^2$, then the Hamilton-Jacobi-Bellman equation of this problem can be expressed as :

$$\rho\frac{\varepsilon(1-\gamma)}{\varepsilon-1}V(K_t) = \max\left[\frac{\varepsilon}{\varepsilon-1}\frac{C_t^{\frac{\varepsilon-1}{\varepsilon}}}{[(1-\gamma)V(K_t)]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}} + X(K,C,\tau)\right] \tag{4.5}$$

and the associated first order conditions with respect to C and τ_j are :

$$\frac{C_t^{-\frac{1}{\varepsilon}}}{[(1-\gamma)V(K_t)]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}} + X_C = 0$$

$$X_{\tau_j} = 0 \qquad \forall j$$

with X_C and X_{τ_j} the derivatives of X with respect to C and τ_j, hence :

$$C_t^{-\frac{1}{\varepsilon}} = V_k[(1-\gamma)V(K_t)]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1} \tag{4.6}$$

and :

$$\text{for } j = 1,\dots,m \quad : \quad YV_k = \sum_{i=1}^{n}\lambda_i\left[f_i\frac{\partial V(\tilde{K}_i)}{\partial \tilde{K}_i}\frac{\partial \tilde{K}_i}{\partial \tau_j} + \frac{\partial f_i}{\partial \tau_j}\left(V(\tilde{K}_i) - V(K)\right)\right] \tag{4.7}$$

The previous equations highlight the trade-off between the different uses of resources. Equation (4.6) gives the optimal arbitrage between the benefits and the opportunity cost of consumption. Equation (4.7) simply states that at the optimum the marginal cost of risk-mitigation spending (on the left hand side) should be equal to the marginal benefits from reducing disaster frequency and intensity (on the right hand side). This framework remains flexible and enables to study a large variety of risks in different economic settings. In the next section, I start with the benchmark case of exogenous disasters (i.e. no risk-mitigation activity) to present in the simplest way the mechanisms driving the link between disasters and growth and how they depend on preferences. Then, I turn to the case of disasters of endogenous probability. A more comprehensive set-up with both disasters of endogenous probability and intensity is presented in the appendix.

4.3 Benchmark : exogenous disasters

4.3.1 Specification

In this section, we consider the simple case of a unique process ($n = 1$), and take the probability of a disaster as fixed ($m = 0$, i.e. no risk-mitigation instrument available), and their intensity as a constant fraction of the capital stock. Specifically, we take $f = 1 + \delta$, i.e. $\mathbb{E}(dq_t) = \lambda(1 + \delta)dt$, and $\tilde{K} = \omega K$ with $\omega \in [0; 1]$ a constant. The variance of the Wiener process is assumed to linearly depend on the level of the capital stock, with $\sigma_w = \sigma K$, so that fluctuations remain proportional to the size of the economy. Finally, we assume production follows from an AK technology. This last assumption is made for two reasons. First, it is technically convenient as it will prove to provide sufficient linearity to the problem to obtain closed-form solutions. Second, the AK specification is relevant in our setting as it captures the "no-rebound" effect observed empirically for natural disasters. As shown by Hsiang & Jina (2014) using the example of hurricanes, natural disasters cause permanent output losses that are not compensated by higher growth rates in the aftermath, nor in two following decades. These evidences therefore suggest that the AK specification is best fitted to model the effect of disasters on long-run growth.

4.3.2 Optimal resources allocation

The shape of the problem leads to the following guess for the value function : [3]

$$V(K) = \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma} \tag{4.8}$$

3. This educated guess follows the result of Weil (1990) who generalizes Merton (1973) result on the functional form of the value function with isoelastic preferences.

with ψ a constant to be determined. Substituting the guess (4.8) into the first order condition with respect to C (4.6) derived in the previous section gives :

$$C^* = \psi K \tag{4.9}$$

and going back to the HJB equation (4.5) we can solve for ψ, the optimal share of capital consumed :

$$\psi = \rho\varepsilon + (1-\varepsilon)\left(A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma}\right) \tag{4.10}$$

and from the law of capital accumulation defined by equation (4.3) we can determine the optimal saving rate $s^* = S^*/Y$:

$$s^* = \frac{1}{A}\left[\varepsilon(A-\rho) + (1-\varepsilon)\left(\frac{\gamma\sigma^2}{2} + \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma}\right)\right] \tag{4.11}$$

Consumption and savings are therefore constant fractions of capital and output on the optimal path. Interestingly, the consumption share is decreasing with risk — i.e. higher σ or λ, lower ω — and risk aversion — higher γ — if and only if $\varepsilon < 1$. Symmetrically, when $\varepsilon < 1$ the saving rate is increasing with risk and risk aversion. This situation can be interpreted as *precautionary savings*, while the opposite one ($\varepsilon > 1$) can be interpreted as *precautionary consumption*. The arbitrage between precautionary savings and consumption depends on the relative importance of an income and a substitution effect caused by an increase in risk. When the IES (ε) takes a low-value, aversion to inter-temporal fluctuations ($1/\varepsilon$) is high, in which case a higher risk of a catastrophe (and therefore a higher risk of being poorer) in the future incentivizes some transfers from current to future consumption. This income effect can be more than compensated by a substitution effect when agents are little averse to fluctuations. In this second situation, when capital is more at risk, the incentives to consume rather than accumulate are higher and an increase in risk leads to more consumption in the present at the expense of savings. The role of the inter-temporal elasticity of substitution in determining the link between risk and consumption/savings decisions has been early emphasized by Leland (1968) and Sandmo (1970), and more recently in the case of natural disasters by Müller-Fürstenberger & Schumacher (2015), Bakkensen & Barrage (2016), Bretschger & Vinogradova (2017) and Akao & Sakamoto (2018). However, because they use a time-additive power utility function, these papers cannot disentangle the effect of risk aversion from aversion to fluctuations. The use of non-expected utility enables to clarify these previous results and better identify the role of each parameter. As illustrated by the following comparative statics, we see that the *sign* of the effect of risk on consumption and savings only depends on the value of ε relative to 1 :

$$\frac{\partial \psi}{\partial \lambda} = -A\frac{\partial s^*}{\partial \lambda} = -(1-\varepsilon)(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} \begin{cases} < 0, & \text{if } \varepsilon < 1. \\ \geq 0, & \text{otherwise.} \end{cases}$$

$$\frac{\partial \psi}{\partial \omega} = -A\frac{\partial s^*}{\partial \omega} = (1-\varepsilon)\lambda(1+\delta)\omega^{-\gamma} \begin{cases} > 0, & \text{if } \varepsilon < 1. \\ \leq 0, & \text{otherwise.} \end{cases}$$

while the *magnitude* of this effect positively depends on the risk aversion coefficient γ since (see proof # 1 in the appendix) :

$$\forall \gamma \neq 1, \quad \frac{\partial \frac{1-\omega^{1-\gamma}}{1-\gamma}}{\partial \gamma} = \frac{ln(\omega)\omega^{1-\gamma}(1-\gamma)+(1-\omega^{1-\gamma})}{(1-\gamma)^2} > 0$$

$$\frac{\partial \omega^{-\gamma}}{\partial \gamma} = -ln(\omega)\omega^{-\gamma} > 0$$

Thus, if a low IES implies that precautionary savings dominate over precautionary consumption, a high value of the RRA simply magnifies this effect but does not play on its sign. The restriction imposed by the time-additive expected utility that $\gamma = 1/\varepsilon$ therefore leads to a misinterpretation of the effect of preferences on the relationship between risk and consumption/savings decisions. In the even more special case where both of these parameters converge to 1, (i.e. when utility is logarithmic as in e.g. Golosov et al., 2014) the results further simplify and disasters do not have any effect on agents savings decisions. Thus, even in this simple benchmark, the generalization to Epstein-Zin-Weil preferences already appears useful as it offers a richer characterization of the effects of risk on individuals' decisions.

4.3.3 Optimal growth and the effects of disasters

The previous results suggest that the effect of disaster *risks* on growth is ambiguous. In some situations, higher risk can foster capital accumulation, and thus economic growth. However, even in this case it remains unclear what is the long-run aggregate impact of disaster *risks* and *strikes* on growth. To examine this issue, we first compute the stochastic growth rate of the economy from the law of capital accumulation as stated by equation (4.3) :

$$\begin{aligned}\frac{dC^*}{C} &= (A-\psi)dt + \sigma dz - (1-\omega)dq_t \\ &= \left[\varepsilon(A-\rho) + (1-\varepsilon)\frac{\gamma\sigma^2}{2} + \frac{1-\varepsilon}{1-\gamma}\lambda(1+\delta)(1-\omega^{1-\gamma})\right]dt + \sigma dz - (1-\omega)dq_t\end{aligned} \tag{4.12}$$

The first term in dt is the trend growth rate, and σdz represents the fluctuations around this trend. When the economy is hit by a shock, consumption decreases by $(1-\omega)$. Note that in a deterministic model without shocks, we obtain the standard Keynes-Ramsey formula where A is the marginal return on capital : $(dC/C)^{*det} = \varepsilon[A-\rho]\,dt$. Finally, because $\mathbb{E}(dz) = 0$ and $\mathbb{E}(dq_t) = \lambda(1+\delta)dt$, the expected growth rate of this economy, which is also the average long-run growth rate g^* is :

$$g^* = \mathbb{E}\left(\frac{dC^*}{C}\right) = \left[\varepsilon(A-\rho) + (1-\varepsilon)\frac{\gamma\sigma^2}{2} + \frac{1-\varepsilon}{1-\gamma}\lambda(1+\delta)(1-\omega^{1-\gamma}) - \lambda(1+\delta)(1-\omega)\right]dt \tag{4.13}$$

The previous formula enables to disentangle the effect on growth of disaster *risks*, i.e. the mechanisms through which the anticipation of disasters may affect economic decisions, from the effect of disaster *strikes* captured by the last term of the right-hand side of equation (4.13). The sensitivity of the expected growth rate to disasters can be analyzed by looking at the following comparative statics :

$$\frac{\partial g^*}{\partial \lambda} = (1+\delta)\left[(1-\varepsilon)\frac{1-\omega^{1-\gamma}}{1-\gamma} - (1-\omega)\right]dt \tag{4.14}$$

$$\frac{\partial g^*}{\partial \omega} = \lambda(1+\delta)\left[1-(1-\varepsilon)\omega^{-\gamma}\right]dt \tag{4.15}$$

From these results, the effects of disaster risks and strikes on growth appear clear. Disaster strikes have an obvious negative effect on average long-run growth : when the probability or the intensity of disasters increases — higher λ, lower ω — the expected drop in output due to shocks is larger and so expected growth declines. However, this effect must be weighted against the ambiguous impact of disaster risks on growth. This effect is driven by precautionary savings or consumption, and is therefore positive when $\varepsilon < 1$ and negative otherwise. In both cases, it is magnified for higher values of risk aversion γ. When $\varepsilon < 1$, since precautionary savings need to compensate for the losses caused by disaster strikes, our results show that disasters and growth can be positively linked in the long-run *if and only if* ε is sufficiently small and γ is sufficiently large, i.e. if the economy displays both high risk aversion and high aversion to inter-temporal fluctuations. Although these results are derived at the optimum—and therefore abstract from many potential market failures—they give theoretical support to the empirical findings of Sawada et al. (2011) who found negative effects of disasters on short-run growth, but positive effects in the long-run as was found by Skidmore & Toya (2002) from a cross-sectional analysis. Indeed, when precautionary savings dominate, despite their negative immediate impact disasters may encourage capital accumulation and thus promote growth in the long-run. As noted by Bakkensen & Barrage (2016), whether cross-sectional or panel analysis are used to assess empirically the impact of disasters may affect the results as these methods will essentially capture different effects. While cross-sectional studies may identify the potentially positive effect of disaster risks on growth, studies using panel data with fixed effect identify the negative effect of disaster strikes.

Two last comments deserve attention. First, it should be noted that disasters generate large transfers between generations. These transfers are due both to the impact of disaster risks — that either favor consumption or savings — on the deterministic pattern of growth and to the stochastic realization of disasters. Second, although higher risk may in some situations be growth enhancing, it unambiguously reduces welfare. This result holds even ignoring the impact of disasters on human lives, and considering only their effect on the stock of capital. Thus, and as pointed out by Akao & Sakamoto (2018) and Bakkensen & Barrage (2016), there are cases in which growth and welfare vary with opposite signs as a response to risk. This last result is important to stress as a positive link between disasters and growth *should not* be interpreted as disasters being welfare-improving.

4.4 Disasters of endogenous probability

4.4.1 Specification

In this section we turn to the situation in which resources can be allocated to reduce the risk of disasters through a unique instrument τ (i.e. $m = 1$). In particular, we assume risk-mitigation spending can reduce the *probability* of disasters. The specification is the same as in the previous section, except for f that we now assume to be a function of τ such that $f = 1 + \delta - \tau^{\alpha}$ with $0 < \alpha < 1$ the inverse of the efficiency of risk-mitigation spending [4]. This specification therefore assumes that the probability of a catastrophe depends on the share of output spent in risk-mitigation. If the entire output was spent to mitigate risk, the probability of a shock would fall to $\lambda\delta$, the probability to face a non-avoidable catastrophe. Absent any abatement activity, the probability would go up to $\lambda(1+\delta)$. If the model remains general with respect to the type of disasters considered, one can understand $\lambda(1-\tau^{\alpha})$ as the probability of an environmental disaster, while $\lambda\delta$ corresponds to the probability of non-environmental disasters such as a stock market collapse, a pandemic or a war. Disasters of endogenous probability have been extensively used in the literature, including in several papers by Barro (2009, 2015) and Ikefuji & Horii (2012). As in the previous section, damages will be assumed to be a constant fraction of the capital stock. I show in the appendix that the model can alternatively be solved for disasters of endogenous intensity as done by Müller-Fürstenberger & Schumacher (2015) and Bretschger & Vinogradova (2017), as well as for multiple disasters and multiple instruments. Since these specifications yield similar intuitions, I focus here on the simplest scenario.

