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ENERGY EFFICIENCY IN THE RESIDENTIAL SECTOR: ANALYSIS ON INVESTMENT DRIVERS AND PUBLIC POLICIES

Marie-Laure Nauleau

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Marie-Laure Nauleau. ENERGY EFFICIENCY IN THE RESIDENTIAL SECTOR: ANALYSIS ON INVESTMENT DRIVERS AND PUBLIC POLICIES. Economics and Finance. EHESS-Paris, 2015. English. NNT: . tel-01618117

HAL Id: tel-01618117

<https://hal.science/tel-01618117v1>

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CENTRE INTERNATIONAL DE RECHERCHE EN ENVIRONNEMENT ET DEVELOPPEMENT

ECOLE DES HAUTES ETUDES EN SCIENCES SOCIALES

AGENCE DE L'ENVIRONNEMENT ET DE LA MAITRISE DE L'ENERGIE



L'EFFICACITE ENERGETIQUE DANS LE SECTEUR RESIDENTIEL FRANÇAIS: ANALYSE DES
DETERMINANTS D'INVESTISSEMENT ET DES POLITIQUES PUBLIQUES

Thèse pour l'obtention du grade de docteur de l'EHESS en sciences économiques, présentée par

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Sous la direction de Philippe Quirion,

Soutenue le 18 juin 2015

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L'efficacité énergétique dans le secteur résidentiel français: analyse des déterminants d'investissement et des politiques publiques

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Résumé

Le poids du secteur résidentiel dans la consommation énergétique des ménages fait de la rénovation énergétique des logements un enjeu important dans la lutte contre le changement climatique. L'ensemble des barrières auxquelles font face les ménages pour investir dans l'efficacité énergétique de leurs logements invite à mieux comprendre les déterminants d'investissement et l'efficacité de l'intervention publique.

Une première partie de la thèse porte sur l'analyse des déterminants de l'investissement des ménages dans l'efficacité énergétique dans leurs logements. Un modèle de choix d'investissement, estimé sur les données de l'enquête annuelle «Maitrise de l'énergie» de l'Ademe, met notamment en lumière l'hétérogénéité des déterminants suivant le type d'investissement.

Une seconde partie de la thèse porte sur l'évaluation de l'efficacité des politiques publiques qui visent à promouvoir l'investissement des ménages dans l'efficacité énergétique, en analysant leur impact à la fois sur la demande et sur l'offre des marchés de l'efficacité énergétique. Du côté de la demande, la thèse recourt à deux méthodes complémentaires : l'évaluation économétrique ex-post, en étudiant spécifiquement l'efficacité du Crédit d'Impôt Développement Durable créé en 2005, et la modélisation technico-économique permettant d'évaluer différents instruments de manière ex-ante. Du côté de l'offre, constatant la structure non concurrentielle des marchés de l'efficacité énergétique, la thèse s'interroge de manière théorique sur l'efficacité des politiques publiques sur des marchés en présence de trois imperfections de marché : l'externalité négative du CO₂ et l'imperfection de la concurrence et de l'information engendrant de la discrimination en prix-qualité.

Abstract

Given the share of the residential sector in households' energy consumption, residential energy retrofitting is a burning issue in the climate change policy strategy. All the investment barriers faced by households invite us to explore the investment factors and to assess the efficiency of public policies.

In a first part, the thesis studies the investment factors by estimating a discrete choice model on data from the French annual "Energy Management" survey conducted by Ademe, particularly focusing on factors heterogeneity among retrofitting types.

A second part of the thesis deals with the assessment of public policy promoting energy efficiency, both from the demand and the supply sides of the energy efficiency markets. Regarding the demand side, the thesis uses two complementary methods: an ex-post econometric study focuses on the French tax credit called Crédit d'Impôt Développement Durable implemented in 2005 while an ex-ante study uses a hybrid energy-economy model to compare different policies. Regarding the supply side, given the high degree of concentration on the energy efficiency markets, we use a theoretical model to assess public policy efficiency in the presence of three market imperfections: the negative externality linked to CO₂ and the imperfections of market competition and information inducing price-quality discrimination.

REMERCIEMENTS

Je tiens tout d'abord à remercier les membres du jury, les rapporteurs, Mme Dorothée Brécard et Mr Patrick Criqui, ainsi que les examinateurs, Mme Amélie Mauroux, Mr Jean-Charles Hourcade et Mr Erwan Gautier, pour avoir bien voulu consacrer leur temps à la lecture et à l'analyse de mon travail.

Je remercie bien sûr chaleureusement Philippe Quirion, qui a encadré ces travaux, orientant ma réflexion sur des pistes innovantes de recherche tout en l'accompagnant sur les questions que j'ai souhaité développer. Je le remercie également, ainsi que Franck Lecocq, le directeur du CIRED, pour m'avoir fait confiance en acceptant que j'adapte mes conditions de travail.

J'en profite pour exprimer le plaisir que ce fut de venir travailler au CIRED. Ces repas quotidiens, partagés par tous, où les chercheurs et les administratifs se côtoient au gré des arrivées, symbolisent pour moi une mixité et une ouverture précieuses, favorisant l'échange et l'apprentissage scientifique et humain. Que ces repas soient pris au soleil ou à l'ombre des grands arbres du Jardin Tropical ne fit que décupler le plaisir de ce quotidien. Un grand merci donc à l'ensemble de mes collègues, connus de près ou de loin et dont la liste serait longue à énumérer, de peupler ainsi ces bons souvenirs. Merci aussi pour leur disponibilité dans le cadre professionnel. Un merci particulier à Louis-Gaëtan Giraudet et Fred Branger pour notre travail commun.

Je souhaite à présent remercier l'équipe du LEMNA, le laboratoire d'économie de Nantes où j'ai pu travailler une partie du temps : ses directeurs, Thomas Vallée et Patrice Guillotreau, pour m'avoir offert une place dans leur laboratoire, ainsi que les doctorants et les chercheurs qui m'ont fait très bon accueil et qui m'ont aussi bien aidé dans mes recherches, François-Charles Wolff en particulier.

Je remercie aussi les ingénieurs de l'ADEME qui m'ont permis d'entreprendre et de mener à bien mes recherches. Laurent Meunier tout d'abord, qui m'a « mis le pied à l'étrier » et sans qui tout le travail sur l'enquête « Maîtrise de l'Energie » n'aurait été possible. Puis Gaël

Callonnec, pour m'avoir proposé ce projet de collaboration en travaillant sur le modèle Menfis de l'ADEME, m'offrant l'opportunité d'une recherche différente, plus « opérationnelle » mais tout aussi exigeante. Je tiens en outre à remercier les personnes de la TNS-Sofres, Prisca Roy notamment, pour notre collaboration au sujet de l'enquête « Maîtrise de l'Energie ».

Enfin, je souhaite exprimer ma gratitude envers mes proches : ma mère, mon frère, et mes amis qui m'ont, pendant plus de 3 ans, écoutée avec gentillesse et fait montre tant bien que mal de curiosité pour l'isolation des murs, les chaudières à condensation, les estimateurs en différence ou encore les tracas de la publication scientifique... Un tendre merci à Mathieu enfin pour avoir partagé quotidiennement cette grande expérience, m'encourageant, me réconfortant ou se réjouissant au gré des hauts et des bas de la thèse.

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Introduction générale

1.1. Investir dans l'efficacité énergétique du secteur résidentiel : un levier d'action majeur dans la lutte contre le changement climatique

Le Groupe d'experts Intergouvernemental sur l'Évolution du Climat (GIEC, IPCC en anglais) fut créé en 1988 en vue de fournir des évaluations détaillées de l'état des connaissances scientifiques sur les changements climatiques, leurs causes et leurs répercussions potentielles. Dans son cinquième rapport d'évaluation rendu public en 2014, celui-ci affirme avec quasi-certitude que l'augmentation des émissions de gaz à effet de serre (GES) d'origine anthropique est la principale cause du réchauffement climatique:

« Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century. » (IPCC 2014, Figure 1)

Le GIEC estime que les scénarios parvenant à maintenir le réchauffement climatique en deçà de 2°C sont caractérisés par des diminutions de 40% à 70% des émissions de GES d'ici 2050 par rapport à 2010; et un niveau d'émission quasi-nul à l'horizon 2100 (IPCC 2014). Ces émissions de GES étant en grande partie issues de la consommation d'énergies d'origine fossile, cela implique donc la mise en place de nouvelles politiques énergétiques afin de réaliser ce que l'on appelle aujourd'hui la « Transition Énergétique ». Celle-ci vise à réduire les consommations énergétiques d'origine fossile au niveau à la fois de la production et de la consommation. Côté

production, il s'agit de restructurer le système productif en diminuant la part des énergies émettrices en GES dans le mix énergétique. Côté consommation, il s'agit de réduire nos besoins d'énergie, en particulier grâce à l'augmentation de l'efficacité énergétique, à savoir la recherche d'une moindre consommation d'énergie pour un service énergétique¹ rendu identique.

Réussir la Transition Energétique dans le secteur résidentiel est un réel enjeu en raison du poids de ce secteur en termes de consommation énergétique et d'émission de CO₂. En France², le secteur résidentiel représente 28% de l'ensemble des consommations d'énergie finale en moyenne sur 2000/2012 (32% pour le transport et 24% pour l'industrie, Figure 2). En termes d'émissions de CO₂, toujours en moyenne sur 2008/2012, sa part baisse à 18%³. Cependant, si l'on réaffecte les émissions de l'appareil productif à la demande finale et si l'on y intègre les émissions importées à partir des données de la comptabilité nationale, l'énergie consommée dans le logement représente alors 34% des émissions de CO₂ d'un ménage français en moyenne pour 2005 (31% pour le transport, Lenglar et al. 2010).

De nombreuses études affirment de plus qu'investir dans l'efficacité énergétique du secteur résidentiel est particulièrement souhaitable tant par le potentiel majeur d'économies d'énergie que ce secteur représente que par la rentabilité estimée des investissements à entreprendre (Levine et al. 2007, Ürge-Vorsatz & Novikova 2008, Lucon et al. 2014). Sous couvert d'hypothèses quant à l'évolution de la rénovation énergétique des bâtiments et de certains modes de consommation⁴, le scénario Négawatt 2011 parvient par exemple à une division par plus de deux des consommations d'énergie finale pour le chauffage et l'eau chaude sanitaire entre 2011 et 2050. Ce faisant, les économies d'énergie dans les secteurs résidentiel et tertiaire se chiffrent à 365 TWh, soit environ 20% des économies d'énergie totales de leur

¹ Les services énergétiques peuvent être définis comme l'ensemble des usages énergétiques dont on retire un certain niveau d'utilité, de bien-être, tels que le confort thermique, la mobilité, etc.

² Au niveau européen, la consommation d'énergie dans les bâtiments résidentiels et commerciaux représente environ 40% de la consommation totale d'énergie finale et 36% des émissions totales de CO₂. http://europa.eu/legislation_summaries/energy/energy_efficiency/en0002_fr.htm

³ 29% pour le transport, 24% pour l'industrie manufacturière, 16% pour l'industrie de l'énergie, 9% pour le tertiaire

⁴ 750000 logements rénovés chaque année en rythme de croisière ; température de chauffage à 19°C ; 2,2 personnes/logement (2 aujourd'hui et 2,25 en 2050 selon les projections de l'INSEE) ; les maisons individuelles ne représentant que 20% du parc de logements neufs (contre 50% dans le scénario tendanciel). <http://www.negawatt.org/scenario-negawatt-2011-p46.html>

scenario⁵. D'autres études soulignent la rentabilité des investissements dans la rénovation énergétique. Reposant sur un calcul de Valeur Actuelle Nette (VAN) intégrant le coût et la durée de vie de l'investissement, les prix des énergies et les économies futurs, ainsi qu'un taux d'actualisation financier, la célèbre étude réalisée au niveau mondial par le cabinet de conseil McKinsey & Company (2009) met en avant des coûts d'abattement négatifs (en euros par tonne de CO₂ évitée) pour les investissements dans l'isolation des logements ou le remplacement des systèmes de chauffage.

Comme le montre Allibe (2012) dans sa thèse, la majeure partie du gisement d'économies d'énergie du secteur résidentiel réside dans les besoins énergétiques thermiques, à savoir le chauffage et l'eau chaude sanitaire. Bien que la part de l'électricité spécifique augmente tendanciellement du fait d'un taux d'équipement des ménages en appareils électroniques croissant, les consommations visant à répondre aux besoins thermiques représente toujours une part substantielle des consommations résidentielles : 71% pour le chauffage, 10% pour l'eau chaude sanitaire, 14% pour l'électricité spécifique et 6% pour la cuisson en moyenne sur 2000/2012 (Figure 3). La rénovation énergétique du parc existant constitue en outre la majeure partie du potentiel d'économies sur ces besoins thermiques en raison de l'écart de performance énergétique entre le neuf et l'existant et du lent renouvellement du parc immobilier (environ 1% par an). La nouvelle réglementation thermique pour les constructions neuves limite en effet la consommation théorique⁶ des logements construits après 2012 à un niveau Bâtiment Basse Consommation (BBC), i.e. à 50 kWh d'énergie primaire⁷ par m² et par an (kWhEP/m²/an), les besoins thermiques ne représentant alors plus qu'une part très faible de la consommation. L'analyse de l'enquête Performance de l'Habitat,

⁵ Les consommations d'énergies totales du scenario passent de 3000 à 1000 TWh entre 2011 et 2050.

⁶ La consommation d'énergie théorique renvoie à la consommation d'énergie conventionnelle obtenue dans les modèles thermiques à partir des caractéristiques énergétiques du logement. **La méthode 3CL-DPE** mise au point par un groupe de travail composé entre autres de représentants de l'ADEME, EDF et GDF est la méthode officielle retenue pour le diagnostic de performance énergétique des logements français.

⁷ Le premier stade énergétique utilisé est l'énergie primaire. Celle-ci est, d'après la définition de l'INSEE, l'ensemble des produits énergétiques non transformés, exploités directement ou importés. Ces produits sont principalement le pétrole brut, le gaz naturel, la biomasse, le rayonnement solaire, l'énergie hydraulique, l'énergie du vent, la géothermie et l'énergie tirée de la fission de l'uranium.

Équipements, Besoins et Usages de l'énergie (Phébus⁸) montre quant à elle qu'en 2012, plus de la moitié (53,6 %) du parc des logements en France métropolitaine consomme théoriquement entre 151 et 330 kWhEP/m²/an, 30,7% consommant plus, 14 % consommant moins (SOeS, CGDD 2014). Il est enfin beaucoup rentable d'un point de vue purement énergétique de rénover que de démolir pour reconstruire : « lorsqu'un bâtiment consomme entre 30 et 50 kWhEP/m²/an⁹, l'énergie grise peut représenter 25 à 50 ans de la consommation de chauffage » (ENERTECH, et al. 2014). Cette rénovation énergétique comprend principalement l'isolation des bâtiments et l'installation de systèmes thermiques performants tels que les pompes à chaleur, les chaudières à condensation ou les équipements utilisant des énergies renouvelables (solaire, biomasse, etc.).

Enfin, outre le changement climatique, les préoccupations croissantes liées à l'indépendance énergétique ou encore à l'instabilité du prix des énergies fossiles, pouvant impacter à la fois la compétitivité et le pouvoir d'achat (précarité énergétique), motivent également l'investissement dans l'efficacité énergétique.

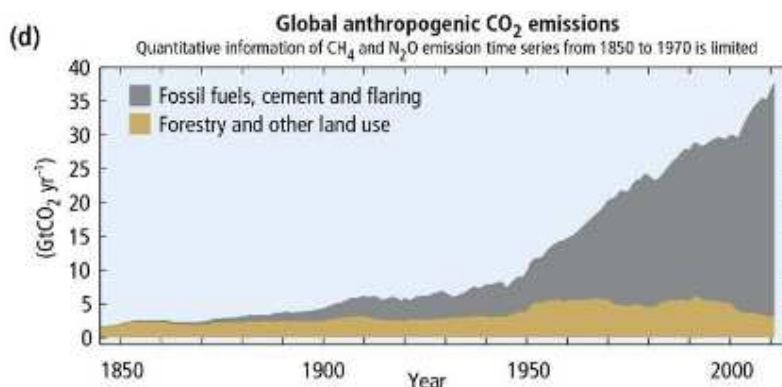


Figure 1. IPCC 2014

⁸ Phebus est une enquête ponctuelle, réalisée par le SOeS pour la 1^{ère} fois en 2014. Elle porte, d'une part, sur les équipements et les usages énergétiques des ménages dans leur logement et, d'autre part, sur le diagnostic de performance énergétique (DPE) du logement.

⁹ De tels niveaux de consommations théoriques sont très faibles et restent très rares dans le parc de logements (0.3% du parc selon l'enquête Phebus).

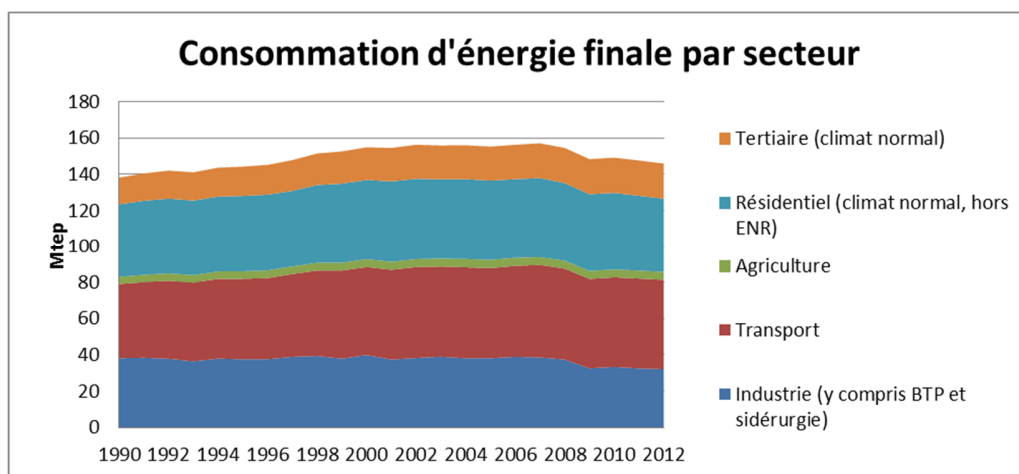


Figure 2. Consommation annuelle d'énergie finale par secteur.

Source : Base France ADEME (Datamed)

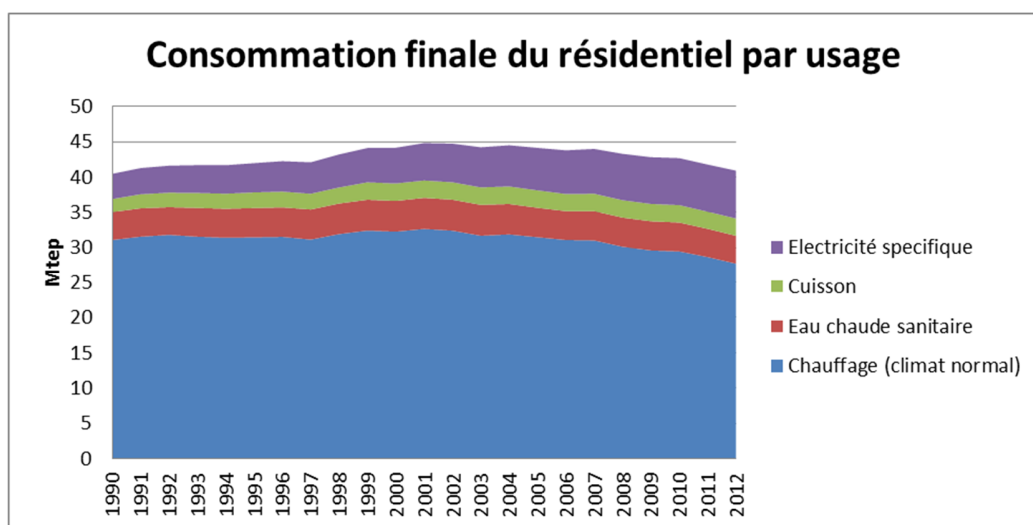


Figure 3. Consommation finale du résidentiel par usage.

Source : Base France ADEME (Datamed)

1.2. Un volontarisme politique croissant pour promouvoir l'efficacité énergétique du secteur résidentiel mais des résultats en deçà des enjeux.

La prise de conscience au niveau politique de ces enjeux se traduit par la promulgation d'objectifs quantifiés. Au niveau européen, outre des engagements globaux tels que le "Triple 20", prévoyant la réduction de 20% des émissions de GES, l'augmentation de 20% de l'efficacité énergétique et l'augmentation de 20% des énergies renouvelables d'ici 2020, ou celui du Paquet Energie Climat pour 2030, prévoyant la réduction de 40% émissions de GES d'ici 2030¹⁰, les directives relatives à la performance énergétique des bâtiments (DPEB) se succèdent dans les années 2000 (2002, 2010, 2012). L'article 4 de la directive relative à l'efficacité énergétique de 2012 impose notamment aux Etats la mise en place de stratégies nationales de rénovation énergétique (Staniaszek 2014).

An niveau national, dans le cadre du Plan climat et de la loi 2005 de programme d'orientation de la politique énergétique (POPE), la France doit réduire ses émissions de gaz à effet de serre d'un facteur 4 entre 1990 et 2050 et améliorer l'intensité énergétique finale de 2 % par an après 2015. Votée en 2009, la loi "Grenelle de l'Environnement" fixe à 38% l'objectif de réduction de la consommation énergétique des bâtiments existants d'ici 2020 par rapport à 2008¹¹ et à 400 000 le nombre de logements devant faire chaque année l'objet d'une rénovation complète à compter de 2013. Très récemment, le projet de loi relatif à la Transition Energétique pour la Croissance Verte voté par l'Assemblée Nationale en octobre 2014¹² fixe notamment comme objectifs de « réduire la consommation énergétique finale de 50% en 2050

¹⁰ Cet objectif contraignant est inscrit dans le Paquet Energie Climat pour 2030 validé par le Conseil européen en octobre 2014. Le niveau des réductions d'émissions de GES est en rapport à leur niveau de 1990.

¹¹ D'après la loi « Grenelle 1 », n° 2009-967 du 3 août 2009 de programmation relative à la mise en œuvre du Grenelle de l'environnement, Article 5. Il est à noter que la loi ne précise pas si les réductions de consommation doivent être en énergie finale ou en énergie primaire. Nous considérerons dans cette thèse que l'objectif est implicitement formulé en énergie finale. Contrairement à l'énergie primaire, l'énergie finale est celle considérée au stade final de la chaîne de transformation de l'énergie, c'est-à-dire au stade de son utilisation par le consommateur final. La différence entre les deux dépend de la quantité d'énergie consommée dans le processus de transformation et d'acheminement (voir chapitre 3).

¹²Projet de loi examiné par le Sénat début 2015.
<http://www.assemblee-nationale.fr/14/projets/pl2188.asp> ou <http://www.senat.fr/leg/pjl14-016.html>.

par rapport à la référence 2012, en visant un objectif intermédiaire de 20% en 2030 », et de « disposer d'un parc immobilier dont l'ensemble des bâtiments sont rénovés en fonction des normes "bâtiment basse consommation (BBC)" ou assimilé, à horizon 2050 ». Pour ce faire, « la France se fixe comme objectif de rénover énergétiquement 500 000 logements par an à compter de 2017. »¹³

Afin d'atteindre ces objectifs, la France, tout comme de nombreux pays en proie aux mêmes problématiques énergétiques, met en place un ensemble politiques publiques visant à promouvoir l'efficacité énergétique dans le secteur résidentiel. Sur le modèle des « Carrots, Sticks, and Sermons », elle combine des politiques incitatives, telles que le taux de TVA réduit depuis 1999, le Crédit d'Impôt Développement Durable (CIDD) depuis 2005 ou encore l'Eco Prêt à Taux Zéro (EcoPTZ) depuis 2009, tous trois subventionnant l'investissement des ménages dans la rénovation énergétique; des politiques réglementaires, telles que la nouvelle réglementation thermique sur les constructions neuves (2012); et des politiques d'information, telles que le Diagnostic de Performance Energétique (DPE), label informant sur l'efficacité énergétique du logement (obligatoire à la vente depuis 2006 et à la location depuis 2007), ou la mise en place d'un guichet unique pour simplifier la recherche d'information des ménages (numéro vert de l'ADEME depuis 2013).

Or, au vu des statistiques sur les consommations énergétiques résidentielles ou sur la rénovation énergétique, il semble que la France soit encore loin d'atteindre ses objectifs. Le Centre d'Etudes et de Recherches sur l'Energie (CEREN) publie chaque année les niveaux de consommations énergétiques résidentielles. En 5 ans, sur la période 2008/2012, les consommations d'énergie du parc des résidences principales n'ont diminué que de 7%, 10% si l'on ne considère que les logements construits avant 1999 (13% pour le chauffage et 8% pour l'eau-chaude sanitaire).¹⁴ L'Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME) publie quant à elle des statistiques sur la rénovation énergétique depuis plus de 10 ans à partir

¹³ Des objectifs globaux sont également inscrits dans le projet de loi : réduire la consommation énergétique primaire des énergies fossiles de 30 % en 2030 par rapport à la référence 2012 ; porter la part des énergies renouvelables à 23 % de la consommation finale brute d'énergie en 2020 (à 32 % en 2030) ; réduire la part du nucléaire dans la production d'électricité à 50 % à l'horizon 2025.