4.4.2 Optimal resource allocation

Applying the new specification, the two first order conditions (4.6) and (4.7) together with the HJB equation (4.5) yield :

$$C^* = \psi K \tag{4.16}$$

and :

$$\tau^* = \left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)} \right)^{\frac{1}{1-\alpha}} \tag{4.17}$$

4. Since $0 < \tau < 1$, a lower value of α means more mitigation can be performed with less resources.

with :

$$\psi = \rho\varepsilon + (1-\varepsilon)\left((1-\tau^*)A - \frac{\gamma\sigma^2}{2} - \lambda f^* \frac{(1-\omega^{1-\gamma})}{1-\gamma}\right) \tag{4.18}$$

and consequently the saving rate $s^* = S^*/Y$ is :

$$s^* = 1 - \tau^* - \frac{1}{A}\left[\rho\varepsilon + (1-\varepsilon)\left((1-\tau^*)A - \frac{\gamma\sigma^2}{2} - \lambda f^* \frac{(1-\omega^{1-\gamma})}{1-\gamma}\right)\right] \tag{4.19}$$

As in the previous section, the IES appears to be the critical determinant in the arbitrage between precautionary savings and consumption. Aversion to risk again plays on the magnitude of these effects, but the link now also depends on the effect of risk on risk-mitigation spending. With respect to risk-mitigation, total spending are found to be a constant share of output on the optimal path. The comparative statics below (equations 4.20-4.23) show that the share τ^* is strictly increasing with disaster risk (higher λ, lower ω) and risk aversion (γ), but aversion to fluctuations plays no role :

$$\frac{\partial \tau^*}{\partial \lambda} = \frac{\lambda^{\frac{\alpha}{1-\alpha}}}{1-\alpha}\left(\frac{(1-\omega^{1-\gamma})\alpha}{A(1-\gamma)}\right)^{\frac{1}{1-\alpha}} > 0 \tag{4.20}$$

$$\frac{\partial \tau^*}{\partial \omega} = \frac{-\omega^{-\gamma}}{1-\alpha}\left(\frac{\lambda\alpha}{A}\right)^{\frac{1}{1-\alpha}}\left(\frac{1-\omega^{1-\gamma}}{1-\gamma}\right)^{\frac{\alpha}{1-\alpha}} < 0 \tag{4.21}$$

$$\frac{\partial \tau^*}{\partial \gamma} = \frac{1}{1-\alpha}\left(\frac{\lambda\alpha}{A}\right)^{\frac{1}{1-\alpha}}\left(\frac{1-\omega^{1-\gamma}}{1-\gamma}\right)^{\frac{\alpha}{1-\alpha}}\left(\frac{ln(\omega)\omega^{1-\gamma}(1-\gamma)+(1-\omega^{1-\gamma})}{(1-\gamma)^2}\right) > 0 \tag{4.22}$$

$$\frac{\partial \tau^*}{\partial \alpha} = \left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right)^{\frac{1}{1-\alpha}} \frac{1}{(1-\alpha)^2}\left[ln\left(\frac{(1-\omega^{1-\gamma})\lambda}{A(1-\gamma)}\right) + \frac{1-\alpha}{\alpha}\right] \tag{4.23}$$

Proof # 1 in the appendix shows that the sign of 4.22 is always positive. The only ambiguous effect is the one of the risk-mitigation efficiency parameter α. As shown in the appendix (see proof # 2) for low values α has a positive effect on τ^*, but above a certain threshold $\bar{\alpha}$ its effect becomes negative. This non-monotonic relationship can be interpreted as a trade-off between more incentives to spend resources in mitigation when it is more efficient (substitution effect) against the possibility to mitigate more with less resources as the efficiency increases (level effect).

4.4.3 Optimal growth and the effects of disasters

The law of capital accumulation in equation (4.3) enables again to compute the stochastic growth rate :

$$\frac{dC^*}{C} = [(1-\tau^*)A - \psi]dt + \sigma dz - (1-\omega)dq_t \tag{4.24}$$

and thus the expected growth rate (which is also the average long-run growth rate) of this economy :

$$g^* = \mathbb{E}\left(\frac{dC^*}{C}\right) = [(1-\tau^*)A - \psi - \lambda f^*(1-\omega)]dt \tag{4.25}$$

This formula provides some novel intuitions relative to the one of the previous section. To better understand the new mechanisms at play, one can decompose the effect of disasters on the average long-run growth rate. Differentiating the expected growth rate with respect to λ, we have :

$$\frac{1}{dt}\frac{\partial g^*}{\partial \lambda} = \underbrace{-A\frac{\partial \tau^*}{\partial \lambda}}_{<0} \underbrace{- \frac{\partial \psi}{\partial \lambda}}_{?} \underbrace{- f^*(1-\omega)}_{<0} \underbrace{- \lambda(1-\omega)\frac{\partial f^*}{\partial \lambda}}_{>0} \tag{4.26}$$

and similarly with respect to ω :

$$\frac{1}{dt}\frac{\partial g^*}{\partial \omega} = \underbrace{-A\frac{\partial \tau^*}{\partial \omega}}_{>0} \underbrace{- \frac{\partial \psi}{\partial \omega}}_{?} \underbrace{+ \lambda f^*}_{>0} \underbrace{- \lambda(1-\omega)\frac{\partial f^*}{\partial \omega}}_{<0} \tag{4.27}$$

What do we learn from these comparative statics ? All terms in equations (4.26) and (4.27) are detailed in the appendix. For both equations, the first two terms can be associated with the effect of disaster *risks*, while the last two correspond to the effect of disaster *strikes*. In the following we focus on the second equation, the derivative of expected growth with respect to ω, the share of capital remaining after a catastrophe. This derivative therefore captures the effect on expected growth of a *reduction* in disaster intensity. Similar intuitions can alternatively be derived from the comparative static with respect to λ.

First, when ω increases, disaster strikes become less harmful to the economy as a smaller share of capital $1-\omega$ is destroyed. This effect is captured by the term $\lambda f^* > 0$ in equation (4.27). How much this effect matters solely depends on the frequency of catastrophes. For more frequent disasters, a reduction of their intensity has larger positive effects on expected growth through this damages term. However, the reduction of disaster intensity has a second, indirect effect on expected growth through expected damages. Indeed, as ω increases, less efforts are performed to mitigate risks. As a result, the equilibrium frequency of disasters λf^* increases and so do expected damages. This second effect is captured by the last term in equation (4.27), $-\lambda(1-\omega)\frac{\partial f^*}{\partial \omega} < 0$. A higher value of ω has therefore an ambiguous impact on expected damages since less intense catastrophes also lead to less stringent mitigation policies and thus to more frequent disasters. In particular, an increase in ω will reduce expected damages from disaster strikes if and only if $f^* > (1-\omega)\partial f^*/\partial \omega$. Contrary to the previous section with exogenous disasters, allowing for the possibility to mitigate catastrophes therefore leads to less obvious results as more intense disasters will drive more careful policies and could *in fine*, for some parameter values, reduce expected damages.

Turning to disaster risks, we first see — as in the previous section — that disaster intensity may either favor or dampen growth through the consumption savings decision. This effect is captured by the term $-\partial \psi/\partial \omega$ that, for realistic parameter values, is positive if and only if $\varepsilon > 1$. This result again says that when the IES is above unity, aversion to fluctuations is low and agents are willing to increase their savings when risk is lowered (and alternatively increase current consumption when risk increases). But in addition to the consumption-savings effect, disaster risks now also affect expected growth through the trade-off between risk-mitigation and savings, given by the term $-A\frac{\partial \tau^*}{\partial \omega} > 0$. Indeed, as τ^* is strictly decreasing in ω, for less intense catastrophes less resources are spent to reduce their probability, which leaves more for savings. Thus, while in the case of exogenous disasters risk was fostering growth if and only if $\varepsilon < 1$, this condition is not sufficient anymore when mitigation is possible. Since higher risk now also leads to a transfer from savings to risk-mitigation, a net increase in savings due to risk becomes possible under slightly more restrictive conditions over ε. Thus, the standard result of the disaster literature that takes $\varepsilon < 1$ as a sufficient condition for disasters to foster capital accumulation is not robust to the introduction of endogenous risk-mitigation policies.

Overall, the introduction of an instrument to reduce disaster probability has an ambiguous effect on growth. If some resources are shifted from capital accumulation to risk-mitigation, in the long run this negative effect might be compensated by the reduction of expected damages from disasters. In a different set-up, Ikefuji & Horii (2012) also found an ambiguous effect on growth of introducing a pollution tax to reduce disaster probability. The underlying mechanisms in this model are different than theirs, but these results bring new evidences that the impact of risk-mitigation policies on growth is ambiguous, even though they positively impact welfare.

4.4.4 Disasters and welfare

From the solution obtained for ψ, we can study the marginal effect of disaster parameters on welfare. As Barro (2009), I compute the marginal rate of substitution between proportionate changes in production (Y) and in disaster probability (λ) :

$$-\frac{\partial V(K)}{\partial \lambda}\frac{\partial Y}{\partial V}\frac{1}{Y} = \frac{1}{\psi}\left[(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} - \lambda^{\frac{\alpha}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}\right] \tag{4.28}$$

This expression thus corresponds to the share of production society is willing to give up for a reduction in disaster frequency. Similarly, for disaster intensity we have :

$$-\frac{\partial V(K)}{\partial \omega}\frac{\partial Y}{\partial V}\frac{1}{Y} = -\frac{\omega^{-\gamma}}{\psi}\left[\lambda(1+\delta) - \lambda^{\frac{1}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}}\right] \tag{4.29}$$

In both cases, comparative statics do not provide straightforward results as their sign depends on parameters' value. In the next section, the calibration will enable to discuss further these results.

Beyond the marginal effect of disasters, one can also be interested in the welfare benefits of the policy instrument. Following the method proposed by Lucas (1987, 2003), I denote Γ the permanent increase in consumption (in percentages) that would be necessary in the scenario without policy instrument to make the agent indifferent with the scenario where the instrument is available. Formally, Γ solves :

$$V(K)|_{\tau=\tau^*} = V((1+\Gamma)K)|_{\tau=0} \tag{4.30}$$

As shown in the appendix, taking the expression of the value function we can characterize Γ analytically. If we denote the consumption share of capital on the optimal path with and without policy instrument respectively $\psi_* = \psi|_{\tau=\tau^*}$ and $\psi_0 = \psi|_{\tau=0}$, then we have :

$$\begin{aligned}\Gamma &= \left(\frac{\psi_*}{\psi_0}\right)^{\frac{1}{1-\varepsilon}} - 1 \\ &= \left(1 + \frac{(1-\varepsilon)(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})\left(\frac{\lambda(1-\omega^{1-\gamma})}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}}{\rho\varepsilon + (1-\varepsilon)\left(A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma}\right)}\right)^{\frac{1}{1-\varepsilon}} - 1\end{aligned} \tag{4.31}$$

As $\alpha \in]0;1[$, one can easily show that Γ is increasing with risk (higher λ and σ, lower ω) and risk aversion (γ) and decreasing with the degree of impatience (ρ). The effect of the IES (ε) however is ambiguous and is further discussed in the next section where parameters are calibrated.

4.5 Quantitative assessment

The previous sections have presented the model and shown its numerous implications. The objective of this section is to illustrate these results quantitatively. The calibration of the model should essentially answer three questions. First, if analytic findings have shown that both a positive and a negative effect of disasters on expected growth were both *possible*, one can wonder how *plausible* are each of these two scenarios. In particular, we will try to assess to what extent individuals should have a strong distaste for risk and fluctuations to perform enough precautionary savings to cover the expected output losses from disaster strikes on the optimal path. Second, while disasters have an unambiguous negative impact on welfare, it is important to assess how large these effects are. Third, this calibration should evaluate to what extent using the more restrictive log-utility and time-additive power utility functions affect our understanding of the link between disasters, economic growth, optimal policies and welfare.

4.5.1 Set-up

4.5.1.1 A country/region extension

The main challenge when calibrating a disaster model is to account for both the low probability but large magnitude of these events on the people impacted, and their rather high frequency but small impact at the aggregate level (see for instance Strobl, 2011). Although powerful to explain the equity premium, the extreme environmental disasters of Barro (2015) — that realize on average once every 100 years and destroy 21% of the capital stock — do not match with observed aggregate damages at a country level. The same can be said of the estimates of future global disasters that Pindyck & Wang (2013) infer from market data. In order to reconcile these low probability and large impact events with aggregate data, I therefore slightly extend the model presented in section 4.4. I consider a country composed of H distinct regions. Each region has its own capital stock k^h, so that the country's aggregate capital stock is $K = \sum_{h=1}^{H} k^h$. I assume all regions share the same characteristics, i.e. all parameters are identical, but are subject to local shocks following independent Poisson processes dq_t^h that they mitigate with their own instrument τ^h.[5] All communities therefore solve the same problem, and on the optimal path they differ only by their level of capital k^h and by the timing of the shocks they face. The law of aggregate capital accumulation on the optimal path is thus :

$$\begin{aligned}\frac{dK^*}{K} &= \sum_{h=1}^{H}\frac{dk^{h^*}}{K} = \sum_{h=1}^{H}\frac{(y^h-\tau^h y^h - c^h)^*}{K}dt + \sum_{h=1}^{H}\frac{\sigma_w^{h,*}}{K}dz - \sum_{h=1}^{H}\frac{\sigma_p^{h,*}}{K}dq^h \\ &= [A(1-\tau^*)-\psi]dt + \sigma dz - \sum_{h=1}^{H}\frac{(1-\omega)k^h}{K}dq^h\end{aligned} \tag{4.32}$$

since $\sigma_w^{h,*} = \sigma k^{h,*}$ and $(y^h - \tau^h y^h - c^h)^* = [A(1-\tau^*)-\psi]k^{h,*}$. As in the previous section, the aggregate capital stock grows deterministically at the rate $A(1-\tau^*)-\psi$, and follows fluctuations of size σ. However, it is now subject to shocks of size $(1-\omega)k^h/K$ with a probability $\mathbb{E}(\sum_{h=1}^{H} dq_t^h)/dt = H\lambda f^*$ per unit of time. If there are many regions, then at the aggregate level the probability of a shock is high, but its average magnitude $(1-\omega)/H$ is low.

5. In this country/region context, these instruments can be thought of as local measures to reduce the risks of environmental disasters, such as investments to build dikes to prevent floods, stricter norms for more resilient buildings, etc. Considering small areas, we can assume that efforts to tackle the sources of climate change have a negligible impact.

4.5.1.2 Calibration

The model is calibrated so as to represent the United States, disaggregated at the county level ($H = 3,142$). The U.S. is an interesting case study as it is one of the countries most impacted by natural disasters (Shi et al., 2015). In particular, the U.S. is by far the country most prone to material damages from cyclones : between 1990 and 2016 it has been hit by only 4% of storms worldwide, but accounts for 60% of global tropical cyclones damages (Bakkensen & Mendelsohn, 2016).

The baseline values of the parameters used in the calibration are given in Table 4.5.1. Following Barro (2009) — and consistent with U.S. data — I assume that the marginal return from capital is 6.9%, and the standard deviation of normal shocks 2%. In the main specification I also assume that the coefficient of relative risk aversion is $\gamma = 3$, and the inter-temporal elasticity of substitution is $\varepsilon = 1$. The value of these two parameters is discussed below, and the implications of alternative choices examined, in particular for values of ε above or below unity. The efficiency of the risk-mitigation technology is taken to be $\alpha = 1/4$ such that cutting by two the risk of a disaster would cost around 6% of GDP. As we know relatively little about this parameter, this is of course subject to debate but it should serve as a starting point for our analysis. Finally, as Barro (2009) I set the rate of time preferences in order to match the expected growth rate. I target a rate of 1.75% that will imply a consumption-income ratio of 70%. Thus, the value of ρ should not represent the ethical discount rate discussed in the climate literature, but rather the value that best explains the data. Table 4.E.1 in the appendix reports the corresponding values for various levels of risk and preferences.

In order to calibrate the risk of environmental disasters, I need to infer the probability (λ) and expected intensity ($1 - \omega$) of these events at the county level. Based on observations from 1930 to 2010, Boustan et al. (2017) find that *severe* disasters have occurred on average 0.307 times every decade in each U.S. county.[6] Although some parts of the U.S. are more impacted than others, they stress that disasters are geographically widespread within the country. Based on this evidence, I assume that the *ex ante* probability of an environmental disaster for a given county each year is $\lambda = 3.07\%$. With respect to the magnitude of these disasters, Boustan et al.

6. These are defined as disasters leading to 25 or more deaths in total. Their dataset includes all types of environmental disasters, and are based on the FEMA roster compeleted with other sources for events that occurred prior 1964.