¹⁴ Consommation en climat normal, i.e. corrigée des variations climatiques.

de l'enquête annuelle « Maîtrise de l'Energie » (TNS Sofres & ADEME 2012) et de l'Observatoire Permanent de l'Amélioration Energétique du logement (OPEN 2009, 2015). L'enquête « Maîtrise de l'Energie » comptabilise tous types de rénovations à composante énergétique et situe la part des logements rénovés chaque année autour de 10% du parc (voir annexe du chapitre 1). Ce taux diminue cependant considérablement lorsqu'on se concentre sur les rénovations énergétiques d'ampleur, i.e. portant sur l'ensemble du logement et conduisant à des économies d'énergie importantes. Parmi les statistiques sur les rénovations lourdes, il existe notamment celles du fichier SGFGAS¹⁵, sur les rénovations bénéficiant du prêt à taux zéro EcoPTZ et devant combiner plusieurs types de travaux, qui chiffrent entre 30 000 et 80 000 le nombre de logements rénovés par an entre 2009 et 2013 (voir chapitre 3); celles de l'ANAH¹⁶, sur les rénovations bénéficiant de ses programmes d'aides et soumises à des gains d'efficacité énergétique minimaux, qui chiffrent entre 60 000 et 75 000 le nombre de logements rénovés par an entre 2012 et 2014. D'après l'Observatoire Permanent de l'amélioration ENergétique du logement, le nombre de rénovations thermiques globales « trois étoiles »¹⁷ réalisées en une seule fois est de 135 000 en 2011 et de 90 000 en 2013 (OPEN 2015). Ces statistiques ne permettent pas de quantification précise de la rénovation sur l'ensemble du parc, notamment en raison du cumul possible entre les aides ou du manque de données sur le logement social. Elles montrent néanmoins que l'on est loin des objectifs fixés, d'autant plus que l'actuel projet de loi vise des rénovations permettant d'atteindre des niveaux de performance BBC, ce qui est loin d'être le cas pour la très grande majorité des travaux réalisés.

Le double constat d'un volontarisme politique dans la mise en œuvre de programmes visant à promouvoir l'investissement dans l'efficacité énergétique des logements et de la faiblesse des résultats au vu des objectifs fixés amène à s'interroger sur la pertinence et l'efficacité des politiques publiques existantes. Ce questionnement est du ressort de l'économie publique. Dans un premier temps, il s'agit de comprendre pourquoi les consommateurs n'entreprennent pas les investissements d'efficacité énergétique qui semblent rentables du

¹⁵ Société de Gestion des Financements et de la Garantie de l'Accession Sociale à la propriété.

¹⁶ Agence Nationale de l'Habitat

¹⁷ Dans la terminologie OPEN, la rénovation « trois étoiles » concerne les interventions pour lesquelles l'isolation, la pose d'ouvertures et d'un chauffage énergétiquement efficaces ont été réalisées.

point de vue « ingénieur », à la manière de l'étude « McKinsey » (2009) par exemple. Ce travail d'identification des barrières à l'investissement permet d'évaluer quelles distorsions génèrent un niveau sous-optimal d'investissement et lesquelles justifient l'intervention publique. La littérature de l'Energy Efficiency Gap explore de longue date ces questions et la section 1.3 résume ses principaux enseignements.

Une fois les imperfections de marché justifiant l'intervention publique identifiées, il s'agit dans un deuxième temps de voir quelles sont les politiques publiques les plus efficaces pour y remédier. Cette deuxième étape permet notamment de comprendre pourquoi les politiques actuellement mises en place peuvent dysfonctionner et quelles seraient, le cas échéant, les pistes d'amélioration. Comme nous allons le voir dans les sections 1.4 et 1.5, bien que certains éléments de réponse existent dans la littérature existante, les perspectives de recherche se font ici plus nombreuses.

1.3. Promouvoir l'investissement dans l'efficacité énergétique du secteur résidentiel : quelles justifications pour l'intervention publique ? Une question d'économie publique investie par la littérature de l'Energy Efficiency Gap.

La littérature de l'Energy Efficiency Gap naît lors de la première vague de politiques d'efficacité énergétique suite aux deux chocs pétroliers des années 1970. Les préoccupations liées aux prix élevés des énergies fossiles ont conduit les Etats fortement dépendants des importations énergétiques à mettre en place des politiques de maîtrise de l'énergie similaires à celles que l'on observe aujourd'hui (incitations fiscales, réglementations thermiques successives pour les constructions neuves, campagnes d'information, etc.). Cette émergence est symbolisée en France par la naissance de l'Agence pour les Economies d'Energie (AEE) en 1974¹⁸, devenant l'Agence Française pour la Maîtrise de l'Energie (AFME) en 1982 puis l'Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME) en 1992. Le contre-choc pétrolier des

¹⁸ Devenant l'Agence Française pour la Maîtrise de l'Energie (AFME) en 1982.

années 1990 a mis en sommeil ces politiques énergétiques, que le changement climatique et la résurgence des énergies chères ont réactualisées au début des années 2000 (Martin et al. 1998, Leray & de la Roncière 2002, Giraudet 2011).

A partir des travaux d'Hausman (1979), les économistes ont d'abord interprété les écarts entre les comportements d'optimisation rationnels des ingénieurs et les comportements d'investissements réels des ménages par des taux d'actualisation des ménages très élevés, bien supérieurs aux taux d'actualisation financiers basés sur le coût d'opportunité du capital (Train 1985). Puis la boîte noire du taux d'actualisation élevé s'est peu à peu ouverte. Les revues de littérature récentes (Gillingham et al. 2009, Allcott & Greenstone 2012, Giraudet 2011, Gillingham & Palmer 2014) s'accordent à classer les barrières à l'investissement en trois catégories :

- les imperfections de marché justifiant l'intervention publique,
- les barrières non imputables à une quelconque imperfection de marché,
- les caractéristiques comportementales divergentes des hypothèses d'optimisation rationnelle de la microéconomie classique.

Outre l'externalité négative issue de la consommation d'énergies fossiles, les imperfections de marché expliquant l'Energy Efficiency Gap ont bien souvent trait à des mécanismes d'information imparfaite : ménages sous-informés sur les problématiques d'efficacité énergétique (celle-ci pouvant être considérée comme un bien public) ; asymétrie d'information entre le vendeur et l'acheteur et possibilité d'aléa moral ; problème principal-agent entre les propriétaires et les locataires d'un logement ; externalités positives non prises en compte (learning-by-doing, neighbor effect). L'Energy Efficiency Gap peut également s'expliquer par des mécanismes de compétition imparfaite sur les marchés de l'efficacité énergétique ou encore par des imperfections de marché sur des marchés connexes : contraintes de liquidités causées par des imperfections sur le marché du crédit ou tarification mal régulée sur le marché de l'énergie.

La seconde catégorie de facteurs pouvant expliquer un niveau d'investissement des ménages moindre que celui prédit par les « ingénieurs » regroupe :

- l'hétérogénéité des consommateurs dans leur valorisation des services énergétiques résultant de l'hétérogénéité des besoins énergétiques, des préférences environnementales, de l'aversion au risque, etc.,
- l'incertitude, sur la qualité des travaux ou sur les prix futurs de l'énergie,
- l'existence de coûts non économiques « cachés », tels que l'inconfort occasionné par les travaux, la perte de luminosité par la réduction des tailles de fenêtres pour diminuer la déperdition de chaleur ou par l'installation d'ampoules basse consommation, etc.,
- l'augmentation possible du niveau de consommation par les ménages ayant investi dans l'efficacité énergétique, i.e. une fois que le rendement de la dépense énergétique s'est amélioré grâce aux travaux, phénomène appelé effet rebond (Sorrell et al. 2009).

L'émergence de l'économie comportementale appliquée à la problématique de l'Energy Efficiency Gap offre enfin une troisième source d'explications, en portant l'attention sur les « préférences non-standards » (incohérence temporelle, préférences contextualisées¹⁹ telles que l'aversion à la perte, etc.) ou sur les « processus décisionnel non-standard » (rationalité limitée, heuristiques décisionnelles sous-optimales, etc.).

1.4. Quels enseignements concernant les politiques actuelles ?

A la recherche des politiques publiques optimales permettant de corriger les imperfections de marché constatées, la littérature de l'Energy Efficiency Gap apporte des éléments de réponses quant à l'inadéquation des politiques actuelles.

Concernant le type d'instrument tout d'abord, force est de constater que les politiques publiques effectivement mises en œuvre divergent souvent de l'optimal. Alors que les instruments type taxe Pigouvienne constituent le plus souvent la politique first best (Giraudet & Quirion 2008, Allcott & Greenstone 2012), ceux-ci sont très rarement concrétisés, laissant place

¹⁹ reference-dependent preferences en anglais

le plus souvent à des subventions ou des labels dans le cas de la rénovation énergétique. Les contraintes d'acceptabilité politique expliquent en grande partie l'absence de taxe Pigouvienne, comme l'attestent les échecs successifs des projets de loi français. Dans le débat depuis 2006 avec le lancement du « Pacte écologique » de la Fondation Nicolas Hulot, le projet de loi sur une taxe carbone est adopté au parlement en décembre 2009 puis immédiatement invalidé par le Conseil Constitutionnel (Combet 2013).²⁰ Plus récemment, en 2013, la loi Brottes visant à instaurer une tarification progressive de l'énergie par le biais d'un bonus-malus en fonction du niveau de consommation de gaz, de chaleur et d'électricité dans les résidences principales²¹ fut également déclarée non conforme à la Constitution par le Conseil constitutionnel. Les contraintes d'acceptabilité politique expliquent également l'absence de mesures réglementaires sur la rénovation énergétique, telles que l'obligation de rénovation en cas de changement de propriété ou d'occupation proposée par Salomon et al. (2005) et étudiée par Giraudet (2011). Bien que ces contraintes de faisabilité doivent être prises en compte afin de produire une recherche pertinente et utile aux régulateurs, il convient d'apprécier le coût d'opportunité à poursuivre les stratégies politiques actuelles donnant priorité aux instruments incitatifs.

Alors que les subventions tiennent une place de choix parmi les politiques existantes, leur efficacité à surmonter de manière significative les barrières à l'investissement ne fait pas consensus au sein de la littérature empirique (voir chapitre 2). Gillingham & Palmer (2014) attribuent l'inefficacité des politiques publiques incitatives telles que les subventions à la présence d'hétérogénéité entre les ménages, induisant ce que l'on appelle souvent « l'effet d'aubaine ». Ce dernier a lieu lorsque les politiques bénéficient aux individus sans pour autant modifier leur comportement d'investissement (Cohen et al. 2012). L'inefficacité des politiques incitatives peut alors fortement dépendre de leur « design ». Le terme « design » renvoie à l'ensemble des modalités de mise en œuvre de la subvention, allant des critères d'éligibilité des ménages et des équipements, au niveau de taux en passant par les différents modes de calcul

²⁰ En 2000, le projet d'extension de la taxe générale sur les activités polluantes (TGAP) aux consommations intermédiaires de certains produits énergétiques, ayant pour but de réduire les émissions de CO₂, avait déjà fait l'objet d'une censure du Conseil constitutionnel.

²¹ Les barèmes dépendaient du mode de chauffage, de la région climatique, du nombre de personnes dans le logement. Les locataires pouvaient déduire du loyer la part du bonus-malus due à la mauvaise isolation du logement.

des subventions (assiette, subventions ad valorem ou prime forfaitaire, etc.). Boomhower & Davis (2014) et Allcott (2014) recommandent ainsi la mise en place de politiques publiques « sur-mesure », ciblées sur les ménages les plus susceptibles d'être impactés par la politique, ou en proportion de leurs difficultés à investir (« consumer-specific subsidies to each consumers' bias»). D'autres contraintes peuvent alors s'imposer au régulateur : des contraintes informationnelles, lorsqu'il s'agit de calibrer la politique aux profils des bénéficiaires ; des contraintes politiques, comme l'attestent les invalidations constitutionnelles des projets de loi au motif de l'inégalité devant l'impôt²² ; ou encore des contraintes institutionnelles, telles que l'influence des lobbys. Au vu de la diversité des dispositifs existants et/ou de leur rapidité d'évolution, attestant peut-être d'une incertitude du régulateur quant au meilleur design à promouvoir, il semble donc important de voir dans quelle mesure l'efficacité de la subvention en dépend, et ce sous contrainte de faisabilité de la politique.

Enfin, la littérature de l'Energy Efficiency Gap s'est longtemps concentrée sur la réponse des ménages, i.e. de la demande, aux politiques publiques. Cependant, l'émergence des concepts issus de l'économie industrielle dans la littérature sur l'efficacité énergétique tend à montrer que la prise en compte des structures de marché modifie l'analyse. Plusieurs études mettent en évidence le haut niveau de concentration des marchés de l'efficacité énergétique (Fischer 2005, Houde 2012), montrant parfois empiriquement le recours des entreprises à des stratégies de discrimination telles que la différenciation en qualité des produits (Houde 2013, Cohen et al. 2014, voir chapitre 4). Ces stratégies ne sont pas neutres et peuvent alors contribuer à l'Energy Efficiency Gap. Elles peuvent en outre interférer avec les politiques publiques et altérer leur efficacité. Ainsi que le souligne Allcott dans sa dernière revue de littérature (2014), cette récente prise en compte de la structure des marchés dans l'évaluation des politiques publiques d'efficacité énergétique ne fait qu'entrouvrir les perspectives de recherche. Alors que les instruments de régulation et d'information (standards et labels) ont déjà fait l'objet d'études, les instruments incitatifs type subventions n'ont reçu que peu

²² Hunt et al. (2015) montrent par exemple que les « écolos » ont moins de barrières à l'investissement, en raison notamment d'une conscience accrue des problématiques énergétiques. Comment alors justifier constitutionnellement une politique discriminante selon les préférences environnementales ?

d'attention. La question du design des subventions peut notamment évoluer une fois les structures de marché prises en compte.

1.5. Le cas français : une information statistique longtemps inexistante ou indisponible.

L'analyse de l'efficacité des politiques publiques existantes s'inscrit dans le champ de l'évaluation ex-post des politiques publiques et requiert la disponibilité de sources statistiques à même d'identifier correctement leurs effets.

Alors que la littérature empirique naît aux Etats-Unis dès la 1^{ère} vague de politiques publiques d'efficacité énergétique, en s'intéressant principalement au crédit d'impôt américain mis en place entre 1977 et 1986 (Cameron 1985, Dubin & Henson 1988, Hassett & Metcalf 1995, etc.), très peu d'études économétriques ex-post ont été réalisées en France lors de cette période (Martin et al. 1998). Les premières études publiées de ce type sont celles de Daussin-Benichou & Mauroux (2012, 2014) évaluant le CIDD à partir de données fiscales. Ce retard peut s'expliquer par une moindre culture statistique dans le processus d'évaluation en France qu'aux Etats-Unis (Violette & Vantzis 2014), mais surtout, comme nous le verrons dans la section 3 puis plus en détails dans le chapitre 1, par la faible disponibilité des sources statistiques portant sur les consommations de biens durables énergétiques des ménages dans leur logement. Certaines sources statistiques existent cependant, bien que très peu exploitées à ce jour. C'est notamment le cas de l'enquête « Maîtrise de l'Energie ». Réalisée depuis plus de dix ans sur un panel tournant de 10000 ménages, cette enquête est entièrement dédiée aux comportements de consommation et d'investissement des ménages en matière énergétique dans leur logement. Les premiers travaux d'évaluation du CIDD de Risch (2013) constituent la seule mobilisation de ces données à des fins de recherche à ce jour, hormis ceux présentés dans cette thèse (voir chapitre 2).

Bien que d'un intérêt plus spécifiquement nationale, la conduite d'évaluation ex-post sur les politiques publiques françaises peut revêtir un intérêt scientifique de plus grande portée. Sur

les subventions notamment, bien que celles-ci aient été étudiées à de nombreuses reprises, des questions de recherche subsistent. Une des questions centrales que pose l'évaluation ex-post des subventions concerne l'additionnalité: combien d'investissement privé généré par la politique ? Or, de futurs travaux empiriques peuvent permettre de mieux comprendre de quoi dépend l'ampleur de cette additionnalité et quels sont ses facteurs d'hétérogénéité. L'effet des subventions est-il uniforme dans le temps, selon les ménages ou encore les types d'investissement? De quelle manière les subventions influencent-elles l'investissement (à la marge extensive ou intensive²³)?

Le défrichage de sources statistiques nouvelles peut enfin nous permettre d'améliorer la compréhension des déterminants de l'investissement dans la rénovation énergétique, travail d'observation essentiel à l'analyse de l'Energy Efficiency Gap. En effet, la microéconomie conçoit les biens durables énergétiques comme un stock S à partir duquel l'utilité provient d'un flux de services futurs, tels que le confort thermique dans le cas de la rénovation énergétique, qui en émanent en fonction de l'intensité d'utilisation de S et d'autres inputs complémentaires à S tels que l'énergie. Modéliser le comportement d'investissement revient à représenter l'arbitrage entre les coûts d'acquisition de S et les bénéfices futurs actualisés de son usage. Identifier l'Energy Efficiency Gap requiert donc de bien représenter tous les coûts et bénéfices, monétisés ou non, de la décision d'investissement. Disposer de données détaillées par type d'investissement de rénovation énergétique, comme c'est le cas pour l'enquête « Maîtrise de l'Energie », nous permet notamment de mieux comprendre si la problématique de l'Energy Efficiency Gap se pose de la même façon selon le type de technologie. Tout comme l'investissement dans la rénovation énergétique se distingue des autres types de biens durables énergétiques tels que les voitures ou les appareils ménagers²⁴, en quoi les types

²³ La marge extensive renvoie à l'effet sur la probabilité d'investir (sur le nombre d'investissement dans la population) tandis que la marge intensive renvoie à l'effet sur le niveau d'investissement (sur la dépense engendré par l'investissement).

²⁴ L'investissement dans la rénovation énergétique se distingue par son caractère irréversible (on investit sur des éléments partiels venant fusionner avec le bien immobilier), par sa « non-standardisation » (chaque rénovation est un « sur-mesure » conçu par les artisans, i.e. le marché aval de la rénovation, marché lui-même atomisé et hétérogène, augmentant encore l'absence d'uniformité), par l'importance de la problématique de l'effet rebond (l'ajustement du niveau de consommation du service énergétique après amélioration de l'efficacité énergétique y étant beaucoup plus probable que pour les appareils ménagers par exemple, cf Cohen et al. 2014).

d'investissements de rénovation énergétique, du simple remplacement de fenêtres à la rénovation BBC complète, sont-ils différents ? Surtout, en quoi la spécificité technologique de certains déterminants peut-elle impacter l'analyse de l'efficacité des politiques publiques ? Dans le cas de la comparaison entre rénovation énergétique et autres biens durables énergétiques, on voit bien notamment comment certaines caractéristiques techniques, telles que l'annexion au bien immobilier, engendrent leurs propres imperfections de marché, telles que les incitations clivées entre locataires et propriétaires par exemple.

1.6. Questions de recherche, plan et apports de la thèse

Cette thèse s'intéresse à l'analyse des déterminants de l'investissement dans l'efficacité énergétique, appliquée en priorité au résidentiel.

La thèse s'articule autour de deux axes de recherche, portant, l'un, sur l'analyse des déterminants de l'investissement des ménages, et l'autre, sur l'évaluation de l'efficacité des politiques publiques qui visent à le promouvoir. Les questions de recherche posées dans la thèse s'insèrent dans l'un ou l'autre de ces champs d'étude et renvoient chacune à un chapitre de la thèse. La thèse accorde une large part à l'évaluation des politiques publiques, celle-ci recouvrant trois chapitres sur quatre, en analysant leur impact à la fois sur la demande et sur l'offre. S'agissant de l'évaluation des politiques publiques du côté de la demande, le recourt parallèle à l'évaluation économétrique ex-post (chapitre 2) et à la modélisation prospective ex-ante (chapitre 3) permet de tirer profit de ces deux méthodologies complémentaires. La confrontation des deux méthodes permet en outre de révéler leurs apports et leurs limites respectives. Faut de données disponibles (voir section 3), l'évaluation des politiques publiques du côté de l'offre (chapitre 4) reste théorique.

Au vu du potentiel d'économies d'énergie qu'elles représentent, une attention particulière est accordée aux mesures de rénovation énergétique, bien que les parties théoriques de la thèse puissent être généralisables à d'autres biens durables énergétiques.

L'attention a de plus été portée sur les déterminants de l'investissement dans l'efficacité énergétique et non sur les déterminants de la consommation énergétique. Par manque de fiabilité des données dont nous disposons sur la consommation énergétique, les déterminants de l'ajustement post-investissement de la consommation (effet rebond) ont été placés en second plan, en se référant alors aux travaux d'Allibe (2012).

Axe 1 : analyse des déterminants de l'investissement dans l'efficacité énergétique du secteur résidentiel

Au sein des mesures de rénovation énergétique, les déterminants de l'investissement sont-ils technologiquement spécifiques? Quelles seraient les implications d'une telle hétérogénéité en termes de modélisation ou de politiques publiques?

La littérature conçoit le plus souvent l'investissement dans l'efficacité énergétique soit au niveau global sur l'ensemble des secteurs, soit au niveau d'une seule technologie et de ses substituts (les systèmes de chauffage d'un côté, les mesures d'isolation de l'autre). Situé entre ces deux approches, le premier chapitre de la thèse appréhende la rénovation énergétique dans son ensemble et analyse ses facteurs d'hétérogénéité. Comme toutes les parties empiriques de la thèse, il utilise les données de l'enquête annuelle « Maîtrise de l'Energie » de l'ADEME. Une analyse économétrique du choix d'investissement montre que certains déterminants de l'investissement sont technologiquement spécifiques.

Une première distinction est établie entre le remplacement des systèmes énergétiques et les mesures d'isolation de l'enveloppe du bâtiment étant donné l'importance spécifique accordée à la durée de vie des équipements dans la dynamique de remplacement des systèmes. Les rénovations « multiples », celle-ci se rapprochant le plus des rénovations « globales » permettant d'atteindre un niveau BBC, sont quant à elles fortement impactées par les spécificités du marché de l'immobilier, que ce soit par ses dynamiques propres (transfert de location ou de propriété) ou par la valorisation de l'efficacité énergétique (la valeur verte) sur ce marché. D'autres distinctions s'opèrent, entre systèmes conventionnels et systèmes innovants

notamment. Ce chapitre montre également comment l'influence des caractéristiques socioéconomiques est technologiquement déterminée.

L'influence hétérogène de la vétusté des équipements ou du marché de l'immobilier conduit à remettre en cause les modélisations du comportement ne tenant pas compte de la technologie ou la mise en œuvre de politiques publiques uniformes.

Ce chapitre est enfin l'occasion de faire une synthèse sur la disponibilité des données en France ainsi qu'une analyse critique des données d'enquête utilisées dans cette thèse.

Axe 2 : évaluation de l'efficacité des politiques publiques visant à promouvoir l'investissement dans l'efficacité énergétique du secteur résidentiel

Quelle est l'efficacité du Crédit d'Impôt Développement Durable (CIDD) mis en place en 2005 en termes d'investissement privé additionnel généré? Quel est son effet sur l'investissement à la marge extensive et intensive ? Son effet est-il hétérogène et, si oui, quels sont ces facteurs d'hétérogénéité?

Le chapitre 2 s'interroge sur l'efficacité des politiques publiques mises en place depuis les années 2000, période d'émergence des politiques publiques actuelles, en commençant par regarder la réponse des ménages, i.e. de la demande, aux politiques publiques en termes d'investissement privé additionnel. Il se concentre sur l'évaluation du CIDD en tant que principal instrument en termes de notoriété et de dépense publique. Disposant d'une période d'observation sur 2002/2011 à partir des données de l'enquête annuelle « Maîtrise de l'Energie », l'identification de l'effet du CIDD sur l'investissement est obtenue par une estimation en différence sur données de panel et en contrôlant de l'évolution temporelle des autres variables explicatives. Le cœur du chapitre est focalisé sur l'effet du CIDD sur l'investissement à la marge extensive et sur l'identification de « l'effet d'aubaine », autrement dit sur la part des consommateurs infra-marginaux ou « free-riders », bénéficiaires de la politique sans que celle-ci n'ait influencé leur décision d'investir. Au vue des données

disponibles, l'évaluation économétrique porte seulement sur les mesures d'isolation (parois opaques et vitrées).

Ce chapitre montre que le CIDD a eu un effet positif significatif sur l'investissement à la marge extensive, mais seulement deux ou trois ans après l'entrée en vigueur de la politique. Ce retard peut être expliqué par des effets d'inertie dus à la notoriété progressive du CIDD au sein de la population et au temps de maturation nécessaire à la prise de décision d'investir dans des travaux de rénovation. La part des « free-riders » est estimée entre 85 à 60% à partir de 2007 et se révèle décroissante dans le temps. Cette part semble également varier en fonction de caractéristiques socio-économiques des ménages et décroître lorsque le taux de subvention augmente. Si l'on considère que les fonds publics dévolus à l'efficacité énergétique sont limités, ces résultats suggèrent de mettre en place des subventions avec des taux de subventions élevés tout en restreignant leur éligibilité aux populations les susceptibles d'être impactées par la politique. Ils suggèrent également de mettre en place des dispositifs simples à appréhender et stables dans le temps.

En marge du chapitre, la même méthode d'identification économétrique est utilisée pour estimer l'effet du CIDD sur les montants d'investissements dans les mesures d'isolation (marge intensive). L'ensemble des estimations permet alors d'obtenir l'effet multiplicatif du CIDD, à savoir le montant d'investissement privé généré par euro de dépense publique.

Enfin, toujours en marge du chapitre, des éléments de réponse concernant la question soulevée au chapitre 1 « le CIDD impacterait-il différemment l'investissement selon le type de travaux », concordent avec l'idée que le CIDD n'a pas d'effet sur la marge extensive de l'investissement en cas de remplacement des systèmes énergétiques.

Au regard des études ex-post sur l'additionnalité des politiques et du projet loi 2015, les politiques annoncées permettront-elles d'atteindre les objectifs fixés? A défaut, quels changements de politiques publiques faut-il promouvoir, s'agissant à la fois de la nature des instruments mis en œuvre et/ou de leurs modalités d'application?

Alors que la littérature recommande le recours à des instruments type taxe Pigouvienne ou à des subventions davantage ciblées, le nouveau projet de loi sur la Transition Energétique n'en prend pas le chemin, revenant à un système de subventions uniformisé et sans renforcement des instruments type taxe Pigouvienne. Le chapitre 3 décrit les politiques envisagées et tente d'évaluer dans quelle mesure elles permettront d'atteindre les objectifs fixés. Il teste ensuite différents scénarios de politiques alternatives, en menant une comparaison « inter-instrument », entre subvention, prêt à taux zéro (EcoPTZ) et taxe carbone, et « intra- instrument », sur le design des subventions en particulier.