(2017) show that these events result in a decline by 5.2% of housing prices in the counties impacted. Although this number does not perfectly reflect productive capital destruction, it can serve as a useful proxy to calibrate disaster impacts at the county level. Other recent studies have assessed the impact of environmental disasters. Looking at the long-run impact through a reduction of the growth rate, Hsiang & Jina (2014) found that the probability of a cyclone reducing 7.4% of income was 5.8% in countries prone to these events. In China, Elliott et al. (2015) estimate that an average damaging typhoon destroys 1.9% of property values where it strikes, but they report destruction up to 64% for the most extreme events. As explained in FEMA (2010), disaster-related damages largely depend on building types and may therefore differ from a country to another. In addition, the actual losses critically depend on insurance coverage. In order to investigate a larger spectrum of situations, I therefore calibrate two additional scenarios. From the expected damages proxied from Boustan et al. (2017), I consider situations where the probability of a disaster is lower, but their intensity on the people impacted is larger. I will refer to the main calibration as a "Moderate disasters" scenario ($\lambda_M = 3.07\%$, $1 - \omega_M = 5.2\%$), and alternatively consider a second "Large disasters" scenario with $\lambda_L = 1.064\%$ and $1 - \omega_L = 15\%$, and a third "Extreme disasters" scenario with $\lambda_E = 0.3991\%$ and $1 - \omega_E = 40\%$. All three scenarios therefore display identical expected damages, that are more or less spread over time and between agents. Considering these three scenarios enables me to draw the link between the model and both the rather moderate disasters of the empirical literature, and the

TABLE 4.5.1 – PARAMETERS USED IN THE CALIBRATION (MAIN SPECIFICATION).

Parameter	Notation	Value
Risk aversion coefficient	γ	3
Intertemporal elast. of subst.	ε	1
Gross return from capital	A	0.069
Damages from moderate disasters	$1 - \omega_M$	5.2%
Damages from large disasters	$1 - \omega_L$	15%
Damages from extreme disasters	$1 - \omega_E$	40%
Ex ante probability of a moderate env. dis.	λ_M	3.07%
Ex ante probability of a large env. dis.	λ_L	1.064%
Ex ante probability of an extreme env. dis.	λ_E	0.3991%
Ratio non-enviromental / environmental disasters	δ	1
St. dev. of normal shocks per year	σ	2%
Inverse of technology efficiency	α	0.25
Number of regions	H	3,142

more catastrophic events often considered in climate models. From the point of view of empirical research, the later scenarios can also be thought of as more disaggregated cases where we focus on the smaller population of the most impacted people with scarce insurance.

Finally, I set the ratio of non-environmental over environmental disaster probability (δ) to 1 in all three scenarios. This parameter does not bear critical implications here, but this simple benchmark yields a probability of non-environmental disasters ($\delta\lambda = 3.07\%$ in the main scenario) that is consistent with the likelihood that Barro & Ursua (2008) report for such events.

Taking the parameters' values in Table 4.5.1, one can compute the main variables of interest. The results are reported in Table 4.5.2. For the main specification ("Moderate disasters"), we obtain that 70.3% of production should be consumed at each period on the optimal path, and 0.12% spent in risk-mitigation. The effect of such investment is to decrease the probability of an environmental disaster by around a fifth, from 3.07% to 2.51%. Although disasters destroy 5.2% of the capital stock in the counties they hit, on average they represent only 0.0017% of U.S. capital stock and occur in 79 counties each year. The expected yearly aggregate damage — and GDP loss — of environmental disasters is thus 0.13%.

TABLE 4.5.2 – VARIABLES COMPUTED AT PARAMETERS' BASELINE VALUE.

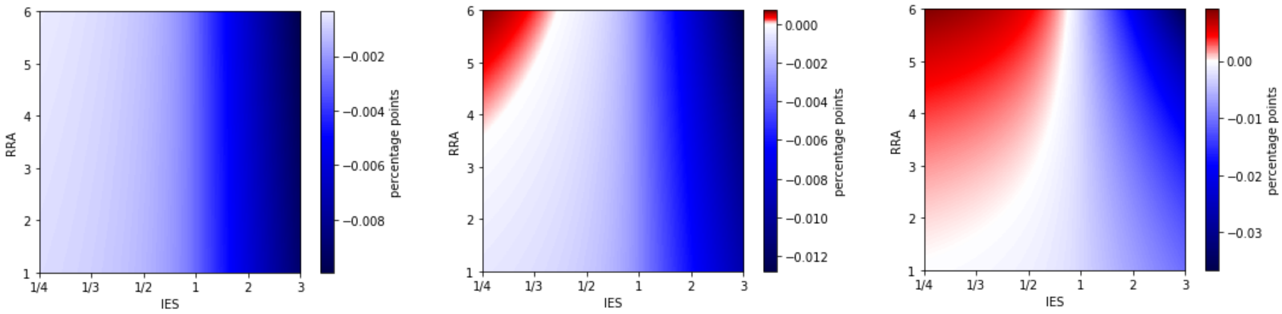
Variable	Notation	Moderate dis.	Large dis.	Extreme dis.
Share of production consumed	ψ/A	70.3%	70.3%	70.3%
Share of production in risk-mitigation	τ^*	0.12%	0.14%	0.30%
Reduction in prob. of an env. disaster	$(\tau^*)^\alpha$	18.4%	19.5%	23.4%
Expected aggregate damages from env. disaster (per year)	$(1-\omega)\lambda[1-(\tau^*)^\alpha]$	0.130%	0.128%	0.122%

4.5.2 How likely is it that disasters foster economic growth?

The literature has not reached a clear consensus over the *true* value of the RRA (γ) and the IES (ε). In an attempt to explain the equity premium puzzle, Mehra & Prescott (1985) argue that a reasonable upper bound for the relative risk aversion coefficient is 10. Barro (2009) shows that within a model displaying rare catastrophic events, a value between 3 and 4 is enough to explain the equity premium, and closer to micro evidences. With respect to the IES, the value is even more debated and there exists contrasted evidences on whether it should be taken as above or below unity. It has been shown by Bansal & Yaron (2004) that in order to explain numerous properties of asset pricing one needs to have simultaneously $\gamma > 1$ and $\varepsilon > 1$, which is at odds with expected utility, and in our case suggests that *precautionary consumption* should be favored in front of higher risks on capital. Yet, most studies on micro data argue that a value of ε lower than unity better represents people's preferences (see Attanasio & Weber, 2010; Havránek, 2015). The choice of high values for both γ and ε is also problematic as it implies an implausibly high timing premium, i.e. individuals' willingness to pay for an earlier resolution of risk becomes too large (see Epstein et al., 2014).

This chapter does not intend to settle this debate. The objective is rather to highlight the implications of the values of these parameters when studying rare catastrophic events within an endogenous growth framework. Figure 4.5.1 plots for the three scenarios and for different values of aversion to risk (γ) and inter-temporal elasticity of substitution (ε) the effect on growth of introducing disasters to the model. That is, it computes the difference between the expected growth rate of the model as calibrated in Table 4.5.1, and the one of the same model with $\lambda = 0$ (or $\omega = 1$). On each figure, the red area is associated with a net positive impact of disasters on expected growth, while the blue area signals a negative impact. When disasters are "moderate", it clearly appears that the values of γ and ε leading to a positive effect of disasters on growth are far beyond what is commonly admitted as plausible in the literature. For "large" disasters, we see that precautionary savings over-compensate the negative impact of disaster strikes for high values of aversion towards risk and fluctuations. For instance, assuming $\gamma = 4$, one could expect disasters to foster growth for $\varepsilon < 0.27$. Although such a value is small compared to standard estimates of the IES, a calibration of a CRRA utility with RRA=1/IES=4 would thus predict a positive impact of "large" disasters on growth. Such a positive effect is obtained for even lower coefficients in the case of "extreme" disasters : assuming again $\gamma = 4$, $\varepsilon < 0.64$ is sufficient to get a positive effect of disasters on expected growth. Interestingly, these results are barely sensitive to the calibration of disaster frequency, although the difference in growth rates is exacerbated in both directions for more frequent events. Expected growth being linear in λ, this parameter affects the relative importance of risk for growth, but quantitatively it has no remarkable effect on the link between preferences and expected growth. However, the results critically depend on the value assigned to disaster intensity. Intuitively, this effect of ω is due to the concavity of the value function which exacerbates the response to disaster risks relative to the impact of disaster strikes for high expected damages.[7]

Figure 4.5.1 – Difference between long-run growth in a disaster vs. disaster free economy.



Moderate dis. Large dis. Extreme dis.

Note : When all parameters are calibrated following Table 4.5.1 except for γ and ε, the expected long-run growth rate is higher in the disaster than in the disaster free economy if and only if γ and ε lie in the red area.

Thus, while in theory *extremely intense*–low probability events could be associated with higher growth rates through precautionary savings, more frequent and less intense disasters should lead to lower growth in this framework. Based on stylized facts derived from the empirical literature, the combination of such extreme risks and high distaste for fluctuations and risk appears unlikely. This evidence suggests that at the optimum in this specific framework precautionary savings may not be sufficient to explain a positive link between disasters and growth as sometimes found in cross-sectional analysis (e.g. Skidmore & Toya, 2002). If this empirical relationship is robust — i.e. not driven by omitted variable bias — future theoretical research should focus on identifying the potential market failures that could explain it, or on other mechanisms such as the role of human capital, endogenous technical progress (as studied in Akao & Sakamoto, 2018), or a potential substitution towards more productive capital.

4.5.3 How much do disasters impact welfare ?

From equations 4.28 and 4.29, we can calculate the marginal rate of substitution between proportionate changes in production and in disaster probability (λ) and intensity (ω). The results are presented in Table 4.5.3 and 4.5.4, that report the values obtained for each of the three

7. The effects of λ and ω can be most easily understood in the case of exogenous disasters by looking at the comparative statics in equations (4.14) and (4.15). In particular, if the derivative of expected growth with respect to ω will always be relatively close to zero because of the term λ factoring the expression, its sign is very sensitive to the value of risk and risk aversion, hence the highly non-linear effect of disaster intensity on precautionary savings.

scenarios, and different levels of risk aversion. In our baseline calibration ($\gamma = 3$) of the "moderate scenario", the coefficient of 2.11 in Table 4.5.3 indicates that to keep welfare constant, an increase by 10% of disaster probability (from 3.07% to 3.377%) would need to be compensated by a permanent increase by 0.65% in production (Y). Considering the "large" disasters and "extreme" disasters scenarios, such 10% increase in disaster probability would need to be compensated by an increase in production by respectively 0.76% and 1.29%. Although expected damages are identical in all three scenarios, the concavity of the utility function implies larger welfare effects for less frequent but more intense events. This difference exacerbates for large values of risk aversion. Thus, while the estimation of the welfare effect of disasters is little sensitive to the choice of the risk aversion parameter for "moderate" events, the calibration of this parameter becomes critical when larger events are considered. For instance, the increase in production necessary to compensate a 10% increase in "extreme" disaster probability is 0.76% assuming log-utility (i.e. $\gamma \to 1$), against 1.29% with a standard calibration of $\gamma = 3$, and 14.69% using an upper bound value of $\gamma = 10$. Interestingly, although the expressions from equations 4.28 and 4.29 depend on ε, as long as the expected growth rate is fixed by adjusting time impatience (ρ) their value is insensitive to the choice of ε. While critical to understand the link between disasters and growth, in this model the IES is therefore irrelevant when it comes to their impact on welfare.

Table 4.5.3 – Marginal rate of substitution between proportionate changes in GDP (Y) and in disaster probability (λ).

	$\gamma \to 1$	$\gamma = 3$	$\gamma = 5$	$\gamma = 10$
Moderate disasters	2.00	2.11	2.22	2.55
Large disasters	6.08	7.14	8.46	13.37
Extreme disasters	19.01	32.38	59.48	368.04

Table 4.5.4 – Marginal rate of substitution between proportionate changes in GDP (Y) and in disaster intensity (ω).

	$\gamma \to 1$	$\gamma = 3$	$\gamma = 5$	$\gamma = 10$
Moderate disasters	-1.21	-1.35	-1.50	-1.95
Large disasters	-0.47	-0.64	-0.89	-1.96
Extreme disasters	-0.25	-0.67	-1.82	-22.26

The calibration of τ^* shows how these marginal effects of disasters on welfare translate into the optimal value of the policy instrument. The values for each of the three scenarios and different levels of risk aversion are reported in Table 4.5.5, while Table 4.5.6 reports Lucas' measure Γ (expressed by equation 4.31) of the total welfare benefits of the policy. Consistent with our previous findings, both τ^* and Γ appear to be larger and more sensitive to the parameterization of risk aversion for disasters of higher magnitude. While a standard calibration $\gamma = 3$ does not make a large difference compared to a logarithmic specification $\gamma \to 1$ for "moderate" disasters, considering "large" and "extreme" events, the benefits of the instrument appear respectively 1.3 and 2.1 times bigger.

TABLE 4.5.5 – OPTIMAL SHARE OF INCOME SPENT IN POLICY INSTRUMENT (τ^*).

	$\gamma \to 1$	$\gamma = 3$	$\gamma = 5$	$\gamma = 10$
Moderate disasters	0.11%	0.12%	0.12%	0.15%
Large disasters	0.12%	0.14%	0.18%	0.34%
Extreme disasters	0.14%	0.30%	0.70%	8.53%

TABLE 4.5.6 – WELFARE BENEFITS OF THE POLICY (Γ).

	$\gamma \to 1$	$\gamma = 3$	$\gamma = 5$	$\gamma = 10$
Moderate disasters	0.46%	0.49%	0.53%	0.64%
Large disasters	0.49%	0.62%	0.78%	1.48%
Extreme disasters	0.62%	1.29%	3.06%	50.36%

In contrast with Lucas (2003) conclusion of low welfare costs from fluctuations, our findings indicate that the benefits from mitigating environmental disasters in the U.S. can be high even ignoring their impact on human lives, although most likely (i.e taking the "moderate disaster" scenario) lower than what Barro (2009) estimates for macroeconomic disasters. These results should raise concerns over the risk of environmental disasters, even more so as Hsiang et al. (2017) predict disaster related damages in the U.S. to be increasing with climate change. Besides the need to mitigate disasters, these results also stress the importance of insurance coverage. Comparing the welfare impact of disasters across scenarios, it clearly appears that spreading the damages would lead to large welfare gains relative to a situation where fewer people are more impacted. As shown by Swiss Re Institute [8], the natural catastrophe protection gap of the

8. http://files.swissre.com/natcat-protection-gap-map/index.html

U.S. amounted to 45% between 2009-2018, leaving almost half of disaster losses uninsured. As part of an adaptation strategy, the improvement of the insurance coverage could thus be very powerful.