Pour ce faire, un modèle de simulation prospectif a été développé en collaboration avec le Service Economie et Prospective de l'ADEME, le Modèle ENergie et FIScalité (Menfis), qui représente l'évolution de la performance et de la consommation énergétique des logements français.²⁵ Au vu de l'importance des déterminants technologiques et pour pouvoir évaluer des politiques technologiquement spécifiques, ce modèle représente explicitement les mesures de rénovation énergétique via l'intégration d'un modèle thermique. Ce modèle endogénéise également les principales barrières à l'investissement d'ordre socioéconomique et technique et calibre les paramètres endogènes sur plusieurs sources statistiques sur 2008/2012. Ce travail permet notamment de quantifier l'importance relative des différentes barrières à l'investissement en termes de gisement d'économies d'énergie potentiel. L'horizon temporel de l'étude est 2025, correspondant à celui des objectifs de court terme et permettant de s'affranchir des dynamiques de long terme telles que le progrès technique.

Les résultats montrent que les politiques annoncées ne permettront pas d'atteindre les 38% de réduction de consommation énergétique, surtout si l'EcoPTZ continue d'afficher un taux de recours aussi faible qu'aujourd'hui. La combinaison du prêt à taux zéro une fois les contraintes d'accès levées et de la taxe carbone telle que recommandée par le rapport Quinet (2008) s'avère être la meilleure politique, tant du point de vue de la réduction des consommations énergétiques, que de l'analyse coût-bénéfice des investissements générés et de

²⁵ Le modèle Menfis fut créé par Gaël Callonnec du Service Economie et Prospective de l'ADEME. L'évolution du modèle et le travail de développement réalisé dans cette thèse sont décrits dans l'annexe A7 du chapitre 3.

l'équilibre budgétaire public. L'impact additionnel des subventions se révèle alors marginal dans ce scénario. Concernant les subventions cependant, les résultats montrent qu'il serait plus coût-efficace de mettre en place des subventions proportionnelles aux économies d'énergie qu'un système reposant sur un taux de subvention uniforme tel que pratiqué actuellement.

Les structures de marché non concurrentielles peuvent-elles contribuer à l'Energy Efficiency gap ? Comment l'efficacité des politiques publiques est-elle altérée par les stratégies industrielles et quelles sont alors les politiques optimales à mettre en place ?

Le quatrième et dernier chapitre de la thèse se concentre cette fois sur l'interaction entre les structures de marché de l'offre, l'Energy Efficiency Gap et l'efficacité des politiques publiques. Les marchés des biens durables énergétiques, en particulier ceux du secteur résidentiel, sont en effet caractérisés par un niveau de concentration élevé permettant la mise en œuvre de stratégies de discrimination des consommateurs, en particulier par la différenciation des produits. Le chapitre commence par apporter des éléments de preuve de l'existence de tels mécanismes dans le secteur résidentiel français. A l'aide d'un modèle théorique de microéconomie industrielle, ce chapitre regarde ensuite comment, en situation de monopole fournissant deux types de consommateurs ayant des dispositions à payer pour l'efficacité énergétique différentes, les stratégies de différenciation produit peuvent contribuer à l'Energy Efficiency Gap. Il évalue l'efficacité des politiques publiques dans ce cadre en recherchant d'abord les politiques optimales puis, selon une approche positive, en analysant des instruments simplifiés, plus proches des politiques observées. Les instruments étudiés sont les subventions, les standards et les taxes sur l'énergie. Etant donné la prépondérance des subventions ad valorem, le plus souvent versées sous condition d'efficacité énergétique minimale, une attention particulière est accordée à la comparaison entre subvention ad valorem et spécifique (i.e. indépendante du prix), ainsi qu'au niveau de taux optimal des subventions.

Les résultats montrent que des stratégies de discrimination en prix/qualité sur des biens durables énergétiques dans une situation de monopole imparfaitement discriminant peuvent être une explication possible de l'Energy Efficiency Gap. Dans un cadre normatif, toutes

combinaisons de deux types d'instruments, parmi les subventions, les taxes et les standards, ainsi que toutes combinaisons de deux niveaux ou taux au sein du même instrument, permettent de rétablir l'optimum social, avec cependant des effets distributifs différents. L'analyse des subventions ad valorem révèle un effet pervers de détérioration de la qualité du bien le plus énergivore lorsqu'on cherche à subventionner le bien le plus énergétiquement efficace. Cet effet pervers, spécifique à la subvention ad valorem, confère un avantage comparatif à la subvention spécifique lorsque les subventions ne portent que sur le bien le plus énergétiquement efficace, ce qui est souvent le cas en pratique. Les résultats suggèrent également un niveau de taxe Pigouvienne sur l'énergie optimale plus élevée que le niveau d'externalité négative, venant ainsi interpellier le résultat contraire classique en situation de monopole.

1.7. Remarques introductives sur l'accès aux données: le défi de l'observation et de l'évaluation empirique.

Dès lors qu'on souhaite analyser empiriquement un mécanisme, se pose la question de l'accessibilité des données et de leur qualité. Observer l'investissement dans la rénovation énergétique est particulièrement compliqué en raison du faible taux de rénovation dans la population et de l'hétérogénéité des mesures de rénovation énergétique. Ces deux caractéristiques supposent de récolter un niveau d'information suffisamment précis et de construire des échantillons suffisamment grands afin d'obtenir des résultats statistiques significatifs. Cela pose notamment problème lors de l'exploitation d'enquêtes généralistes issues de la statistique publique. Les travaux de Charlier sur l'enquête Logement de l'INSEE (2006) ont notamment montré les apports et les limites de telles données. De plus, particularité française, les statistiques énergétiques ainsi que leur exploitation ont été jusqu'à aujourd'hui essentiellement du ressort du CEREN, centre de recherche privé affilié aux fournisseurs d'énergies historiques et à l'ADEME, et non de la statistique publique. La prise de conscience actuelle des enjeux énergétiques semble cependant bouger légèrement les lignes comme nous le montre la réalisation de l'enquête PHEBUS en 2013/2014 par le SOeS, le Service

d'Observation Statistique du *ministère de l'Ecologie, du Développement durable et de l'Energie*, entièrement dédiée aux comportements de consommations énergétique et à l'efficacité énergétique des équipements.

Cette relative rareté des sources sur le sujet justifie l'intérêt porté tout au long de la thèse aux données de l'enquête « Maîtrise de l'Energie ». Comme toujours lorsqu'on se retrouve dépositaire de données issues d'une enquête que l'on n'a pas conçue, la nature des données conditionne les questions de recherche auxquelles il est possible de répondre et les méthodes économétriques qu'il est possible d'utiliser. Quelques remarques introductives me semblent ainsi nécessaires pour comprendre les partis pris méthodologiques de la thèse.

Pour contextualiser, deux types de données sont récurrentes au sein de la littérature: les données de « préférences révélées » d'une part, issues de l'observation des caractéristiques des ménages et des biens lors d'investissements réellement effectués par les ménages, et celles de « préférences déclarées » d'autre part, issues de déclarations des ménages. Les préférences révélées peuvent provenir d'enquêtes ménages, de données administratives (données fiscales), ou encore de bases de données du secteur privée (de la grande distribution notamment). Les déclarations à l'origine des « préférences déclarées » concernent soit des investissements réellement entrepris par les ménages, soit des choix hypothétiques conçus dans des enquêtes de « choice experiment »²⁶.

Les préférences révélées sont le plus souvent utilisées dans l'évaluation ex-post des politiques publiques, laquelle nécessite en effet l'observation de choix réels. Des méthodes économétriques propres à l'évaluation des politiques publiques sont alors utilisées (estimation en différence, double différence, matching, régression en discontinuité, etc. Givord 2010). Il s'agit, au vue des données disponibles, d'utiliser toutes les discontinuités possibles dans les mécanismes à l'étude pour identifier leurs effets causaux. Récemment, les techniques de « randomisation » ont fait leur apparition dans la littérature sur les politiques d'efficacité énergétique. A l'image des expérimentations de biologie ou de médecine, il s'agit de construire

²⁶ Il existe cependant une ambiguïté dans la littérature. Pour certains chercheurs, les préférences déclarées (stated preferences) renvoient uniquement aux enquêtes de choice experiment (Train & Atherton 1995, Axsen et al. 2009), pour d'autres non (Michelsen & Madlener 2012).

un protocole d'enquête contenant en lui-même l'identification de l'effet causal de la politique. Ces expérimentations aléatoires contrôlées sont néanmoins très coûteuses et nécessitent un important travail en amont en partenariat avec les décideurs politiques, ce qui explique qu'aujourd'hui peu de projets de recherche soient en mesure de les mettre en place²⁷.

Les enquêtes de choice experiment sont quant à elles spécifiquement construites pour tester des hypothèses de recherche sur les comportements d'investissement. Rivers & Jaccard (2005) conçoivent leur enquête pour estimer les coûts intangibles des investissements d'efficacité énergétique dans le secteur industriel, Mau et al. (2008) conçoivent la leur pour estimer le « neighbor effect » tandis que Farsi (2010) s'intéresse à l'effet de l'aversion au risque ou que Martin (2011) essaye de dissocier les préférences associées aux bénéfices environnementaux de celles associées aux économies d'énergie. Les enquêtes de choice experiment ont en outre le grand intérêt de fournir des données appropriées pour l'estimation de modèles structurels de choix discret, lesquels permettent notamment d'inférer des dispositions à payer et des taux d'actualisation implicites. Ces données contiennent en effet tous les attributs spécifiques à chaque alternative d'un ensemble de choix préalablement défini, ce qui n'est pas le cas des données de préférences révélées, où seule l'alternative choisie est observée. Dans certains cas, des techniques économétriques existent pour reconstituer l'ensemble de choix en reconstruisant les attributs des alternatives non-choisies à partir de l'information disponible²⁸ et ainsi estimer des modèles de choix discret à partir de données de préférences révélées. Cependant, ces techniques sont très difficiles à appliquer aux mesures de rénovation énergétique en raison de leur caractère très hétérogène.

Les données de l'enquête « Maîtrise de l'Énergie » font partie des « préférences révélées », justifiant le recours aux méthodes économétriques propres à l'évaluation des politiques publiques. Il est à noter toutefois qu'un travail effectué en première année de thèse (et présenté à la conférence IAEE de Venise 2012) a tenté d'estimer un modèle économétrique structurel de choix discret à partir de ces données d'enquête. La première étape consistait à recréer l'ensemble des alternatives non-choisies de l'ensemble de choix à partir de l'information

²⁷ <http://e2e.haas.berkeley.edu/> pour plus d'information sur les recherches menées aux Etats-Unis.

²⁸ Pour un exemple de ces techniques, voir (Fortin et al. 2010).

statistique disponible. J'ai considéré qu'en raison d'une trop grande hétérogénéité des alternatives et/ou d'un manque d'information statistique, les résultats économétriques de cette première étape étaient cependant trop faibles pour permettre de poursuivre convenablement ces travaux.

L'accessibilité des données est encore plus compliquée du côté de l'offre des marchés de la rénovation énergétique. Outre la dispersion de l'information sur le marché en aval (les artisans), la teneur stratégique des données industrielles rend tout accès à ces données difficile aux chercheurs indépendants. A l'origine du chapitre 4, un travail de recherche sur la disponibilité des données fut menée afin d'explorer les questions de recherche de manière empirique. Il s'agissait notamment d'observer l'effet du CIDD sur les prix des équipements. Parmi les sources statistiques disponibles, telles que l'enquête à l'origine de l'Indice des Prix des travaux d'Entretien-Amélioration des logements (IPEA) du SOeS²⁹, ou encore les enquêtes des observatoires Observ'ER ou OPEN³⁰, aucune n'en permettait l'identification. Cette absence de données explique l'approche théorique finalement adoptée dans le chapitre 4. La quasi-inexistence des données sur le secteur tertiaire explique également sa mise à l'écart de cette thèse.

²⁹ <http://www.statistiques.developpement-durable.gouv.fr/indicateurs-indices/r/indice-prix-lentretien-amelioration-ipea.html>

³⁰ Observ'ER, l'observatoire des énergies renouvelables, réalise des enquêtes pour suivre l'évolution des marchés des pompes à chaleur et du solaire thermique. Les données de prix ne permettent pas d'études économétriques (échantillons trop faibles, données trop peu détaillées et provenant de déclarations des installateurs et non de transactions). Les données de l'enquête réalisée auprès des industriels par l'Observatoire Permanent de l'amélioration Énergétique des logements (OPEN 2009) sont également inappropriées. Toutes ces enquêtes sont en outre privées.

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Chapter 1 Energy efficiency investment drivers depend on the technology: an econometric study based on households' investment choices.

1. Introduction and motivations

Since the 2000's, the implementation of French public policies dedicated to the promotion of energy efficiency investment of the residential building stock have been progressively developed: a reduced value-added tax (VAT) since 1999, an income tax credit called *Crédit d'Impôt Développement Durable (CIDD)* since 2005, an Energy Performance Diagnosis (EPD) since 2006, a zero rate loan since 2009, a new thermal regulation since 2012, a lump-sum premium in 2014. Their design has also rapidly evolved. The evolution of the CIDD tax credit is a good illustration of the compromise between the efforts to improve cost-efficiency while limiting public cost and the lobbying from the supply side. After a period of increasing refinement from 2005 to 2014 in order to make the CIDD relevant to each specific situations,³¹ we are assisting to the return of a simplified CIDD scheme for 2015: entirely harmonized, the CIDD will subsidize all eligible energy efficiency investments at 30% of their material cost whatever the retrofitting type or the households' situations.³² The arbitrage between these two forces, precision vs simplification, has been a big issue in the policy debate. Critics have risen

³¹ To give some examples: between 2006 and 2009, tax credit rates were increased from 25% to 40% of material costs for energy conservation measures in old buildings (built before 1977) only in case of recent housing transfer, since 2009, labor costs have been eligible to the CIDD subsidization but only for building envelope insulation measures, since 2012, tax credit rates have been majored only in case of certain retrofitting combinations or minored in case of windows, etc. (see chapter 2)

³² *Projet de loi relatif à la transition énergétique pour la croissance verte*, <http://www.assemblee.nationale.fr/14/projets/pl2188.asp> puis <http://www.senat.fr/leg/pjl14-016.html>.

against this increasing refinement arguing that such complexity prevents households from understanding the policy. However, we can wonder if the opposite view, a unique rate level for all investments, is a better answer. Allcott (2014) notably recommends to implement “consumer-specific subsidies tailored to each consumer’s bias”.³³ This arbitrage between specialization and generalization raises questions about the heterogeneity of investments addressed by the policy. How do heterogeneous investment drivers impact households’ response to the policy? What are the implications in terms of policy design?

These questions regarding investment heterogeneity, both in terms of drivers and policy response, are also at stake for simulation modelling works. In the recent literature on energy-economy models dealing with the French residential sector, we observe diverging views regarding the appropriate level of heterogeneity to consider. Allibe (2012) and Charlier & Risch (2012) adopt a technically explicit approach detailing retrofits (window insulation, wall insulation, heating system replacement, etc.), while Giraudet et al. (2012) represent energy-conservation investments without specifying technologies. Endogenous modelling regarding retrofitting dynamics differ as well. In Giraudet et al. (2012) and Charlier & Risch (2012), the cost-benefit analysis, integrating both economic and non-economic factors, impacts both the extensive and the intensive margins of the retrofitting investments.³⁴ In Allibe (2012) however, investments are partly driven by technological factors: investment decision (the extensive margin) is exogenously triggered by the end of the life time of each building element while energy efficiency level (the intensive margin) is endogenously determined by a household’s optimization. The latter modelling has strong implications in terms of policy response: an economic incentive raising the economic profitability of an investment cannot increase the investment at the extensive margin and thus cannot impact the dynamics of renovation.

In the empirical literature, analysis on energy efficiency investment determinants are based on the observations of “revealed” and/or “stated” preferences. Revealed preferences come from the observation of households’ and housing’s intrinsic characteristics when

³³ “Consumer’s bias” can be considered as all the investment barriers reviewed in the introduction. Recall that, among all the investment barriers, only the market imperfections can justify public intervention.

³⁴ The effect on the extensive margin of the investment is the effect on the probability of investing while the effect on the intensive margin is the effect on its intensity level (quality/quantity).

households make real investment choices. Stated preferences come from subjective declarations on the importance of attributes specific to the choice alternatives. Such declarations concern either real investment choices or hypothetical ones designed in choice experiment surveys.

When relying on real households' choices (1150 subsidized investors), Michelsen & Madlener (2012) investigate how German homeowners decide in favor of certain type of innovative residential heating system based on renewable energies (gas- or oil-fired condensing boilers with solar thermal support, heat-pumps or biomass-fired boilers) "by means of a combination of stated and revealed preferences data" in order to provide some information about households' preferences on economic and non-economic costs and benefits (purchase cost, energy savings, comfort, independence from fossil fuels, environmental protection, social image, etc.). Using multinomial logit models, they found that, when the adoption decision takes place in new construction, the preferences for heating system attributes play a different role depending on the system type. For instance, independence from fossil fuels (resp. expectations on energy savings) favors relatively more wood systems and heat-pumps (resp. condensing boilers). In case of systems replacement in existing dwellings, socio-economic variables matter more in households' decision than the preferences for heating system attributes.

Still relying on real households' choices, Jakob (2007) analyzes the barriers and drivers of building envelope insulation in Swiss single-family houses using a survey gathering objective characteristics and households' subjective perceptions. He conducts parallel studies on the technical, legal and economic dimensions as well as on their motivations. He finds that investment is triggered by general renovation activity such as building extensions, by the end of the element lifetime and by concerns regarding the energy savings and the Environment. Only the latter leads to the most energy-efficient renovations.

However, these two studies are restricted to certain retrofitting types, either on innovative heating systems (Michelsen & Madlener 2012) or on insulation measures (Jakob 2007). To our knowledge, the related literature using choice experiment surveys also restricts the analysis to certain retrofitting types. Indeed, studied alternatives are generally close

substitutes such as different heating systems (Bigano & Alberini 2014) or different micro-generation technologies (Claudy et al. 2011). An exception is Jaccard & Dennis (2006) who compare discount rates estimates for households' investments in insulation and in heating systems and find lower discount rates for heating systems (10%) than for insulation (20%).

Existing studies which compare the investment drivers of different retrofitting types are generally based on more generalist surveys. Charlier (2012) uses the 2006 Dwelling survey, conducted by the French National Institute of Statistics (INSEE) to look at the determinants of expenditures distinguishing between insulation works, heating system installation/replacement and non-energy retrofitting (repair). The study finds for example that households' income is a discriminatory variable for expenditures in repair works but not in energy efficiency renovation, while tenure (owner-occupier vs tenant) is significant for expenditures in energy efficiency renovation but not for replacement expenditures. Using the American housing survey, Gans (2012)³⁵ compares energy efficient investments with non-energy "cosmetic" ones. He finds that the planned tenure has a negative effect only in case of energy efficient investment and concludes that households do not believe in the possibility to capitalize the green value of their dwelling in the housing market. However, such data do not include any stated preferences on investment drivers. Finally, other studies belonging to the ex-post policy evaluation literature, like in Grösche & Vance (2009), are based on the same kind of surveys. They use the differences in retrofitting types to provide heterogeneity between the choice alternatives in order to estimate discrete choice model. Therefore, they implicit assume a homogenous policy response among all the retrofitting alternatives.

In this paper, we analyze through an empirical investigation how the determinants of the investment decision vary with retrofitting categories and discuss the implications of their heterogeneity in terms of investment modelling and policy design. We use data from the French annual survey « Energy Management » (EM) dedicated to residential energy efficiency over the period 2007/2012. Whereas previous works are usually restricted to certain retrofitting type,

³⁵ He chooses heater investment to represent energy efficient investment and use a bivariate probit model of the joint decisions for planned decision and renovation investment (and a 2SLS model) on an unbalanced panel data set of 42019 individuals in the US.

this paper adopts a broader perspective dealing with all types of energy-efficient investments. The studied retrofitting types all involve energy efficiency investment but they are distinguished between conventional systems replacement (heating, water-heating and ventilation), innovative systems (heat-pumps and renewable energy equipment), glazed surfaces insulation, opaque surfaces insulation and multiple-measures retrofit. Since these retrofitting categories differ in terms of disturbance, complexity, level of risks or uncertainty, environmental benefits, etc., we use their intrinsic differences to provide insights on households' preferences. Moreover, in line with Michelsen & Madlener (2012), we propose to assess the determinants of the French households' retrofitting investment decision estimating a multinomial logit model on data combining both revealed and stated preferences. To our knowledge, such approach is still quite rare, especially in France.

We find a heterogeneous influence on the investment decision of both revealed and stated preferences. A first distinction is made between investments in energy systems and investments in building envelope insulation. Drivers such as the opportunities created by recent move-in or access to ownership, other non-energy retrofit and the expectations regarding the green value are more specific to multiple-measures retrofitting. Secondary distinctions can be made inside the heating systems category between "conventional" systems (boilers, radiators) and "innovative" ones (renewable energy equipment, heat-pumps) given the heterogeneous influence of the "wear and tear", the economic profitability, the age of the building, the households' income and their socio professional category. Besides, investments in glazed surfaces insulation share more similarities with investments in conventional heating systems than with investments in opaque surface insulation.

The remainder of the paper is structured as follows: section 2 provides an overview of the French context, section 3 describes the survey and the variables. Section 4 and 5 respectively present the econometric model and the results, before concluding in section 6.

2. The French context.

Although energy performance in buildings has become a major stake in climate policy, French empirical literature is tiny. The first wave of concerns and public policy emergence as regards dwellings' energy efficiency occurred in the 1970's in the post oil crisis period. However, to our knowledge, it has not led to the development of ex-post empirical policy assessments (Leray & de la Roncière 2002, Martin et al. 1998), by contrast with the U.S. in particular. During the current wave of concerns related to global warming, empirical studies have started to emerge. As mentioned above, Charlier (2012) uses the 2006 Dwelling survey (Enquête Logement) conducted by the French National Institute of Statistics (INSEE) to analyze household's expenditures in renovation works. Mauroux (2012) and Daussin-Benichou & Mauroux (2014) use fiscal data over 2005/2008 to assess the French income tax credit implemented to encourage households' investment in energy conservation and renewable energy equipment in their dwellings (see chapter 2). However, in both cases, data do not provide much information as regards the nature of the households' energy efficiency investments. In the fiscal data, there is no information on the retrofitting type or on any circumstances. In the 2006 Dwelling survey, there is a chapter of questions on retrofitting investments³⁶ but without any special focus on energy efficiency. Moreover, French dwelling surveys contain too few retrofitting observations given the low retrofitting rate among the population (687 with insulation measures and/or equipment installation/replacement out of a sample of 17000 households in 2006).

Actually, French public statistics have not historically dealt with the issues related to buildings' energy performance and retrofitting investment. To illustrate that point, French institutions involved in residential energy efficiency (CGDD, ADEME, CSTB, ANAH, EDF, etc.) have been coordinating for the first time in 2013/2014 to build a first survey dedicated to households' energy consumption and investment in their dwellings.³⁷ Other existing data sources have been restricted to private research. The CEREN, the French statistical office on the

³⁶ As well as in the Family Budget survey made by INSEE.

³⁷http://www.statistiques.developpement-durable.gouv.fr/sources-methodes/enquete-nomenclature/1541/0/enquete-performance-lhabitat-equipements-besoins-usages.html?tx_ttnews.

energy sector under the supervision of ADEME and historical national energy suppliers, has built a panel of households dedicated to residential energy consumption and investment.³⁸ Finally, ADEME has funded at least two surveys dedicated to residential energy consumption and investment: the EM survey, from which our data come, since the late 1980's (see section 3 and appendix A2) and the OPEN survey after 2005. Data from OPEN survey are owned by the private statistical office BIIS and are complicated to use.³⁹ Data from the EM survey have been made available on request for researchers since 2010 (see appendix A2) and have already been used by Risch (2013) to assess the French Income Tax credit system (see chapter 2).

3. Data

3.1 The EM survey⁴⁰

ADEME, the French Agency for Environment and Energy Management, has funded since 1986 an annual survey called “the Energy Management survey” (EM survey) entirely dedicated to residential energy consumption and investments in dwellings' energy efficiency. Around 10 000 households answer a first questionnaire providing socio-economic variables, housing information (type of building, heating energy source, building date, etc.), and information about dweller's situation (occupation status, move-in date). Those who have invested in energy efficiency retrofitting during the last year (around 10% each year) answer a second questionnaire providing information on retrofitting types, investment costs, some payment modalities, the economic or non-economic incentives investors have benefited from (including tax credit), as well as other qualitative information such as their motivation, personal context, satisfaction, etc. In this second questionnaire, each investment is described by 1 to 4 items taken from a retrofitting options list. Retrofitting options include insulation (external insulation

³⁸ The access to this panel is restricted to the CEREN. I have asked to get access to the data at the beginning of my PhD thesis but my request has been rejected. The CEREN also conducts surveys dedicated to the replacement of heating systems (CEREN 2014).

³⁹ I have tried to use these data since Ademe and Biis allowed me to have access to the households' database. However, it was not worth the data cleaning required to exploit these data given their redundant nature compared to the EM survey. The suppliers' database, which would have had a real added-value to the EM survey has never been available, although I also made a request at the beginning of my PhD thesis.

⁴⁰ This section is very similar to section 3.1 in chapter 2. This repetition has been done to make independent the two chapters.

of wall, internal insulation of wall, roof, attic, ceiling, windows, shutters), heating system improvement (thermostatic valves, heat cost allocators, ambient thermostat, programming equipment), new heating system (radiator, boiler, wood stove, heat-pump, solar heater) or heating system replacement (with information on fuel switching). Multimodal questions on the barriers and drivers of households' investment have been included in the survey since 2002 (2004 for the barriers) but the modalities have been stabilized only from 2007, that is why we use data over 2007/2012.

These annual surveys have been conducted by the French Market Institute TNS-SOFRES and have aimed to provide static annual observatories rather than research studies. An important work of harmonization has therefore been done in order to build consistent time series (see appendix A2).