4.5.4 Does using Epstein-Zin-Weil preferences matters quantitatively ?

The previous results show that using the restrictive class of time-additive power utility in dynamic stochastic models of disasters may lead not only to qualitative mis-interpretations, but also to potentially large quantitative errors. As it imposes that RRA=1/IES, and because the associated parameters have empirically different values, this constraint implies two potential problems. On the one hand, if one calibrates a CRRA utility assuming RRA=1/IES is in the range of 3–4 to correctly capture risk aversion, he will overestimate the importance of precautionary savings. As shown above, for relatively large disasters, this could lead to wrongly conclude that disasters foster long-run growth. On the other hand, when taking lower values to better match evidences regarding the IES, it leads to underestimate the effect of disasters on welfare and the optimal effort that should be performed to mitigate them. These results confirm that our analytic evidences matter quantitatively. They also bring support to previous studies that introduced Epstein-Zin-Weil utility in Integrated Assessment Models (IAMs) of the climate literature (see Crost & Traeger, 2014; Jensen & Traeger, 2014; Cai & Lontzek, 2018), and showed numerically that it implied a higher carbon price. Although the use of non-expected utility may require intensive computations in these models, the present results suggest that the choice of the utility function should be taken cautiously. As the risks embedded in these models are usually large, the effect on the model's output may be quite important.

4.6 Conclusion

This chapter proposed a stylized model of endogenous growth with endogenous disasters in a framework where individuals exhibit recursive preferences. The model was fully solved analytically, and the numerous mechanisms through which disasters affect growth and welfare were highlighted with an emphasis on how they each depend on preferences for risk on the one side, and inter-temporal fluctuations on the other. The ability to disentangle these two concepts appeared critical as they each play very distinct roles. In a calibration of the model based on empirical evidence about disaster impacts in the U.S., the chapter has shown that the use of non-expected utility also matters quantitatively. While a proper calibration of the model leads to rejecting the hypothesis that precautionary savings may overcompensate losses from disaster strikes, a calibration of a more restrictive CRRA utility with high risk aversion and large disasters would induce the opposite conclusion. In addition, disasters are found to have large welfare impacts, but these effects are also sensitive to the calibration of risk aversion, hence the need to use a flexible framework to correctly calibrate this parameter.

This analysis should be taken as a first step towards a better understanding of the effect of preferences on the link between disasters, growth, and welfare. To keep the model tractable and as intuitive as possible, a certain number of potentially relevant mechanisms have been left aside. In particular, the literature has shown that when facing disasters, the possibility to switch from physical to human capital could have important implications (see Ikefuji & Horii, 2012; Bakkensen & Barrage, 2016; Akao & Sakamoto, 2018). Disasters could also positively impact productivity through a "build back better" effect (Hallegate & Dumas, 2009). The model is also silent about the role of trade as an adaptation mechanism. Finally, if our calibration exercise has shown that insurance could play an important role in mitigating the welfare cost of disasters, deeper modeling of the insurance market (as investigated by Ikefuji & Horii, 2012; Müller-Fürstenberger & Schumacher, 2015) could also provide novel insights. All these fascinating elements should be seen as avenues for future research. Given the important welfare implications of disasters, I believe a lot of efforts are needed to improve our understanding of their link with the economy.

4.A General framework

We assume preferences from consumption can be represented by the following utility function :

$$(1-\gamma)U_t = \left[C_t^{\frac{\varepsilon-1}{\varepsilon}} dt + e^{-\rho dt}\left((1-\gamma)\mathbb{E}U(t+dt)\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}} \tag{4.33}$$

where ρ is the pure rate of time preferences, γ the coefficient of relative risk aversion, and ε the inter-temporal elasticity of substitution. The recursive form of the utility yields the following Hamilton Jacobi Bellman (HJB) equation :

$$(1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}} dt + e^{-\rho dt}\left((1-\gamma)\mathbb{E}V(K_{t+dt})\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}} \tag{4.34}$$

The law of capital accumulation is defined as :

$$dK_t = [Y_t - \sum_{j=1}^{m} \tau_{j,t} Y_t - C_t]dt + \sigma_{w,t} dz - \sum_{i=1}^{n} \sigma_{p,i,t} dq_{i,t} \tag{4.35}$$

where dz is a Wiener process with scaling term σ_w, and $dq_{i,t}$ a Poisson process with endogenous parameter, i.e. $\mathbb{E}dq_{i,t} = \lambda_i f_i dt$ with λ_i a constant and f_i a function of abatement activities to be defined. Shocks are also supposed to be of endogenous size, and we denote $\tilde{K}_i$ the stock of capital after a shock from the i^{th} Poisson process occurred. From the stochastic law of capital accumulation, one can substitute for the expectation term in equation (4.34) using the change of variable formula and Îto's lemma, which yields :

$$\mathbb{E}V(K_{t+dt}) = V(K_t) + \mathbb{E}dV(K_t)$$

$$= V(K_t) + V_k[(1 - \sum_{j=1}^{m} \tau_{j,t})Y_t - C_t] + \frac{1}{2}V_{kk}(\sigma_w dz)^2 + \sum_{i=1}^{n} \mathbb{E}\left(V(\tilde{K}_{i,t}) - V(K_t)\right) dq_{i,t}$$

$$= V(K_t) + V_k[(1 - \sum_{j=1}^{m} \tau_{j,t})Y_t - C_t]dt + \frac{1}{2}V_{kk}\sigma_w^2 dt + \sum_{i=1}^{n} \lambda_i f_i \left(V(\tilde{K}_{i,t}) - V(K_t)\right) dt$$

Substituting back into the HJB equation (4.34) gives :

$$(1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}}dt + e^{-\rho dt}\left((1-\gamma)V(K_t) + (1-\gamma)V_k[(1-\sum_{j=1}^{m}\tau_{j,t})Y - C]dt + (1-\gamma)\frac{1}{2}V_{kk}\sigma_w^2 dt \right.\right.$$
$$\left.\left. + (1-\gamma)\sum_{i=1}^{n}\lambda_i f_i\left(V(\tilde{K_{i,t}}) - V(K_t)\right)dt\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}} \tag{4.36}$$

Then, following the strategy used by Epaulard & Pommeret (2003), we denote :

$$X(K,C,\tau) = V_k[(1-\sum_{j=1}^{m}\tau_{j,t})Y - C] + \frac{1}{2}V_{kk}\sigma_w^2 + \sum_{i=1}^{n}\lambda_i f_i\left(V(\tilde{K_{i,t}}) - V(K_t)\right)$$

where τ is the vector of all τ_j, $j = 1,\ldots,m$. Making use of two approximations when dt is small enough, $e^{-\rho dt} \simeq 1-\rho dt$ and $(1+xdt)^a \simeq 1+axdt$, we have :

$$(1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}}dt + (1-\rho dt)\left((1-\gamma)V(K_t)\left[1+\frac{X(K,C,\tau)dt}{V(K_t)}\right]\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}}$$

$$\Leftrightarrow \quad (1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}}dt + (1-\rho dt)\left((1-\gamma)V(K_t)\right)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\left(\left[1+\frac{\varepsilon-1}{\varepsilon(1-\gamma)}\frac{X(K,C,\tau)dt}{V(K_t)}\right]\right)\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}}$$

$$\Leftrightarrow \quad (1-\gamma)V(K_t) = \max\left[C_t^{\frac{\varepsilon-1}{\varepsilon}}dt + (1-\rho dt)\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right.$$
$$\left. + (1-\rho dt)\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\frac{\varepsilon-1}{\varepsilon(1-\gamma)}\frac{X(K,C,\tau)dt}{V(K_t)}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}}$$

and because $dt^2 = 0$, we can simplify the expression :

$$(1-\gamma)V(K_t) = \max\left[\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\right.$$
$$\left. + \left(C_t^{\frac{\varepsilon-1}{\varepsilon}} - \rho\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}} + \frac{\varepsilon-1}{\varepsilon(1-\gamma)}\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\frac{X(K,C,\tau)}{V(K_t)}\right)dt\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}}$$

$$\Leftrightarrow \quad (1-\gamma)V(K_t) = \max(1-\gamma)V(K_t)$$

$$\times\left[1+\frac{\left(C_t^{\frac{\varepsilon-1}{\varepsilon}}-\rho\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}+\frac{\varepsilon-1}{\varepsilon(1-\gamma)}\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\frac{X(K,C,\tau)}{V(K_t)}\right)dt}{\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}}\right]^{\frac{\varepsilon(1-\gamma)}{\varepsilon-1}}$$

$$\Leftrightarrow\quad 0=\max\frac{\varepsilon(1-\gamma)}{\varepsilon-1}\frac{\left(C_t^{\frac{\varepsilon-1}{\varepsilon}}-\rho\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}+\frac{\varepsilon-1}{\varepsilon(1-\gamma)}\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}\frac{X(K,C,\tau)}{V(K_t)}\right)}{\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}}}$$

$$\Leftrightarrow\quad \rho\frac{\varepsilon(1-\gamma)}{\varepsilon-1}V(K_t)=\max\left[\frac{\varepsilon}{\varepsilon-1}\frac{C_t^{\frac{\varepsilon-1}{\varepsilon}}}{\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}}+X(K,C,\tau)\right]\qquad(4.37)$$

From the previous equation we obtain the following first order conditions with respect to C and τ_j :

$$\frac{C_t^{-\frac{1}{\varepsilon}}}{\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}}+X_C=0\qquad(4.38)$$

$$X_{\tau_j}=0\qquad\forall j\qquad(4.39)$$

with X_C and X_{τ_j} the derivatives of X with respect to C and τ_j, hence :

$$C_t^{-\frac{1}{\varepsilon}}=V_k\left[(1-\gamma)V(K_t)\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}$$

and :

$$YV_k=\sum_{i=1}^{n}\lambda_i\left[f_i\frac{\partial V(\tilde{K}_i)}{\partial\tilde{K}_i}\frac{\partial\tilde{K}_i}{\partial\tau_j}+\frac{\partial f_i}{\partial\tau^j}\left(V(\tilde{K}_i)-V(K)\right)\right]$$

4.B Exogenous disasters

In this section we assume $n=1$ and $m=0$, $\tilde{K}=\omega K$ with ω constant, and $f=(1+\delta)$. We also assume $\sigma_w=\sigma K$ and $Y=AK$. The shape of the problem leads to the following guess for the value function :

$$V(K)=\psi^{\frac{1-\gamma}{1-\varepsilon}}\frac{K^{1-\gamma}}{1-\gamma}$$

with ψ a constant to be determined. Substituting the guess into the first order condition derived in the previous section gives :

$$C^{-\frac{1}{\varepsilon}} = \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{-\gamma} (1-\gamma)^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1} (\psi^{\frac{1-\gamma}{1-\varepsilon}})^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1} (K^{1-\gamma})^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1} (1-\gamma)^{-\frac{\varepsilon-1}{\varepsilon(1-\gamma)}+1} = (\psi K)^{-\frac{1}{\varepsilon}}$$

$$\Leftrightarrow \quad C^* = \psi K$$

In order to check our guess for the value function is correct, we substitute it into the HJB equation and determine the value of ψ that enables to solve the problem. Recall equation (4.37) :

$$\rho \frac{\varepsilon(1-\gamma)}{\varepsilon-1} V(K_t) = \max \left[\frac{\varepsilon}{\varepsilon-1} \frac{C_t^{\frac{\varepsilon-1}{\varepsilon}}}{[(1-\gamma)V(K_t)]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}} + X(K,C) \right]$$

with $X(K,C) = V_k[AK-C] + \frac{1}{2} V_{kk} \sigma_w^2 + \lambda(1+\delta)\left(V(\tilde{K}) - V(K)\right)$ and $V(K) = \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma}$, so that :

$$X(K,C) = \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{-\gamma}[AK - \psi K] - \frac{\gamma\sigma^2}{2} \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma} - \lambda(1+\delta)(1-\omega^{1-\gamma}) \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma}$$

$$= \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} \left[A - \psi - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta) \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right]$$

and :

$$\frac{C_t^{\frac{\varepsilon-1}{\varepsilon}}}{[(1-\gamma)V(K_t)]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}} = \frac{(\psi K)^{\frac{\varepsilon-1}{\varepsilon}}}{\left[\psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma}\right]^{\frac{\varepsilon-1}{\varepsilon(1-\gamma)}-1}} = \psi \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma}$$

Hence, going back to the HJB :

$$\rho \frac{\varepsilon(1-\gamma)}{\varepsilon-1} \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma} = \max \left[\frac{\varepsilon}{\varepsilon-1} \psi \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} + \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} \left[A - \psi - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta) \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right] \right]$$

$$\Leftrightarrow \quad \rho\varepsilon + (1-\varepsilon)A - (1-\varepsilon)\frac{\gamma\sigma^2}{2} - (1-\varepsilon)\lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} = \varepsilon\psi + (1-\varepsilon)\psi = \psi$$

So the only remaining unknown, that is the consumption share of capital on the optimal path, is :

$$\psi = \rho\varepsilon + (1-\varepsilon)\left(A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} \right) \tag{4.40}$$

One can then use the law of capital accumulation defined by equation (4.35) to compute both the optimal saving rate $s^* = S^*/Y$ and the stochastic growth rate of the economy :

$$s^* = \frac{Y - C^*}{Y} = 1 - \frac{\psi}{A} = \frac{1}{A}\left[\varepsilon(A-\rho) + (1-\varepsilon)\left(\frac{\gamma\sigma^2}{2} + \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma}\right)\right]$$

and :

$$\frac{dK^*}{K} = \frac{dC^*}{C} = (A-\psi)dt + \sigma dz - (1-\omega)dq_t$$

$$= \left[\varepsilon(A-\rho) + (1-\varepsilon)\frac{\gamma\sigma^2}{2} + \frac{1-\varepsilon}{1-\gamma}\lambda(1+\delta)(1-\omega^{1-\gamma})\right]dt + \sigma dz - (1-\omega)dq_t$$

Finally, using the fact that $\mathbb{E}(dz) = 0$ and $\mathbb{E}(dq_t) = \lambda(1+\delta)dt$, one can easily recover the expected growth rate and the associated comparative statics with respect to risk and risk aversion. The sign of these expression can easily be determined except for the effect of risk aversion. Indeed, the overall effect of risk aversion on expected growth $g^* = \mathbb{E}(dC^*/C)$ may be positive or negative depending on the value of the IES :

$$\frac{\partial g^*}{\partial \gamma} = (1-\varepsilon)\left(\frac{1}{2} + \lambda(1+\delta)\frac{ln(\omega)\omega^{1-\gamma}(1-\gamma) + (1-\omega^{1-\gamma})}{(1-\gamma)^2}\right)dt \quad \begin{cases} > 0, & \text{if } \varepsilon < 1. \\ \leq 0, & \text{otherwise.} \end{cases}$$

Proof #1 : To show this, let's define $g(\gamma) = ln(\omega)\omega^{1-\gamma}(1-\gamma) + (1-\omega^{1-\gamma})$. First, notice that $g(1) = 0$. Then, if we take the derivative of this function, we have :

$$g'(\gamma) = ln(\omega)\left[-ln(\omega)\omega^{1-\gamma}(1-\gamma) - \omega^{1-\gamma}\right] + ln(\omega)\omega^{1-\gamma}$$

$$= -[ln(\omega)]^2\omega^{1-\gamma}(1-\gamma)$$

Thus, for $\omega > 0$, $g'(\gamma) < 0$ for $\gamma < 1$ and $g'(\gamma) > 0$ for $\gamma > 1$, hence $g(1)$ is a global minimum and

$g(\gamma) > 0$ for $\omega > 0$ and $\gamma \neq 1$. □

4.C Catastrophes of endogenous probability

In this section we turn to disasters of endogenous probability. We keep the assumption that ω is fixed, but we now take $m = 1$ (i.e. there exist one risk-mitigation instrument) and $f = 1 + \delta - \tau^{\alpha}$ with $0 < \alpha < 1$. Production still comes from an AK technology and the Wiener process is still scaled by a standard deviation $\sigma_w = \sigma K$. The general form of the problem being the same as in the previous section, we again make the following guess :

$$V(K) = \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma}$$

Substituting the guess into the two first order conditions, and applying our new specification, we obtain :

$$C^* = \psi K$$

and :

$$AKV_k = \lambda \alpha \tau^{\alpha-1} V(K)(1-\omega^{1-\gamma})$$

$$\Leftrightarrow \quad \tau^* = \left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)} \right)^{\frac{1}{1-\alpha}}$$

It is straightforward to show that τ^* is increasing with λ and γ (see proof #1 above) and decreasing with ω. The effect of α is less obvious, but one can show that τ^* is an increasing function of α if and only if α is below some threshold value $\bar{\alpha}$, and decreasing otherwise.

Proof #2 : Differentiating τ^* with respect to α we get :

$$\frac{\partial \tau^*}{\partial \alpha} = \left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)} \right)^{\frac{1}{1-\alpha}} \frac{1}{(1-\alpha)^2} \left[ln\left(\frac{(1-\omega^{1-\gamma})\lambda}{A(1-\gamma)} \right) + \frac{1-\alpha}{\alpha} \right]$$

we can see that this derivative is negative if and only if $\frac{1-\alpha}{\alpha} < -ln\left(\frac{(1-\omega^{1-\gamma})\lambda}{A(1-\gamma)}\right)$, the right hand side being a positive constant since for credible parameters values the term contained in the log will be below 1. Then, as $0 < \alpha < 1$ it is obvious that for α close to 0 the derivative will be negative, while for α close to 1 it will be positive. Hence, we have a threshold $\bar{\alpha}$ such that :

$$\frac{\partial \tau^*}{\partial \alpha} \begin{cases} > 0 \text{ for } \alpha < \bar{\alpha} \\ < 0 \text{ otherwise} \end{cases}$$

□

We can then solve for ψ. The problem is the same as in the case of exogenous shocks except that now :

$$X(K,C,\tau) = \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} \left[(1-\tau)A - \psi - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta-\tau^{\alpha}) \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right]$$

Hence, going back to the HJB :

$$\rho \frac{\varepsilon(1-\gamma)}{\varepsilon-1} \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma} = \frac{\varepsilon}{\varepsilon-1} \psi \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} + \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} \left[(1-\tau^*)A - \psi - \frac{\gamma\sigma}{2} - \lambda f^* \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right]$$

$$\Leftrightarrow \quad \psi = \rho\varepsilon + (1-\varepsilon)\left((1-\tau^*)A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta-\tau^{*\alpha}) \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right)$$

and finally, substituting for τ^* we get :

$$\psi = \rho\varepsilon + (1-\varepsilon)\left[A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} + (\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}}) \left(\frac{\lambda(1-\omega^{1-\gamma})}{A^{\alpha}(1-\gamma)} \right)^{\frac{1}{1-\alpha}} \right]$$

Lastly, we can compute the optimal saving rate and optimal growth rate of this economy starting from the stochastic law of capital accumulation defined by equation (4.35) :

$$s^* = \frac{Y(1-\tau^*) - C^*}{Y} = 1 - \tau^* - \frac{\psi}{A} = 1 - \tau^* - \frac{1}{A}\left[\rho\varepsilon + (1-\varepsilon)\left((1-\tau^*)A - \frac{\gamma\sigma^2}{2} - \lambda f^* \frac{(1-\omega^{1-\gamma})}{1-\gamma} \right) \right]$$

$$\frac{dK^*}{K} = \frac{dC^*}{C} = [(1-\tau^*)A - \psi]dt + \sigma dz - (1-\omega)dq_t$$

and so the expected growth rate is :

$$g^* = \mathbb{E}\left(\frac{dC^*}{C} \right) = [(1-\tau^*)A - \psi - \lambda f^*(1-\omega)]dt \tag{4.41}$$

We can then compute comparative statics to analyze the incidence of disasters. Differentiating with respect to λ yields :

$$\frac{1}{dt}\frac{\partial g^*}{\partial \lambda} = -A\frac{\partial \tau^*}{\partial \lambda} - \frac{\partial \psi}{\partial \lambda} - f^*(1-\omega) - \lambda(1-\omega)\frac{\partial f^*}{\partial \lambda} \tag{4.42}$$

with :

$$-A\frac{\partial \tau^*}{\partial \lambda} = -A\frac{\lambda^{\frac{\alpha}{1-\alpha}}}{1-\alpha}\left(\frac{(1-\omega^{1-\gamma})\alpha}{A(1-\gamma)}\right)^{\frac{1}{1-\alpha}} < 0$$

$$-\frac{\partial \psi}{\partial \lambda} = (1-\varepsilon)\left[(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} - \lambda^{\frac{\alpha}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}\right] \quad \begin{cases} > 0, & \text{if } \varepsilon < 1. \\ \leq 0, & \text{otherwise.} \end{cases}$$

$$-f^*(1-\omega) = -(1-\omega)\left[1+\delta - \left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}}\right] < 0$$

$$-\lambda(1-\omega)\frac{\partial f^*}{\partial \lambda} = \frac{(1-\omega)\alpha}{1-\alpha}\left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}} > 0$$

and similarly with respect to ω :

$$\frac{1}{dt}\frac{\partial g^*}{\partial \omega} = -A\frac{\partial \tau^*}{\partial \omega} - \frac{\partial \psi}{\partial \omega} + \lambda f^* - \lambda(1-\omega)\frac{\partial f^*}{\partial \omega} \tag{4.43}$$

with :

$$-\frac{\partial \tau^*}{\partial \omega}A = A\left(\frac{\lambda\alpha}{A}\right)^{\frac{1}{1-\alpha}}\frac{\omega^{-\gamma}}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{1-\gamma}\right)^{\frac{\alpha}{1-\alpha}} > 0$$

$$-\frac{\partial \psi}{\partial \omega} = -(1-\varepsilon)\omega^{-\gamma}\left[\lambda(1+\delta) - \lambda^{\frac{1}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}}\right] \quad \begin{cases} < 0, & \text{if } \varepsilon < 1. \\ \geq 0, & \text{otherwise.} \end{cases}$$

$$\lambda f^* = -\lambda(1+\delta) + \lambda\left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}} > 0$$

$$-\lambda(1-\omega)\frac{\partial f^*}{\partial \omega} = -\frac{1-\omega}{1-\alpha}\left(\frac{(1-\omega^{1-\gamma})\lambda\alpha}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}-1}\frac{\lambda^2\alpha^2}{A}\omega^{-\gamma} < 0$$

Finally with respect to welfare, one can start from the expression of the value function :

$V(K) = \psi^{\frac{1-\gamma}{1-\varepsilon}} \frac{K^{1-\gamma}}{1-\gamma}$. Then differentiating with respect to λ, ω and Y, one obtains :

$$-\frac{\partial V(K)}{\partial \lambda}\frac{\partial Y}{\partial V}\frac{1}{Y} = -\frac{\partial \psi}{\partial \lambda}\frac{\psi^{\frac{1-\gamma}{1-\varepsilon}-1}}{1-\varepsilon}K^{1-\gamma}\frac{1}{\psi^{\frac{1-\gamma}{1-\varepsilon}}}\frac{A^{1-\gamma}}{Y^{1-\gamma}} = -\frac{\partial \psi}{\partial \lambda}\frac{1}{(1-\varepsilon)\psi}$$

$$= \frac{1}{\psi}\left[(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma} - \lambda^{\frac{\alpha}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}\right]$$

and :

$$-\frac{\partial V(K)}{\partial \omega}\frac{\partial Y}{\partial V}\frac{1}{Y} = -\frac{\partial \psi}{\partial \omega}\frac{\psi^{\frac{1-\gamma}{1-\varepsilon}-1}}{1-\varepsilon}K^{1-\gamma}\frac{1}{\psi^{\frac{1-\gamma}{1-\varepsilon}}}\frac{A^{1-\gamma}}{Y^{1-\gamma}} = -\frac{\partial \psi}{\partial \omega}\frac{1}{(1-\varepsilon)\psi}$$

$$= -\frac{\omega^{-\gamma}}{\psi}\left[\lambda(1+\delta) - \lambda^{\frac{1}{1-\alpha}}\frac{(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})}{1-\alpha}\left(\frac{1-\omega^{1-\gamma}}{A(1-\gamma)}\right)^{\frac{\alpha}{1-\alpha}}\right]$$

In order to obtain Lucas' measure (Lucas, 1987, 2003) of the welfare benefits from the policy instrument, we again start from the expression of the value function :

$$V(K)|_{\tau=\tau^*} = V((1+\Gamma)K)|_{\tau=0}$$

$$\Leftrightarrow \qquad \psi_*^{\frac{1-\gamma}{1-\varepsilon}}\frac{K^{1-\gamma}}{1-\gamma} = \psi_0^{\frac{1-\gamma}{1-\varepsilon}}\frac{[(1+\Gamma)K]^{1-\gamma}}{1-\gamma} \qquad \Leftrightarrow \qquad \Gamma = \left(\frac{\psi_*}{\psi_0}\right)^{\frac{1}{1-\varepsilon}} - 1$$

and since :

$$\psi_* = \psi_0 + (1-\varepsilon)(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})\left(\frac{\lambda(1-\omega^{1-\gamma})}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}$$

we have :

$$\Gamma = \left(1 + \frac{(1-\varepsilon)(\alpha^{\frac{\alpha}{1-\alpha}} - \alpha^{\frac{1}{1-\alpha}})\left(\frac{\lambda(1-\omega^{1-\gamma})}{A^{\alpha}(1-\gamma)}\right)^{\frac{1}{1-\alpha}}}{\rho\varepsilon + (1-\varepsilon)\left(A - \frac{\gamma\sigma^2}{2} - \lambda(1+\delta)\frac{(1-\omega^{1-\gamma})}{1-\gamma}\right)}\right)^{\frac{1}{1-\varepsilon}} - 1 \qquad (4.44)$$

4.D With multiple catastrophes of endogenous probability and endogenous magnitude

We now turn to the case where the capital stock is subject to shocks coming from two independent Poisson processes (i.e. $n = 2$) with different frequencies and intensities. As in section

4.4, the probability of a shock of type 1 is assumed endogenous to risk-mitigation activities τ_1, and $\mathbb{E}dq_t^1 = \lambda_1 f_1 dt$ with $f_1 = 1+\delta-\tau_1^{\alpha_1}$. Its intensity is again supposed to be a fixed proportion of the capital stock and $\tilde{K}_1 = \omega_1 K_1$. However, we now have an additional process whose probability will be assumed exogenous and simply equal to $\mathbb{E}dq_t^2 = \lambda_2 dt$, but whose intensity will be endogenized. The specification of this second process roughly follows the one proposed by Bretschger & Vinogradova (2017). For simplicity, we abstract from the modelling of pollution as can be found in their paper, and simply assume shocks depend on some adaptation efforts τ_2 such that $\tilde{K}_2 = K-(\nu-\alpha_2\tau_2)K$. We consider τ_2 as the share of production spent in adaptation policies as it enables to reduce the negative impact of disasters but does not reduce their likelihood. The share of capital that remains after a shock is denoted $\omega_2(\tau_2) = 1-\nu+\alpha_2\tau_2$, and ν is therefore the share of capital destroyed by disasters absent any adaptation activity. For simplicity we consider the case without Brownian motion so that $\sigma_w = 0$. As in the previous section, production is derived from an AK technology. Making a similar guess as before, we have :

$$C^* = \psi K \tag{4.45}$$

$$\begin{aligned} AKV_k &= \lambda_1\alpha_1\tau_1^{\alpha_1-1}V(K)(1-\omega_1^{1-\gamma}) \\ \Leftrightarrow \quad \tau_1^* &= \left(\frac{(1-\omega_1^{1-\gamma})\lambda_1\alpha_1}{A(1-\gamma)}\right)^{\frac{1}{1-\alpha_1}} \end{aligned} \tag{4.46}$$

and :

$$\begin{aligned} AKV_k &= \lambda_2\frac{\partial V(\tilde{K}_2)}{\partial\tilde{K}_2}\frac{\partial\tilde{K}_2}{\partial\tau_2} = \lambda_2\omega_2^{-\gamma}V_k\alpha_2 K \\ \Leftrightarrow \quad \omega_2^* &= \omega_2(\tau_2^*) = \left(\frac{\lambda_2\alpha_2}{A}\right)^{\frac{1}{\gamma}} \end{aligned} \tag{4.47}$$

hence :

$$\tau_2^* = \frac{\omega_2^*-(1-\nu)}{\alpha_2} \tag{4.48}$$

The expression of τ_1^* remains the same as in section 4.4. Interestingly, the adaptation policy τ_2^* solely depends on the efficiency of the technology α_2, and on the difference between the share of capital remaining after catastrophes at equilibrium, ω_2^*, relative to the case absent adaptation policies, $1-\nu$. The share of capital preserved at equilibrium depends positively on the probability of an adverse event λ_2, on the efficiency of adaptation technology α_2, and negatively on the interest rate A. Given that $0 < (\lambda_2\alpha_2)/A < 1$, risk aversion γ also plays positively on ω_2^*. Thus, as for the first instrument τ_1^*, risk and risk aversion positively affect the optimal instrument τ_2^*, but the efficiency of the instrument α_2 has an ambiguous effect.

Given the independence of the two catastrophes and of the two instruments, the share of output that should optimally be spent to mitigate each catastrophe is not affected by the existence of the other. Contrary to Martin & Pindyck (2015) who investigate the binary decision to undertake a project to avert or not a catastrophe when facing multiple types of disasters, standard cost-benefit analysis holds in this framework. For each catastrophe, the marginal cost of mitigation efforts should equate the marginal benefits of reducing this specific catastrophe. However, because each catastrophe impacts the trajectory of output, the amounts of resources spent in each instrument $\tau_1^* Y_t$ and $\tau_2^* Y_t$ depend on the *existence* and *realization* of other catastrophes as well. The full trajectory of output Y_t can be determined applying similar methods than the ones used in the previous specifications. With :

$$X(K,C,\tau) = \psi^{\frac{1-\gamma}{1-\varepsilon}} K^{1-\gamma} \left[(1-\tau_1-\tau_2)A - \psi - \lambda_1(1+\delta-\tau_1^{\alpha_1}) \frac{(1-\omega_1^{1-\gamma})}{1-\gamma} - \lambda_2 \frac{(1-(\omega_2^*)^{1-\gamma})}{1-\gamma} \right]$$

we find :

$$\psi = \rho\varepsilon + (1-\varepsilon)\left((1-\tau_1^*-\tau_2^*)A - \lambda(1+\delta-(\tau_1^*)^{\alpha}) \frac{(1-\omega^{1-\gamma})}{1-\gamma} - \lambda_2 \frac{(1-(\omega_2^*)^{1-\gamma})}{1-\gamma} \right)$$

Once ψ is obtained, one can easily plug this result into the stochastic law of motion of capital and compute the stochastic and expected growth rate of this economy. The results provide similar intuitions to the ones discussed in section 4.4.