3.2. Variables⁴¹

The aim of this study is to observe how revealed and stated preferences vary with the retrofitting type. Revealed preferences refer to households' and housing characteristics while stated preferences refer to households' declaration on investment drivers.

We only include in the analysis occupying-homeowners as the EM survey imperfectly measures the energy retrofitting of the rented dwelling stock (see appendix A2). We also exclude from the sample new buildings (i.e. built the year of the survey) not concerned by the retrofitting.

"Single measure" retrofitting categories are: the insulation of opaque surfaces (roofs, walls, floor, ceiling), the insulation of glazed surfaces (mainly windows), the installation of "conventional" heating systems (gas or fuel boilers and radiators), the installation of heating regulation and ventilation systems, the installation of "innovative" heating systems (heat-pumps or renewable energy equipment such as wood heating system and solar water heater). "Multiple measures retrofits" combine at least two single measures as previously described. Investments in these retrofitting categories differ in terms of:

⁴¹ The description of the household and housing characteristics is very similar to the one in section 3.2 in chapter 2. This repetition has been done to make independent the two chapters.

- costs (higher for global renovation),
- lifetime (shorter life duration for systems and windows than for building envelope insulation),
- energy efficiency (higher for global renovation),
- independence from fossil fuels (renewable energy vs gas/fuel),
- environmental impact,
- hidden costs related to disturbance (higher for building envelope insulation),
- technical and logistic complexity (higher for multiple-measures retrofit),
- risks, uncertainty (higher for innovative systems or retrofits requiring higher workers skills).

Households' and housing characteristics variables are selected on the basis of the literature on household investment modeling in residential energy efficiency (Cameron 1985, Dubin & Henson 1988, Jakob 2007, Michelsen & Madlener 2012). The basics of those models consist of calculating the return on retrofitting investment by comparing initial cost with future economic savings in a cost-benefit analysis, in which technological, socio-economic and contextual constraints can interact.⁴² The **socio-demographic variables** influencing the investment decision in the model are the *Annual income of the dwelling*, the *Socio-professional category*, the *Family size* and the *Age of the head of the household*. The *Annual income of the dwelling* determines the households' financial possibilities and their opportunity cost of time.⁴³ This variable is also a proxy for households' discount rate, included in each profitability calculation. Indeed, several studies showed that the discount rate, in other words the preference for the present, decreases with income (Train 1985). Therefore, higher incomes can promote investment with longer life duration or payback period. Given the life cycle theory, the

⁴² The selection of such variables is similar to the one in chapter 2, except that we do not include information on energy heating sources and price in order to keep a larger sample.

⁴³ Since the information collection and the implementation phases of a retrofitting project are time consuming.

Age of the head of the household or the *Family size* may reflect the financial and situational constraints of the dwelling. Distinguishing between *Entrepreneurs* (in a wide meaning including farmers and retailers), *Managers* (including *Liberals professions*), *Employees* and *Inactive*, the *Socio-professional category* captures aspects linked to education and the opportunity cost of time. The level of education or the heterogeneity of professional skills can also modify the preferences toward innovation and uncertainty. Rogers' theory on innovation diffusion categorizes adopters into innovators, early adopters, early majority, late majority and laggards. It notably describes innovators as individuals willing to take risks, with the highest social status and with financial liquidity (Rogers 1962).

The *Building completion date* and the *Building type* are the **home characteristics** variables included in the model to describe the energy performance and the importance of energy consumption, conditioning the profitability of the investment. The *Building completion date* is segmented following the evolution of the French thermal regulations. The *Building type* variable, which differentiates between individual houses and collective flats, also reflects the difficulties inherent to the collective decision process for households living in multi-family dwellings. The *Heating degree days (HDD)* and the *Category of city* are used to represent the **climatic and spatial characteristics of the dwelling**. The *HDDs* are regional averages taken from external data source.⁴⁴ They influence the energy performance of a retrofitting investment, as the energy needs vary according to the outside temperature. The *Category of city* allows for the differentiation between urban and rural regions and captures aspects such as storage space availability (for fuel or wood) or supply-side structure of the residential energy efficiency market.

The **stated preferences** are captured by households' declarations as regards their motivations to retrofit. These variables come from two questions in the second questionnaire: ***“Among the following list, what was the main reason why you invested in retrofitting?”*** and ***“In addition to this first motivation, what were the two main supplementary incentives among***

⁴⁴http://www.statistiques.developpement-durable.gouv.fr/energie-climat/r/statistiques-regionales.html?tx_ttnews. Heating degree day (HDD) is a measurement of the gap between outside temperatures and an inside temperature of comfort. These HDD are averaged over the period 1981/2011 for each region in order to avoid taking into account annual variations.

the second list below?'. The non-response rate is respectively 2% and 10% for the first and the second questions. For the first question, modalities are: *the reduction of the energy bill, comfort improvement, thermal insulation, acoustic insulation, ventilation, the replacement of an old heating system, the green value of the real estate asset, other*. For the second question, they are: *the access to ownership, a recent move-in, other non-energy retrofitting, a subsidy, a zero rate loan, a classical loan, another financial support (family, inheritance), tax credit, reduced VAT, energy performance diagnosis, advertisement, institutional information, personal advices, external decision (co-ownership)*. Some modalities have been gathered or excluded from the analysis in case of marginal importance. The following section links these modalities with the type of preferences they reflect.

Perceived economic profitability of the investment

As regards economic profitability, the EM survey distinguishes between two types of future benefits: the *Savings on the Energy Bill* and the *Green Value*. The first motive refers to the use of a durable good whereas the second one refers to the capitalization of an asset. The perception of the green value means that households believe that they can get benefits from the capital appreciation of their asset. This solves problems related to the possibly long payback period of such investments. The presence of a green value is an emerging theme in the empirical literature (e.g. Gans 2012). In France, the *Energy Performance Diagnosis EPD* has been mandatorily joined in each real estate transaction since September 2006 (and mandatorily posted in the real estate advertisement since 2011). A study based on French notary database (DINAMIC 2013) suggests a significant effect on the real estate pricing.

Contrary to Michelsen & Madlener (2012) or other purposely designed surveys, the EM survey does not explicitly ask households to weight the importance of the up-front costs, which is notably useful to compare with the weight of the anticipated future gains and to infer a discount rate. However, questions as regards economic incentives decreasing up-front costs can be used as proxy for the ponderation on up-front costs. The incentives perceived as the most important are the *Tax credit* referring to the CIDD income tax credit nationally implemented since 2005 (see Chapter 2) and the *Reduced Value Added Tax (VAT)* having been reduced from

19.6% to 5.5% (or 7% depending on the year) since 1999 for energy efficiency retrofitting. However, incentives such as tax credits can also act as a signal, conferring credibility to certain goods through the approval of the regulator and therefore adding an “announcement effect” to the first “price effect” (Koomey 2002). The *Other financial support* variable gathers all the other economic incentives (mainly soft loans including zero rate ones from 2009 and other financial support such as family inheritance) which are more related to the problem of liquidity constrained faced by the households.

Subjective importance attributed to information provision

Most of market failures discussed in the energy efficiency gap literature refer to imperfect information (Gillingham & Palmer 2013). Among them, the households’ lack of knowledge/awareness on energy retrofitting can be improved by information provision programs (Allcott & Greenstone 2012). In the EM survey, public information provision is embedded by *Institutional information*, provided by the French Agency for Environment and Energy Management (ADEME) and its territorial agencies called Energy Info Office (Espace Info Energie EIE), and by the *Energy Performance Diagnosis (EPD)*. Note that the visibility of the EIE is quite thin among households: over 2007/2012, between 20 and 29% of households of the studied sample knows the EIE, and between 4 and 7% of them has already contacted them. Already presented as a signal on the housing market regarding the problematic of the green value, the EDP can also be an indicator for the energy savings potential. Information provision can also come from the private sector, through an *Advertisement*, that is standardized marketing information, or from *Advices*, i.e. information got either from a relative or a professional in an inter-personal relationship. Such information provision variables can also reflect the weight of hidden costs linked to search cost though we do not know the degree of passivity of the household in the information acquisition.

Contextual factors

Contextual factors can be related to the state of energy performance of the dwelling. The fact to reach the end of a building component lifetime and to require its replacement is referred by the household as the break beyond repair or the necessity to retrofit a deteriorated

building element and is synthesized in the “*wear and tear*” dummy. *Other non-energy retrofitting* undertaken for other motives (“cosmetic” types of investment, dwelling extensions, etc.) can also offer an opportunity for energy efficiency investments. In both cases, the fact to invest anyway in some retrofitting changes the counterfactual of households’ decision. Compared to the default alternative, the up-front costs of the energy-efficiency investment is only the surplus due to the energy efficiency improvement (insulation layers, the differences between the standard and the high energy efficiency system, etc.), whether for economic or non-economic costs (such as opportunity cost of time, decision inertia, discomfort due to the works etc.).

Other contextual factors concern the situation of the household in the dwelling: *a recent move* into a new dwelling can trigger households’ investment decision. The period of transition is often considered as an appropriate timing to retrofit (empty dwelling, non-energy retrofitting to be done, etc.). Correlated to a new move-in, the access to ownership often means access to the credit market and triggers the investment decision in overcoming the barriers linked to split incentives between landlords and tenants. In the absence of green value and assuming a period of occupancy long enough, a new move-in or a new ownership also mean that the household is more likely able to recover the initial investment over the starting period of occupancy. Finally, the respondents can precise if the investment decision did not exclusively belong to them (made by the *Co-ownership* for example).

Other non-energy and non-economic attributes

The retrofitting provides other non-energy or non-economic retrofitting-specific benefits such as *Comfort*, *Acoustic insulation* and *Thermal insulation*. The desire of *Comfort* can be related to sensorial attributes (the sensation of warmth, the diminution of cool air streams), health attributes (air sanity) or even aesthetic attributes. However, due to the nature of data (see the last paragraph of this section), the information on hidden benefits is rather restrained in the EM survey. Also note that the modality “Thermal insulation” is structurally correlated with surface insulation measures and does not provide any information regarding the corresponding non-economic benefits it refers to. However, since each investor answers two

modalities in the second question, we keep this modality to avoid treating differently surface insulation measures and other retrofitting.

General concerns

Finally, we capture **general stated preferences** about the environment and the economic context, possibly revealing environmental preferences. In the EM survey, households are hence asked every year to prioritize their concerns about diverse socio-political issues. We include three dummy variables called *Unemployment*, *Climate Change*, and *Energy savings*, which equal one if the households consider that problems related to respectively unemployment, climate change and promoting energy savings are one of their top priorities.

Before presenting the method, recall that as the EM survey is not purposely designed for investment modelling, some imperfections characterize its design. First, households have to answer only one modality in the first question and two in the second one (see section 3.1). Therefore, the absence of answer on another modality does not systematically mean that the corresponding incentive does not matter. Second, the stated preferences variables are not exhaustive and do not systematically reflect precise alternative-specific attribute.⁴⁵ For example, hidden benefits related to environmental preferences are not explicitly mentioned or we cannot say if the subsidy matters for its economic profitability or its “announcement effect”. In some sense, such data are less accurately designed than stated preferences from choice experiments to provide precise quantification (such as the estimation of households’ discount rate).⁴⁶ However, such data do not suffer from the “hypothetical bias”⁴⁷ and constitute a homogenous and rather large database fitted for this exploratory research.

⁴⁵ We would have preferred that the EM survey allows households to answer negatively or positively for each modality with a system a quantification to weight each positive or negative answer. In December 2013, I asked Ademe and TNS Sofres to modify the modalities in future surveys in order to be more accurate in terms of research questions but they argued that the continuity of the survey should not be broken.

⁴⁶ Choice experiment surveys provide data containing all the required attributes variables for all the alternative of the choice set, which is particularly useful to estimate structural choice models.

⁴⁷ “Consumers might have a tendency to say that they would purchase a high efficiency appliance more readily than they actually do” (Train & Atherton 1995). This is probably the case for the very high WTP for CO2 savings in Farsi (2010) for example.

4. Method⁴⁸

In order to rank the preferences in order of importance and to get intuitions regarding their discriminating power, we first draw up statistics on the distribution of each revealed and stated preferences variables distinguished by the retrofitting categories described in section 3.2.