4.E Calibration

TABLE 4.E.1 – CALIBRATION OF TIME IMPATIENCE (ρ) TO MATCH A 1.75% EXPECTED GROWTH RATE (g^*).

		Moderate dis.	Large dis.	Extreme dis.
ε	γ			
1/3	$\to 1$	0.014	0.014	0.016
1/3	3	0.015	0.016	0.022
1/3	5	0.016	0.019	0.033
1/3	10	0.019	0.026	0.135
$\to 1$	$\to 1$	0.049	0.049	0.049
$\to 1$	3	0.049	0.049	0.048
$\to 1$	5	0.049	0.049	0.048
$\to 1$	10	0.049	0.048	0.043
1.5	$\to 1$	0.054	0.054	0.054
1.5	3	0.054	0.054	0.053
1.5	5	0.054	0.054	0.051
1.5	10	0.053	0.052	0.028

Bibliographie

Jan Abrell, Mirjam Kosch, & Sebastian Rausch. How Effective Was the UK Carbon Tax ? — A Machine Learning Approach to Policy Evaluation. CER-ETH Economics working paper series 19/317, CER-ETH - Center of Economic Research (CER-ETH) at ETH Zurich, April 2019.

ADEME. Représentations sociales de l'effet de serre. Technical report, 2018.

Ken-Ichi Akao & Hiroaki Sakamoto. A theory of disasters and long-run growth. *Journal of Economic Dynamics and Control*, 95 :89–109, 2018.

Anna Alberini, Andrea Bigano, Milan Ščasný, & Iva Zvěřinová. Preferences for Energy Efficiency vs. Renewables : What Is the Willingness to Pay to Reduce CO2 Emissions ? *Ecological Economics*, 144, February 2018.

Alberto Alesina, Stefanie Stantcheva, & Edoardo Teso. Intergenerational Mobility and Preferences for Redistribution. *American Economic Review*, 108(2) :521–554, February 2018.

Yann Algan, Elizabeth Beasley, Daniel Cohen, Martial Foucault, & Madeleine Péron. Qui sont les gilets jaunes et leurs soutiens ? Technical report, CEPREMAP et CEVIPOF, 2019.

Soren Anderson, Ioana Elena Marinescu, & Boris Shor. Can Pigou at the Polls Stop US Melting the Poles ? Working Paper 26146, National Bureau of Economic Research, August 2019.

Julius J. Andersson. Carbon taxes and co2 emissions : Sweden as a case study. *American Economic Journal : Economic Policy*, 11(4) :1–30, 2019.

Orazio Attanasio & Guglielmo Weber. Consumption and saving : Models of intertemporal allocation and their implications for public policy. *Journal of Economic Literature*, 48(3) :693–751, 2010.

Shahzeen Z. Attari, Mary Schoen, Cliff I. Davidson, Michael L. DeKay, Wändi Bruine de Bruin, Robyn Dawes, & Mitchell J. Small. Preferences for change : Do individuals prefer voluntary actions, soft regulations, or hard regulations to decrease fossil fuel consumption ? *Ecological Economics*, 68(6) :1701 – 1710, 2009.

Emmanuelle Augeraud-Véron, Fabbri Giorgio, & Katheline Schubert. The value of biodiversity as an insurance device. Working Papers hal-01779333, HAL, Apr 2018.

Laura Bakkensen & Lint Barrage. Do disasters affect growth ? A macro model-based perspective on the empirical debate. Working paper, Brown University, 2016.

Laura A. Bakkensen & Robert Mendelsohn. Risk and adaptation : Evidence from global hurricane damages and fatalities. *Journal of the Association of Environmental and Resource Economists*, 3(3) :555 – 587, 2016.

James Banks, Richard Blundell, & Arthur Lewbel. Quadratic engel curves and consumer demand. *The Review of Economics and Statistics*, 79(4) :527–539, nov 1997.

Ravi Bansal & Marcelo Ochoa. Temperature, aggregate risk, and expected returns. Working Paper 17575, National Bureau of Economic Research, 2011.

Ravi Bansal & Amir Yaron. Risks for the long run : A potential resolution of asset pricing puzzles. *Journal of Finance*, 59(4) :1481–1509, 2004.

Ravi Bansal, Marcelo Ochoa, & Dana Kiku. Climate change and growth risks. Working Paper 23009, National Bureau of Economic Research, 2016.

Andrea Baranzini & Stefano Carattini. Effectiveness, earmarking and labeling : testing the acceptability of carbon taxes with survey data. *Environmental Economics and Policy Studies*, 19 (1) :197–227, January 2017.

Robert Barro. Rare disasters and asset markets in the twentieth century. *The Quaterly Journal of Economics*, 121(3) :823–866, 2006.

Robert Barro. Rare disasters, asset prices, and welfare costs. *American Economic Review*, 99(1) : 243–264, 2009.

Robert Barro. Environmental protection, rare disasters and discount rates. *Economica*, 82 :1–23, 2015.

Robert Barro & José Ursua. Macroeconomic crises since 1870. *Brookings Papers on Economic Activity*, pages 255–335, 2008.

William J. Baumol & Wallace E. Oates. The use of standards and prices for protection of the environment. *The Swedish Journal of Economics*, 73(1) :42–54, 1971.

Liam F. Beiser-McGrath & Thomas Bernauer. Could revenue recycling make effective carbon taxation politically feasible ? *Science Advances*, 5(9) :eaax3323, September 2019.

Mahdi Ben Jelloul, Antoine Bozio, Thomas Douenne, Brice Fabre, & Claire Leroy. Budget 2019 : quels effets pour les ménages ? *Notes IPP*, (37), January 2019.

Roland Bénabou & Jean Tirole. Mindful Economics : The Production, Consumption, and Value of Beliefs. *Journal of Economic Perspectives*, 30(3) :141–164, August 2016.

Yoav Benjamini & Yosef Hochberg. Controlling the False Discovery Rate : A Practical and Powerful Approach to Multiple Testing. *Journal of the Royal Statistical Society : Series B (Methodological)*, 57(1), 1995.

Antonio Bento, Lawrence Goulder, Mark Jacobsen, & Roger von Haefen. Distributional and efficiency impacts of increased us gasoline taxes. *American Economic Review*, 99(3) :667–699, nov 2009.

Antonio M. Bento & Mark Jacobsen. Ricardian rents, environmental policy and the 'double-dividend' hypothesis. *Journal of Environmental Economics and Management*, 53(1) :17 – 31, 2007.

Robert P. Berrens, Alok K. Bohara, Hank C. Jenkins-Smith, Carol L. Silva, & David L. Weimer. Information and effort in contingent valuation surveys : application to global climate change using national internet samples. *Journal of Environmental Economics and Management*, 47(2) : 331–363, March 2004.

Audrey Berry. The distributional effects of a carbon tax and its impact on fuel poverty : A microsimulation study in the french context. *Energy Policy*, 124 :81–94, 2019.

Antoine Bommier, Asen Koshov, & François Le Grand. On monotone recursive preferences. *Econometrica*, 85(5) :1433–1466, 2017.

Nicholas Bornstein & Bruno Lanz. Voting on the environment : Price or ideology ? evidence from swiss referendums. *Ecological Economics*, 67(3) :430–440, 2008.

François Bourguignon & Amadeo Spadaro. Microsimulation as a tool for evaluating redistribution policies. *The Journal of Economic Inequality*, 4(1) :77–106, Apr 2006.

Leah Platt Boustan, Matthew E Kahn, Paul W Rhode, & Maria Lucia Yanguas. The effect of natural disasters on economic activity in us counties : A century of data. Working Paper 23410, National Bureau of Economic Research, May 2017.

A. Lans Bovenberg & Ruud A. de Mooij. Environmental levies and distortionary taxation. *The American Economic Review*, 84(4) :1085–1089, 1994a.

Lans Bovenberg & Ruud de Mooij. Environmental taxes and labor-market distortions. *European Journal of Political Economy*, 10(4) :655 – 683, 1994b.

Lans Bovenberg & Frederick van der Ploeg. Optimal taxation, public goods and environmental policy with involuntary unemployment. *Journal of Public Economics*, 62(1) :59 – 83, 1996.

Pierre C. Boyer, Thomas Delemotte, Germain Gauthier, Vincent Rollet, & Benoît Schmutz. Les déterminants de la mobilisation des Gilets jaunes. *Revue économique*, 71, 2020.

Runar Brannlund & Lars Persson. To tax, or not to tax : preferences for climate policy attributes. *Climate Policy*, 12(6) :704–721, November 2012.

Steven Brechin. Public opinion : a cross-national view. In *Handbook of Climate Change and Society*. Routledge, lever-tracy, constance edition, 2010. ISBN 978-1-135-99850-9.

Pierre Bréchon, Frédéric Gonthier, & Sandrine Astor. *La France des valeurs. Quarante ans d'évolutions*. Broché, presses universitaires de grenoble edition, 2019.

Jack W. Brehm. *A theory of psychological reactance*. A theory of psychological reactance. Academic Press, Oxford, England, 1966.

Lucas Bretschger & Alexandra Vinogradova. Best policy response to environmental shocks : Applying a stochastic framework. *Journal of Environmental Economics and Management*, 2017.

Abigail L. Bristow, Mark Wardman, Alberto M. Zanni, & Phani K. Chintakayala. Public acceptability of personal carbon trading and carbon tax. *Ecological Economics*, 69(9) :1824–1837, July 2010.

Robert J. Brulle, Jason Carmichael, & J. Craig Jenkins. Shifting public opinion on climate change : an empirical assessment of factors influencing concern over climate change in the U.S., 2002–2010. *Climatic Change*, 114(2) :169–188, September 2012.

Benjamin Bureau. Distributional effects of a carbon tax on car fuels in france. *Energy Economics*, 33 :121–130, 2011.

Dominique Bureau, Fanny Henriet, & Katheline Schubert. Pour le climat : une taxe juste, pas juste une taxe. *Les notes du conseil d'analyse économique*, (50) :12, 2019.

Marshall B. Burke, Edward Miguel, Shanker Satyanath, John A. Dykema, & David B. Lobell. Warming increases the risk of civil war in africa. *Proceedings of the National Academy of Sciences*, 106(49) :20670–20674, 2009.

Yongyang Cai & Thomas S. Lontzek. The social cost of carbon with economic and climate risks. *Journal of Political Economy*, 2018.

Colin Camerer & Robin Hogarth. The Effects of Financial Incentives in Experiments : A Review and Capital-Labor-Production Framework. *Journal of Risk and Uncertainty*, 19 :7–42, 1999.

Trudy Ann Cameron. Individual option prices for climate change mitigation. *Journal of Public Economics*, 89(2) :283–301, February 2005.

Stuart Capstick, Lorraine Whitmarsh, Wouter Poortinga, Nick Pidgeon, & Paul Upham. International trends in public perceptions of climate change over the past quarter century. *Wiley Interdisciplinary Reviews : Climate Change*, 6(1) :35–61, 2015.

Stefano Carattini, Andrea Baranzini, Philippe Thalmann, Frédéric Varone, & Frank Vöhringer. Green Taxes in a Post-Paris World : Are Millions of Nays Inevitable ? *Environmental and Resource Economics*, 68(1) :97–128, September 2017.

Stefano Carattini, Maria Carvalho, & Sam Fankhauser. Overcoming public resistance to carbon taxes. *Wiley Interdisciplinary Reviews : Climate Change*, 9(5) :e531, 2018.

Clément Carbonnier. Who pays sales taxes ? evidence from french vat reform 1987-1999. *Journal of Public Economics*, 91 :1219–1229, 2007.

Eduardo Cavallo, Sebastian Galiani, Ilan Noy, & Juan Pantano. Catastrophic natural disasters and economic growth. *Review of Economics and Statistics*, 95(5) :1549–1561, 2013.

CGDD. France National Low-Carbon Strategy. Technical report, Ministry of Ecology, 2015.

CGDD. Chiffres clés du climat France, Europe et Monde. Technical report, 2019.

Ujjayant Chakravorty, Bertrand Magné, & Michel Moreaux. A hotelling model with a ceiling on the stock of pollution. *Journal of Economic Dynamics and Control*, 30(12) :2875 – 2904, 2006.

Raphaël Challier. Rencontres aux ronds-points. *La Vie des idées*, February 2019.

Todd L. Cherry, Steffen Kallbekken, & Stephan Kroll. Accepting market failure : Cultural worldviews and the opposition to corrective environmental policies. *Journal of Environmental Economics and Management*, 85 :193–204, September 2017.

Mireille Chiroleu-Assouline. Le double dividende. les approches théoriques. 2001.

Marie Clerc & Vincent Marcus. Elasticité-prix des consommations énergétiques des ménages. Technical report, Insee, sep 2009.

DARA Climate Vulnerable Forum. Climate Vulnerability Monitor. Technical report, 2012.

Mathilde Closset, Sosso Feindouno, Patrick Guillaumont, & Catherine Simonet. A Physical Vulnerability to Climate Change Index : Which are the most vulnerable developing countries ? *FERDI Working Paper*, page 37, 2018.

R. H. Coase. The problem of social cost. *The Journal of Law & Economics*, 3 :1–44, 1960.

Emmanuel Combet, Frédéric Ghersi, & Jean-Charles Hourcade. Taxe carbone, une mesure socialement régressive. vrais problèmes et faux débats. 2009.

Julie Anne Cronin, Don Fullerton, & Steven Sexton. Vertical and Horizontal Redistributions from a Carbon Tax and Rebate. *Journal of the Association of Environmental and Resource Economists*, 6(S1) :169–208, 2019.

Benjamin Crost & Christian Traeger. Optimal co2 mitigation under damage risk valuation. *Nature Climate Change*, 4(7) :631, 2014.

Guillermo Cruces, Ricardo Perez-Truglia, & Martin Tetaz. Biased perceptions of income distribution and preferences for redistribution : Evidence from a survey experiment. *Journal of Public Economics*, 98 :100–112, February 2013.

Lucas W. Davis & Christopher R. Knittel. Are fuel economy standards regressive ? *Journal of the Association of Environmental and Resource Economists*, 6(S1) :S37–S63, 2019.

Judith I.M. de Groot & Geertje Schuitema. How to make the unpopular popular ? policy characteristics, social norms and the acceptability of environmental policies. *Environmental Science and Policy*, 19-20 :100 – 107, 2012.

Angus Deaton & John Muelbauer. An almost ideal demand system. *American Economic Review*, 70(3) :312–336, 1980b.

Melissa Dell, Benjamin F. Jones, & Benjamin A. Olken. Temperature shocks and economic growth : Evidence from the last half century. *American Economic Journal : Macroeconomics*, 4(3) :66–95, July 2012.

José-Frédéric Deroubaix & François Lévèque. The rise and fall of French Ecological Tax Reform : social acceptability versus political feasibility in the energy tax implementation process. *Energy Policy*, 34(8) :940–949, May 2006.

Olivier Deschênes & Michael Greenstone. Climate change, mortality, and adaptation : Evidence from annual fluctuations in weather in the us. *American Economic Journal : Applied Economics*, 3(4) :152–85, October 2011.

Xavier d'Haultfoeuille, Isis Durrmeyer, & Philippe Février. Le coût du bonus/malus écologique. Que pouvait-on prédire ? *Revue économique*, 62(3) :491–499, 2011.

Terry Dinan. Offsetting a carbon tax's costs on low-income households. Technical report, Congressional Budget Office Working Paper, November 2012.

Marcello D'Orazio, Marco Di Zio, & Mauro Scanu. *Statistical matching : Theory and practice*. Wiley, Chichester, 2006b.

Thomas Douenne. Les effets redistributifs de la fiscalité carbone en france. *Note IPP*, (34), 2018.

Thomas Douenne. The vertical and horizontal distributive effects of energy taxes : A case study of a french policy. *The Energy Journal*, forthcoming.

Thomas Douenne & Adrien Fabre. Opinions des français sur les politiques climatiques. *Document de travail du Cepremap*, (1906), 2019a.

Thomas Douenne & Adrien Fabre. Can We Reconcile French People with the Carbon Tax ? Disentangling Beliefs from Preferences. *FAERE Working Paper*, 2019b.

Thomas Douenne & Adrien Fabre. French attitudes on climate change, carbon taxation and other climate policies. *Ecological Economics*, 169(C), 2020.

Simon Dresner, Louise Dunne, Peter Clinch, & Christiane Beuermann. Social and political responses to ecological tax reform in Europe : an introduction to the special issue. *Energy Policy*, 34(8) :895–904, May 2006a.

Simon Dresner, Tim Jackson, & Nigel Gilbert. History and social responses to environmental tax reform in the United Kingdom. *Energy Policy*, (8) :930–939, May 2006b.

Stefan Drews & Jeroen van den Bergh. What explains public support for climate policies ? a review of empirical and experimental studies. *Climate Policy*, 16(7) :855–876, 2016.

James N. Druckman & Mary C. McGrath. The evidence for motivated reasoning in climate change preference formation. *Nature Climate Change*, 9(2) :111–119, February 2019.

Darrell Duffie & Larry Epstein. Stochastic differential utility. *Econometrica*, 60(2) :353–394, 1992.

Phillip J. Ehret, Leaf Van Boven, & David K. Sherman. Partisan Barriers to Bipartisanship : Understanding Climate Policy Polarization. *Social Psychological and Personality Science*, 9(3) : 308–318, April 2018.

Robert Elliott, Eric Strobl, & Puyang Sun. The local impact of typhoons on economic activity in china : A view from outer space. *Journal of Urban Economics*, 88(C) :50–66, 2015.

Anne Epaulard & Aude Pommeret. Recursive utility, endogenous growth and the welfare cost of volatility. *Review of Economic Dynamics*, 6(3) :672–684, 2003.

Larry Epstein & Stanley Zin. Substitution, risk aversion and the temporal behavior of consumption ans asset returns : A theoretical framework. *Econometrica*, 57(4) :937–969, 1989.

Larry G. Epstein, Emmanuel Farhi, & Tomasz Strzalecki. How much would you pay to resolve long-run risk ? *American Economic Review*, 104(9) :2680–97, September 2014.

James A. Espey & Molly Espey. Turning on the lights : A meta-analysis of residential electricity demand elasticities. *Journal of Agricultural and Applied Economics*, 36(1) :65–31, april 2004.

Molly Espey. Explaining the variation in elasticity estimates of gasoline demand in the united states : A meta-analysis. *The Energy Journal*, 17(3) :49–60, 1996.

Emmanuel Farhi & Xavier Gabaix. Optimal taxation with behavioral agents. *American Economic Review*, 2020.

FEMA. HAZUS-MH MR5 Technical Manual. Technical report, Washington, DC., 2010.

Anke Fischer, Vera Peters, Jan Vávra, Mirjam Neebe, & Boldizsár Megyesi. Energy use, climate change and folk psychology : Does sustainability have a chance ? results from a qualitative study in five european countries. *Global Environmental Change*, 21(3) :1025 – 1034, 2011.

Florens Flues & Alastair Thomas. The distributional effects of energy taxes. Technical Report 23, OCDE Taxation Working Papers, 2015.

Jaume Freire-González. Environmental taxation and the double dividend hypothesis in CGE modelling literature : A critical review. *Journal of Policy Modeling*, 40(1) :194–223, 2018.

Cary Funk & Brian Kennedy. The Politics of Climate. *Pew Research Center*, page 114, 2016.

Xavier Gabaix. Variable rare disasters : An exactly solved framework for ten puzzles in macro-finance. *The Quarterly Journal of Economics*, 127(2) :645–700, 2012.

Z. Eylem Gevrek & Ayse Uyduranoglu. Public preferences for carbon tax attributes. *Ecological Economics*, 118 :186–197, October 2015.

Edward L. Glaeser & Matthew E. Kahn. The greenness of cities : Carbon dioxide emissions and urban development. *Journal of Urban Economics*, 67(3) :404–418, May 2010.

Christian Gollier. *Pricing the Planet's Future : The Economics of Discounting in an Uncertain World*. Princeton University Press, 2013.

Russell Golman, George Loewenstein, Karl Ove Moene, & Luca Zarri. The Preference for Belief Consonance. *Journal of Economic Perspectives*, 30(3) :165–188, August 2016.

Mikhail Golosov, John Hassler, Per Krusell, & Aleh Tsyvinksi. Optimal taxes on fossil fuel in general equilibrium. *Econometrica*, 82(1) :41–88, 2014.

Lawrence Goulder & Ian Parry. Instrument choice in environmental policy. *Review of Environmental Economics and Policy*, 2(2) :152–174, 2008.

Lawrence H. Goulder. Environmental taxation and the double dividend : A reader's guide. *International Tax and Public Finance*, 2 :157 – 183, 1995.

Lawrence H. Goulder, Ian W.H. Parry, Roberton C. Williams, & Dallas Burtraw. The cost-effectiveness of alternative instruments for environmental protection in a second-best setting. *Journal of Public Economics*, 72(3) :329 – 360, 1999.

Joshua Graff Zivin, Solomon M. Hsiang, & Matthew Neidell. Temperature and human capital in the short and long run. *Journal of the Association of Environmental and Resource Economists*, 5(1) :77–105, 2018.

Corbett Grainger & Charles Kolstad. Who pays a price on carbon. *Environmental and Resource Economics*, 46(3) :359–376, 2010.

Patrick Guillaumont. Measuring vulnerability to climate change for allocating funds for adaptation. In *Towards a Workable and Effective Climate Regime*. CEPR Press, scott barett, carlo carraro and jaime de melo edition, 2015.

Stéphane Hallegate & Patrice Dumas. Can natural disasters have positive consequences ? investigating the role of embodied technical change. *Ecological Economics*, 68(3) :777–786, 2009.

James Hammitt. Are the costs of proposed environmental regulations overestimated ? evidence from the cfc phaseout. *Environmental and Resource Economics*, 16(3) :281–302, 2000.

Bill Hampel, Jennifer Boldero, & Roger Holdsworth. Gender patterns in environmental consciousness among adolescents. *The Australian and New Zealand Journal of Sociology*, 32 (1) :58–71, March 1996.

W. Michael Hanemann. Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses. *American Journal of Agricultural Economics*, 66(3) :332–341, 1984.

L. P. Hansen & T. J. Sargent. Discounted linear exponential quadratic gaussian control. *IEEE Transactions on Automatic Control*, 40(5) :968–971, 1995.

Niklas Harring & Sverker C. Jagers. Should We Trust in Values ? Explaining Public Support for Pro-Environmental Taxes. *Sustainability*, 5(1) :1–18, 2013.

Bard Harstad. Pledge-and-review bargaining : from kyoto to paris. Working paper, 2020.

Tomáš Havránek. Measuring Intertemporal Substitution : The Importance of Method Choices and Selective Reporting. *Journal of the European Economic Association*, 13(6) :1180–1204, 12 2015.

Ray Hilborn, Orensanz J. M. (Lobo), & Ana M. Parma. Institutions, incentives and the future of fisheries. *Phil. Trans. R. Soc. B*, 360 :47–57, 2005.

Stefan Hoderlein & Sonya Mihaleva. Increasing the price variation in a repeated cross section. *Journal of Econometrics*, 147 :316–325, 2008.

Imke Hoppe, Monika Taddicken, & Anne Reif. What do people know about climate change — and how confident are they ? On measurements and analyses of science related knowledge. *Journal of Science Communication (Jcom)*, 17(3) :1–26, July 2018.

Carl I. Hovland, Irving L. Janis, & Harold H. Kelley. *Communication and persuasion ; psychological studies of opinion change*. Communication and persuasion ; psychological studies of opinion change. Yale University Press, New Haven, CT, US, 1953.

Solomon Hsiang, Robert Kopp, Amir Jina, James Rising, Michael Delgado, Shashank Mohan, D.J. Rasmussen, Robert Muir-Wood, Paul Wilson, Michael Oppenheimer, Kate Larsen, & Trevor Houser. Estimating economic damage from climate change in the united states. *Science*, 356 :1362–1369, 2017.

Solomon M. Hsiang & Amir S. Jina. The Causal Effect of Environmental Catastrophe on Long-Run Economic Growth : Evidence From 6,700 Cyclones. NBER Working Papers 20352, National Bureau of Economic Research, Inc, July 2014.

Shi-Ling Hsu, Joshua Walters, & Anthony Purgas. Pollution tax heuristics : An empirical study of willingness to pay higher gasoline taxes. *Energy Policy*, 36(9) :3612–3619, 2008.

Masako Ikefuji & Ryo Horii. Natural disasters in a two-sector model of endogenous growth. *Journal of Public Economics*, 96 :784–796, 2012.

IPCC. AR5 Climate Change 2014 : Mitigation of Climate Change (section 7.8.1). Technical report.

Mark R. Jacobsen. Evaluating us fuel economy standards in a model with producer and household heterogeneity. *American Economic Journal : Economic Policy*, 5(2) :148–87, May 2013.

Jesse D. Jenkins. Political economy constraints on carbon pricing policies : What are the implications for economic efficiency, environmental efficacy, and climate policy design ? *Energy Policy*, 69 :467–477, June 2014.

Svenn Jensen & Christian Traeger. Optimal climate change mitigation under long-term growth uncertainty : Stochastic integrated assessment and analytic findings. *European Economic Review*, 69(C) :104–125, 2014.

Peter M. Jones. Urban road pricing : public acceptability and barriers to implementation. In *Button and Verhoef, (eds.) Road pricing, traffic congestion and the environment*, pages 263–284. Edward Elgar Publishing, 1998.

Dan M Kahan. Ideology, motivated reasoning, and cognitive reflection. *Judgment and Decision Making*, 8(4) :18, 2013.

Dan M. Kahan, Ellen Peters, Maggie Wittlin, Paul Slovic, Lisa Larrimore Ouellette, Donald Braman, & Gregory Mandel. The polarizing impact of science literacy and numeracy on perceived climate change risks. *Nature Climate Change*, 2(10) :732–735, October 2012.

Steffen Kallbekken & Marianne Aasen. The demand for earmarking : Results from a focus group study. *Ecological Economics*, 69 :2183–2190, 2010.

Steffen Kallbekken & Håkon Sælen. Public acceptance for environmental taxes : Self-interest, environmental and distributional concerns. *Energy Policy*, 39(5) :2966–2973, May 2011.

Steffen Kallbekken, Stephan Kroll, & Todd L. Cherry. Do you not like Pigou, or do you not understand him ? Tax aversion and revenue recycling in the lab. *Journal of Environmental Economics and Management*, 62(1) :53–64, July 2011.

Louis Kaplow. Horizontal equity : New measures, unclear principles. Working Paper 7649, National Bureau of Economic Research, April 2000.

Christos Karydas & Anastasios Xepapadeas. Pricing Climate Change Risks : CAPM with Rare Disasters and Stochastic Probabilities. Working Paper Series 19/311, CER-ETH, 2019.

Robert Keohane & David Victor. Cooperation and discord in global climate policy. *Nature Climate Change*, 6 :570–575, 2016.

Suzi Kerr & Richard G. Newell. Policy-induced technology adoption : Evidence from the u.s. lead phasedown. *The Journal of Industrial Economics*, 51(3) :317–343, 2003.

Judd B. Kessler & Michael I. Norton. Tax aversion in labor supply. *Journal of Economic Behavior & Organization*, 124 :15–28, April 2016.

Ewald Kiel & Friedrich Rost. *Einführung in die Wissensorganisation : grundlegende Probleme und Begriffe*. Ergon-Verlag, 2002. ISBN 978-3-89913-246-5.

David Klenert, Linus Mattauch, Emmanuel Combet, Ottmar Edenhofer, Cameron Hepburn, Ryan Rafaty, & Nicholas Stern. Making carbon pricing work for citizens. *Nature Climate Change*, 8(8) :669, August 2018.

Jacob Klok, Anders Larsen, Anja Dahl, & Kirsten Hansen. Ecological Tax Reform in Denmark : history and social acceptability. *Energy Policy*, 34(8) :905–916, May 2006.

Matthew J. Kotchen, Kevin J. Boyle, & Anthony A. Leiserowitz. Willingness-to-pay and policy-instrument choice for climate-change policy in the United States. *Energy Policy*, 55 :617–625, April 2013.

Patrick W. Kraft, Milton Lodge, & Charles S. Taber. Why People "Don't Trust the Evidence" : Motivated Reasoning and Scientific Beliefs. *The ANNALS of the American Academy of Political and Social Science*, 658(1) :121–133, March 2015.

David Kreps & Evan Porteus. Temporal resolution of uncertainty and dynamic choice theory. *Econometrica*, 46(1) :185–200, 1978.

Karolina Kuklinska, Lidia Wolska, & Jacek Namiesnik. Air quality policy in the u.s. and the eu – a review. *Atmospheric Pollution Research*, 6(1) :129 – 137, 2015.

Ziva Kunda. The Case for Motivated Reasoning. *Psychological Bulletin*, 108(3) :480–498, 1990.

Ilyana Kuziemko, Michael I. Norton, Emmanuel Saez, & Stefanie Stantcheva. How elastic are preferences for redistribution ? evidence from randomized survey experiments. *American Economic Review*, 105(4) :1478–1508, April 2015.

Xavier Labandeira, José Labeaga, & Miguel Rodríguez. A residential energy demand system for spain. *The Energy Journal*, 27 :87–112, 2006.

Sébastien Lecocq & Jean-Marc Robin. Estimating almost-ideal demand-systems with endogenous regressors. *Stata Journal*, 15(2) :554–573, 2015.

Tien Ming Lee, Ezra M. Markowitz, Peter D. Howe, Chia-Ying Ko, & Anthony A. Leiserowitz. Predictors of public climate change awareness and risk perception around the world. *Nature Climate Change*, 5(11) :1014–1020, November 2015.

Anthony A. Leiserowitz. International Public Opinion, Perception, and Understanding of Global Climate Change. *Human development report*, 2007.

Hayne E. Leland. Saving and uncertainty : The precautionary demand for saving. *The Quaterly Journal of Economics*, 82(3) :465–473, 1968.

Marion Leroutier. Carbon pricing and power sector decarbonisation : Evidence from the uk. *FAERE Working Paper*, (12), 2019.

Aura Leulescu & Mihaela Agafitei. Statistical matching : a model based approach for data integration. Technical report, Eurostat, August 2013.

Arik Levinson. Energy Efficiency Standards Are More Regressive Than Energy Taxes : Theory and Evidence. *Journal of the Association of Environmental and Resource Economists*, 6(S1) :7–36, 2019.

Arthur Lewbel. Identification and estimation of equivalence scales under weak separability. *Review of Economic Studies*, 56 :311–16, 1989.

Andrew T. Little. The Distortion of Related Beliefs. *American Journal of Political Science*, 63(3) : 675–689, July 2019.

Alberto Longo, Anil Markandya, & Marta Petrucci. The internalization of externalities in the production of electricity : Willingness to pay for the attributes of a policy for renewable energy. *Ecological Economics*, 67(1) :140–152, August 2008.

Robert Lucas. *Models of Business Cycles*. Oxford : Basil Blackwell, 1987.

Robert Lucas. Macroeconomic Priorities. *American Economic Review*, 93(1) :1–14, March 2003.

Sara Maestre-Andrés, Stefan Drews, & Jeroen van den Bergh. Perceived fairness and public acceptability of carbon pricing : a review of the literature. *Climate Policy*, 19(9) :1186–1204, October 2019.

Justin Marion & Erich Muehlegger. Fuel tax incidence and supply conditions. *Journal of Public Economics*, 95(9) :1202–1212, 2011.

Ian Martin & Robert Pindyck. Averting Catastrophes : The Strange Economics of Scylla and Charybdis. *American Economic Review*, 105(10) :2947–85, October 2015.

Aaron M. McCright & Riley E. Dunlap. The Politicization of Climate Change and Polarization in the American Public's Views of Global Warming, 2001–2010. *The Sociological Quarterly*, 52 (2) :155–194, May 2011.

Aaron M. McCright, Riley E. Dunlap, & Chenyang Xiao. Increasing Influence of Party Identification on Perceived Scientific Agreement and Support for Government Action on Climate

Change in the United States, 2006–12. *Weather, Climate, and Society*, 6(2) :194–201, December 2013.

Rajnish Mehra & Edward C. Prescott. The equity premium : A puzzle. *Journal of Monetary Economics*, 15(2) :145–161, 1985.

Robert Merton. Optimal consumption and portfolio rules in a continuous time model. *Journal of Economic Theory*, 3 :373–413, 1971.

Robert C. Merton. An intertemporal capital asset pricing model. *Econometrica*, 41(5) :867–887, 1973.

Gilbert Metcalf. A distributional analysis of green tax reforms. *National Tax Journal*, 52(4) : 655–682, December 1999.

Anthony Millner & Hélène Ollivier. Beliefs, politics, and environmental policies. *Review of Environmental Economics and Policy*, 10(2) :226–244, 2016.

James J. Murphy, P. Geoffrey Allen, Thomas H. Stevens, & Darryl Weatherhead. A Meta-analysis of Hypothetical Bias in Stated Preference Valuation. *Environmental and Resource Economics*, 30 (3) :313–325, March 2005.

Brian Murray & Nicholas Rivers. British Columbia's revenue-neutral carbon tax : A review of the latest "grand experiment" in environmental policy. *Energy Policy*, 86 :674–683, November 2015.

Richard A. Musgrave. Horizontal equity, once more. *National Tax Journal*, 43(2) :113–122, June 1990.

Georg Müller-Fürstenberger & Ingmar Schumacher. Insurance and climate-driven extreme events. *Journal of Economic Dynamics and Control*, 54 :59–73, 2015.

Véronique Nichèle & Jean-Marc Robin. Simulation of indirect tax reforms using pooled micro and macro french data. *Journal of Public Economics*, 56(2) :225–244, 1995.

William D. Nordhaus. A review of the stern review on the economics of climate change. *Journal of Economic Literature*, 45(3) :686–702, September 2007.

Ilan Noy. The macroeconomic consequences of disasters. *Journal of Development Economics*, 88 : 221–231, 2009.

OCDE. *Effective Carbon Rates 2018*. 2018.

José Luis Montiel Olea & Carolin Pflueger. A robust test for weak instruments. *Journal of Business & Economic Statistics*, 31(3) :358–369, 2013.

Stan Olijslagers & Sweder van Wijnbergen. Discounting the Future : on Climate Change, Ambiguity Aversion and Epstein-Zin Preferences. Discussion Paper 13708, CEPR, 2019.

Michèle Pappalardo, Jimmy Armoogum, Jean-Paul Hubert, Sophie Roux, Pres Paris-Est, Thomas Le Jeannic, Bernard Quételard, Cete Nord-Picardie, Francis Papon, Régis de Solère, Dominique François, Marina Robin, Richard Grimal, Elisabeth Bouffard-Savary, Zahia Longuar, Jean-Pierre Nicolas, Damien Verry, Yann Caenen, Insee Île-de France, Christine Couderc, Jérémy Courel, IAU Île-de France, Christelle Paulo, & Thierry Siméon. La mobilité des Français Panorama issu de l'enquête nationale transports et déplacements 2008. page 228, 2010.

Ian Parry. Increasing carbon pricing in the eu : Evaluating the options. *European Economic Review*, 121 :103341, 2020.

David Pearce. The role of carbon taxes in adjusting to global warming. *The Economic Journal*, 101(407) :938–948, 1991.

Michaja Pehl, Anders Arvesen, Florian Humpenöder, Alexander Popp, Edgar G. Hertwich, & Gunnar Luderer. Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling. *Nature Energy*, 2(12) : 939–945, December 2017.

R. Perman, Y. Ma, M. Common, D. Maddison, & J. Mcgilvray. *Natural Resource and Environmental Economics*. Pearson Education Limited, 2011.

A.C. Pigou. *The Economics of Welfare*. Macmillan, 1920.

Robert S. Pindyck. Climate change policy : What do the models tell us ? *Journal of Economic Literature*, 51(3) :860–72, September 2013.

Robert S. Pindyck & Neng Wang. The economic and policy consequences of catastrophes. *American Economic Journal : Economic Policy*, 5(4) :306–39, November 2013.

William A Pizer & Steven Sexton. The Distributional Impacts of Energy Taxes. *Review of Environmental Economics and Policy*, 13(1) :104–123, 2019.

Robert A. Pollak & Terence J. Wales. Demographic variables in demand analysis. *Econometrica*, 49(6) :1533–1551, 1981.

J. Poore & T. Nemecek. Reducing food's environmental impacts through producers and consumers. *Science*, 360(6392) :987–992, June 2018.

James Poterba. Lifetime incidence and the distributional burden of excise taxes. *American Economic Review*, 79(2) :325–330, May 1989.

James Poterba. Is the gasoline tax regressive ? *Tax Policy and the Economy*, 5 :145–164, 1991.

Ryan Rafaty. Perceptions of Corruption, Political Distrust, and the Weakening of Climate Policy. *Global Environmental Politics*, 18(3) :106–129, June 2018.

Sebastian Rausch & Giacomo A. Schwarz. Household heterogeneity, aggregation, and the distributional impacts of environmental taxes. *Journal of Public Economics*, 138 :43–57, 2016.

Sebastian Rausch, Gilbert E. Metcalf, & John M. Reilly. Distributional impacts of carbon pricing : A general equilibrium approach with micro-data for households. *Energy Economics*, 33 (Supplement 1) :S20–S33, 2011.

Miguel Tovar Reaños & Nikolas Wölfing. Household energy prices and inequality : Evidence from german microdata based on the easi demand system. *Energy Economics*, 70 :84–97, 2018.

David P. Redlawsk. Hot Cognition or Cool Consideration ? Testing the Effects of Motivated Reasoning on Political Decision Making. *The Journal of Politics*, 64(4) :1021–1044, November 2002.

Thomas Rietz. The equity risk premium a solution. *Journal of Monetary Economics*, 22(1) :117–131, 1988.

J. Rogelj, M. den Elzen, & N. et al. Höhne. Paris agreement climate proposals need a boost to keep warming well below 2°c. *Nature*, 534 :631–639, 2016.

Nicolas Ruiz & Alain Trannoy. Le caractère régressif des taxes indirectes : les enseignements d'un modèle de micro-simulation. *Économie et Statistique*, (413) :21–46, 2008.

Håkon Sælen & Steffen Kallbekken. A choice experiment on fuel taxation and earmarking in Norway. *Ecological Economics*, 70(11) :2181–2190, September 2011.

James Sallee. Pigou creates losers : On the implausibility of achieving pareto improvements from efficiency-enhancing policies. Working Paper 25831, National Bureau of Economic Research, 2019.

Agnar Sandmo. The effect of uncertainty on saving decisions. *The Review of Economics Studies*, 37(3) :353–360, 1970.

Paola Sapienza & Luigi Zingales. Economic experts versus average americans. *American Economic Review*, 103(3) :636–42, May 2013.

Yasuyuki Sawada, Rima Bhattcharyay, & Tomoaki Kotera. Aggregate impacts of natural and man-made disasters : A quantitative comparison. Discussion papers 11023, Research Institute of Economy, Trade and Industry (RIETI), 2011.

Katheline Schubert. La valeur du carbone : niveau initial et profil temporel optimaux. 2008.

Ken Sennewald & Klaus Wälde. "Itô's Lemma" and the Bellman Equation for Poisson Process : An Applied View. *Journal of Economics*, 89 :1–36, 2006.

Paola Serafino & Richard Tonkin. Statistical matching of european union statistics on income and living conditions and the household budget survey. Technical report, Eurostat, 2017.

Tali Sharot, Christoph Korn, & Raymond Dolan. How unrealistic optimism is maintained in the face of reality. *Nature Neuroscience*, 14 :1475–1479, 2011.

Peijun Shi, Jing'ai Wang, Wei Xu, Tao Ye, Saini Yang, Lianyou Liu, Weihua Fang, Kai Liu, Ning Li, & Ming Wang. *World Atlas of Natural Disaster Risk*, pages 309–323. Springer Berlin Heidelberg, 2015.

James Shortle & Richard D. Horan. Policy instruments for water quality protection. *Annual Review of Resource Economics*, 5(1) :111–138, 2013.

Robert Y. Shum. Effects of economic recession and local weather on climate change attitudes. *Climate Policy*, 12(1) :38–49, January 2012.

Mark Skidmore & Hideki Toya. Do natural disasters promote long-run growth ? *Economic Inquiry*, 40(4) :664–687, 2002.

Susanne Soretz. Efficient dynamic pollution taxation in an uncertain environment. *Environmental and Resource Economics*, 36(1) :57–84, 2007.

John D. Sterman. Risk Communication on Climate : Mental Models and Mass Balance. *Science*, 322(5901) :532–533, October 2008.

Nicholas Stern. *The Economics of Climate Change : The Stern Review*. Cambridge University Press, 2007.

Nicholas Stern & Joseph E. Stiglitz. Report of the High-Level Commission on Carbon Prices. Technical report, Carbon Pricing Leadership Coalition, 2017.

Paul C. Stern, Thomas Dietz, & Linda Kalof. Value Orientations, Gender, and Environmental Concern. *Environment and Behavior*, 25(5) :322–348, September 1993.

Thomas Sterner. Environmental tax reform in Sweden. *International Journal of Environment and Pollution*, August 2014.

Joseph E. Stiglitz. Addressing Climate Change through Price and Non-Price Interventions. *European Economic Review*, May 2019.

Bruce Stokes, Richard Wike, & Jill Carle. Global Concern about Climate Change, Broad Support for Limiting Emissions. *Pew Research Center*, page 44, 2015.

Dalia Streimikiene, Tomas Balezentis, Ilona Alisauskaite-Seskiene, Gintare Stankuniene, & Zaneta Simanaviciene. A Review of Willingness to Pay Studies for Climate Change Mitigation in the Energy Sector. *Energies*, 12(8) :1481, January 2019.

Eric Strobl. The Economic Growth Impact of Hurricanes : Evidence from U.S. Coastal Counties. *The Review of Economics and Statistics*, 93(2) :575–589, 2011.

Abigail B. Sussman & Christopher Y. Olivola. Axe the Tax : Taxes are Disliked More than Equivalent Costs. *Journal of Marketing Research*, 48(SPL) :S91–S101, February 2011.

Lars Svensson. Portfolio choice with non-expected utility in continuous time. *Economics Letters*, 30(4) :313–317, 1989.

David Terkla. The efficiency value of effluent tax revenues. *Journal of Environmental Economics and Management*, 11(2) :107 – 123, 1984.

Michael Thaler. The "Fake News" Effect : An Experiment on Motivated Reasoning and Trust in News. page 111, 2019.

Philippe Thalmann. The Public Acceptance of Green Taxes : 2 Million Voters Express Their Opinion. *Public Choice*, 119(1) :179–217, April 2004.

Thomas Tietenberg. *Emissions trading : Principles and practice, 2nd ed.* Resources for the Future, Washington, DC, 2006.

Christina Tobler, Vivianne H.M. Visschers, & Michael Siegrist. Addressing climate change : Determinants of consumers' willingness to act and to support policy measures. *Journal of Environmental Psychology*, 32(3) :197–207, 2012.

Gordon Tullock. Excess benefit. *Water Resources Research*, 3(2) :643–644, 1967.

UNEP. Emissions Gap Report 2018. Technical report, 2018.

Paul Upham, Lorraine Whitmarsh, Wouter Poortinga, Kingsley Purdam, Andrew Darnton, Carly McLachlan, & Patrick Devine-Wright. Public Attitudes to Environmental Change : a selective review of theory and practice. Technical report, Living With Environmental Change, 2009.

Leaf Van Boven, Phillip J. Ehret, & David K. Sherman. Psychological Barriers to Bipartisan Public Support for Climate Policy. *Perspectives on Psychological Science*, 13(4) :492–507, July 2018.

Ton S. van den Bremer & Frederick van der Ploeg. Pricing Carbon Under Economic and Climatic Risks : Leading-Order Results from Asymptotic Analysis. OxCarre Working Papers 203, Oxford Centre for the Analysis of Resource Rich Economies, University of Oxford, 2018.

Frederick van der Ploeg & Aart de Zeeuw. Climate tipping and economic growth : Precautionary capital and the price of carbon. *Journal of the European Economic Association*, 16(5) : 1577–1617, 2017.

Philippe Weil. Nonexpected utility in macroeconomics. *The Quaterly Journal of Economics*, 105 (1) :29–42, 1990.

Martin Weitzman. On modeling and interpreting the economics of catastrophic climate change. *Review of Economics and Statistics*, 91(1) :1–19, 2009.

Sarah West & Roberton Williams. Estimates from a consumer demand system : implications for the incidence of environmental taxes. *Journal of Environmental Economics and Management*, 47(3) :535–558, 2004.

Lorraine Whitmarsh. Scepticism and uncertainty about climate change : Dimensions, determinants and change over time. *Global Environmental Change*, 21(2) :690–700, May 2011.

Lorraine Whitmarsh & Stuart Capstick. 2 - Perceptions of climate change. In Susan Clayton & Christie Manning, editors, *Psychology and Climate Change*, pages 13–33. Academic Press, January 2018.

Roberton Williams, Hal Gordon, Dallas Burtraw, Jared Carbone, & Richard D. Morgenstern. The initial incidence of a carbon tax across income groups. *National Tax Journal*, 68(1) :195–214, 2015.

Klaus Wälde. Optimal saving under poisson uncertainty. *Journal of Economic Theory*, 87 :194–217, 1999.

Jack Zhou. Boomerangs versus Javelins : How Polarization Constrains Communication on Climate Change. *Environmental Politics*, 25(5), September 2016.

Andreas Ziegler. Political orientation, environmental values, and climate change beliefs and attitudes : An empirical cross country analysis. *Energy Economics*, 63 :144–153, March 2017.