Second, in order to capture the effects of each driver *ceteris paribus*, we estimate a multinomial logit explaining the choice between each retrofitting type made by households in function of all revealed and stated preferences variables. The multinomial logit model is a basic among the Random Utility Maximization models. Such models assume that individuals make their choices optimizing their level of utility. The utility associated with individual *i* choosing the alternative *j* is $V_{ij} + \varepsilon_{ij}$, composed of an observable part V_{ij} and a random term ε_{ij} which corresponds to elements unobservable or unknown by the modeler. The probability that individual *i* chooses *j* among *J* alternatives is equal to the probability that the utility derived from the alternative *j* is the highest utility that he can get from all the alternatives:

$$P(\text{Choice}_i = j) = P(V_{ij} + \varepsilon_{ij} = \max(V_{ij'} + \varepsilon_{ij'}, \forall j' \in J)) \quad (1)$$

V_{ij} is assumed to be a linear function of the observable explanatory variables X_i described in section 3.2: $V_{ij} = \beta_j X_i' + \alpha_j$, with β_j the alternative-specific coefficients to be estimated. We include alternative-specific constants α_j in order to control for heterogeneous sample size between the retrofitting categories. In the multinomial model, the explanatory variables X_i are individual-specific, i.e. depending on individual *i* but not on alternative *j*. In logit models, the residuals are assumed independently and equally distributed by a Type I Extreme Value distribution (Weibull distribution), which gives:

⁴⁸ This section is largely inspired by Afsa Essafi (2003).

$$P(\text{Choice}_i = j | X_i) = \frac{e^{V_{ij}}}{\sum_{j'=1}^J e^{V_{ij'}}},$$

(2)

In particular:

$$\ln\left(\frac{P(\text{Choice}_i = j_1 | X_i)}{P(\text{Choice}_i = j_2 | X_i)}\right) = X_i(\beta_{j_1} - \beta_{j_2}),$$

(3)

showing that what matters is the relative level of utility between the alternatives and not the absolute value. We set all the coefficients of a chosen reference alternative equal to zero ($\beta_{j_1} = \dots = \beta_{j_K} = 0$) in order to identify the model. Moreover, equation (3) shows that the ratio of probabilities between two alternatives does not depend on the other alternatives. This propriety is called the Independence from Irrelevant Alternatives (IIA). This IIA hypothesis can be violated if two or more alternatives share too much common characteristics compared to the other alternatives. We define the choice set in order to ensure the validity of the IIA hypothesis, which possibly lead to a choice set more restrictive in the multinomial model than in the statistics.

Deriving equation (3) with respect to $x_{(k)}$, with $j_1 = j$ and j_2 defined as the reference alternative j_{ref} , we get:

$$\beta_{kj} = \frac{\partial(P(j | X_i) / P(j_{ref} | X_i))}{\partial x_{(k)}} \frac{1}{P(j | X_i) / P(j_{ref} | X_i)}, \quad (4)$$

with $\frac{\partial(P(j | X_i) / P(j_{ref} | X_i))}{\partial x_{(k)}}$ the derivative of the probability ratio. β_{kj} informs us on the

sign of the effect of $x_{(k)}$ on the probability of choice but not on its magnitude. Moreover, we see that the effect of $x_{(k)}$ on the probability of choice varies with the individuals (with X_i). Therefore, in order to approach the average marginal effects of X_i on the choice probabilities,

we derive the estimated probabilities with respect to all X_i for all the individual observations and we present the average over the sample for each variable. The model is estimated by maximum likelihood method.

Note that in the absence of alternative-specific explanatory variables, the multinomial model is more a descriptive tool performing discriminant analysis than a structural discrete choice model (Afsa Essafi 2003). Moreover, summary statistics and econometric estimates provide complementary results. Indeed, the econometric model performs in identifying the discriminating power among choice alternatives of each variable *ceteris paribus* but loses information regarding the effect size of a variable relatively to the others. For example, if a variable is homogeneously chosen as a major driver among all alternatives, the econometric model cannot reflect it. Such ranking is only visible in the summary statistics.

5. Results

Due to their complementarity, summary statistics and econometric results are jointly analyzed for each variable. Table 1 shows summary statistics on the distribution of the retrofitting types and the cross distribution between the explanatory variables and the retrofitting categories. Recall that The “single-measure” retrofitting categories are: “glazed surfaces insulation” (mainly windows), opaque surfaces insulation (roofs, walls, floor, ceiling), the installation of “conventional heating systems” (gas or fuel boilers, radiators), the installation of “heating regulation and ventilation” systems, the installation of “innovative heating systems” (heat-pumps or equipment producing renewable energy such as wood heating system, solar water heater). “Multiple-measures retrofit” combines at least two single measures as previously described. Regarding multiple-measures retrofit, we distinguish between the combination of glazed and opaque surfaces insulation, the combination of glazed surfaces insulation and conventional heating system installation and other “multiple-measures” retrofits.⁴⁹ The last column of Table 1 shows the distribution of household and housing characteristics for the total sample selected in section 3.2 (investors and non-investors). The sample is weighted to be

⁴⁹ Further categorization leads to too small sample size.

representative (see appendix A2). Table 2 shows the estimated average individual marginal effects of the multinomial logit model. In order to ensure the validity of the IIA hypothesis, we gather the two “conventional heating systems” and “regulation/ventilation systems” categories (column 3 and 5 in Table 1) into one category called “conventional systems” and all the retrofitting combinations (column 6 to 8 in Table 1) into another one category called “multiple retrofitting”. In the econometric model, the *move-in-date* and the *Age of the head of the household* variables are dropped due to colinearity with respectively the stated preferences variable *Move* and the *Family size* variable. Finally, the discriminating power of the investment drivers identified in the econometric results (Table 2) is summarized in Table 3 with some rearrangement in the variables. ++ (resp. --) means that the stated driver has a significant positive (resp. negative) marginal effect above 10 (resp. below -10) percentage points for the particular retrofitting type compared to other alternatives. + and - are the same for significant effects of lower magnitude.

Housing and spatial characteristics

In Table 1, collective flats are under-represented in the investors’ sample compared to the full sample, especially for the categories “multiple retrofitting”, “opaque surface insulation” and “innovative systems” (respectively 3.5%, 3.5% and 10% compared to 26.9% in the full sample). This is confirmed in the econometrics results in Table 2: living in multi-family dwelling favors more glazed surfaces insulation and conventional systems installation than other retrofitting types by increasing their probability of choice by respectively 18.7 and 11.1 percentage points. Therefore, the difficulties inherent to the collective decision process increase in case of “opaque surface insulation” and “multiple retrofitting”, both characterized by relatively high level of costs and disturbance.

As expected, the more recent the buildings, the less likely are households’ investments in glazed surfaces insulation or multiple retrofit: living in buildings built after 1989 rather than before 1975 decreases their probability of choice by respectively 10.4 and 11.4 percentage points (Table 2). Since heating systems are characterized by shorter lifetimes and are necessarily replaced, building completion date less matters in case of investments in “innovative” or

“conventional systems”: living in buildings built after 1989 instead of before 1975 increases the probability of choice by nearly 10 percentage points each. Colder climate conditions reflected by higher HDD also expectedly favor more investment in opaque surface insulation measures than other retrofits (Table 2). Regarding the *Category of city*, it does not significantly discriminate between retrofitting types, except that it is more likely to invest in innovative systems in small cities and rural areas than in the Parisian agglomeration (Table 2). This is notably explained by the presence of heat-pumps which are more easily installed in large surface area.

Household characteristics

Table 1 shows that, whatever the retrofitting type, investors have relatively higher income than the full sample. Income distribution is even more shifted upwards for investors in innovative systems: the fact to be in the highest income bracket (>36300 euros) rather than in the lowest one (<18500 euros) increases the probability to invest in “innovative” systems rather than other retrofitting alternatives by 3.4 percentage points (Table 2). As regards the socio-professional category, Entrepreneurs are relatively more prone to invest in multiple retrofitting and in innovative heating systems: they represent 14.3% and 8.1% of the respective sample compared to 6.4% in the full sample or to less than 6% for the other retrofitting types (Table 1, confirmed in Table 2). This corroborates the idea that innovators have higher financial capacities and higher social status, making them less risk-averse. Education, partly reflected by income level, may also foster environmental preferences and thus innovative systems. Note that being in the highest income bracket also decreases the probability to invest in opaque insulation rather than other retrofitting alternatives by 4.4 percentage points. This is due to the fact that low income households invest relatively more in opaque surface insulations than in other retrofitting: they represent 20% in the “opaque surface insulation” sample while they only represent 10% in the “innovative systems” sample for example (Table 1).

Inactive (especially elderly people i.e. Inactive older than 54 years) are in turn relatively more prone to invest in glazed surface insulation and conventional systems: they represent 46% and 43.2% of the respective sample compared to less than 31% for the other retrofitting types (except for opaque surfaces insulation at 39%, Table 1, results confirmed in Table 2). “Single-

person households” and young people (<35 years old) are also under-represented among investors compared to the full sample (Table 1). In particular, living as a couple (at least two persons) slightly increases the probability to invest in multiple retrofitting and innovative systems installations by 3 percentage points each (Table 2). As in the life cycle theory, the influence of households’ age and family size shows that the retrofitting investments, especially the major ones (multiple-measures retrofits), take place in specific times in households’ life cycle.

General concern

Both Table 1 and Table 2 show that households’ concerns regarding unemployment, climate change and energy savings are not very discriminating in the investment choice. Nevertheless, households claiming concerns for *Energy savings* are more prone to invest in multiple retrofitting whereas those concerned by *Unemployment* are slightly more prone to invest in windows insulation (Table 2). This suggests that environmental preferences play a positive role in major retrofitting investments, as opposed to the feeling of economic insecurity.

Up-front costs and future benefits considerations

In terms of future economic benefits, *Savings in the energy bill* are among the most important motivations and clearly prevail on *Green value* in absolute (respectively always above 20% and always below 7%, Table 1). However, considerations on future energy bills favor relatively more innovative systems by increasing probability of choice by 7 percentage points while expectations on green value capitalization favor relatively more building envelope insulation by increasing probability of choice by 7 percentage points (Table 2). Multiple measures retrofitting are favored by both (probability of choice increased by 7 percentage points in both cases). Therefore, building envelope insulation is more associated with the valuation of the real estate asset. Related to the Gans’ case study (2012) for example, which looks for the presence of a green value based on data on heating systems replacement, we could argue that the green value would be more easily visible based on data on opaque surface insulation measures.

Regarding non-energy and non-economic benefits, the desire of *Comfort* is widely shared for most of the retrofit types (always above 30%, Table 1)⁵⁰ except for systems (respectively 11.3% and 23% for “conventional” and “innovative” ones). Table 2 confirms that hidden benefits such as *Comfort* prevail in case of investment in insulation measures and multiple-measures retrofits as opposed to investment in systems. Recall that results regarding hidden benefits for opaque surface insulation may be biased due to the presence of the modality “Thermal insulation”.

Regarding households’ considerations on economic up-front costs, Table 1 shows that the major perceived incentives are the most famous public policy, namely the *Tax Credit* and the *Reduced VAT*. However, whereas the importance of the *Reduced VAT* is quite homogeneous among retrofit types (between 13 and 28%), the considerations on the *Tax credit* varies a lot and is much larger for innovative heating systems (64%) and global renovation (50.7%) than for heating regulation for example (4.6%).⁵¹ In Table 2, the influence attributed to the *Tax Credit* significantly increases the probability of choice in windows insulation, innovative systems and multiple retrofitting by respectively 9.7, 7.6 and 4.5 percentage points (consequently decreasing the probability of choice in opaque surface insulation and conventional systems by respectively 15.3 and 6.5 percentage points). It is interesting to note that, while the Tax Credit was purposely implemented to promote energy savings, the investment category which is the most favored by the Tax Credit, namely windows insulation, is also the least favored when considering the influence of future energy savings. Related to what we will see in chapter two, we can also notice that perceived efficiency of the tax credit seems different between glazed and opaque surface insulation whereas the study presented in chapter 2 rather concludes in the sense of a similarity in the CIDD effects on these two retrofitting types. However, let recall that households have largely declared *Tax credit* as important even for opaque insulation measures (15% in Table 1, the second most important incentives of the 2nd question). The importance attached to *Other financial supports* (low-interest loans and inheritance) is secondary compared to the *Tax*

⁵⁰ Results regarding hidden benefits are biased for opaque surface insulation due to the presence of the *Thermal insulation* modality.

⁵¹ This category includes also retrofitting on ventilation which is not covered by the tax credit. Yet, ventilation is in minority in the sample.

Credit and the *Reduced VAT* (always below 12.5%, Table 1), except for multiple retrofitting (18.5%). Table 2 confirms that these *other financial supports* favor relatively more multiple-measures retrofit by increasing their probability of choice by 11 percentage points. More able to solve households' liquidity constraints than subsidies (*Tax Credit, Reduced VAT*), these financial supports logically prevail in case of major retrofits (multiple-measures ones) characterized by higher up-front costs. Moreover, the zero rate loan implemented after 2009 and included in this variable is only eligible for certain retrofitting combinations (see chapter 2).

Information provision

Table 1 shows that information provision is quite important for households (18 and 30% considering all information vectors). The personalized relationship reflected by the *Advices* variable is the most important vector (between 9 and 20%), suggesting the weight of the information search costs. Its influence nonetheless decreases in case of multiple-measures retrofit (9%), i.e. when the technical complexity or the costs increase. Table 2 points out that *Advices* favor relatively more investments in conventional systems (increasing the probability of choice by 4.6 percentage points). "Standardized" institutional information provision is perceived as more marginal, both in the public and the private sector: <5% for the ADEME agencies *EIE* and <6.3% for the *EPD* for the public sector; <6% for the private sector (*Advertisement*). However, as confirmed in Table 2, while public information provision favors relatively more investment in multiple-measures retrofits (increasing the probability by respectively 8.7 and 6.5 percentage points for the *EPD* and the *EIE*), private information provision (*Advertisement*) favors relatively more windows insulation (increasing the probability by 6.5 percentage points, as opposed to multiple retrofit especially). Therefore, if marketing strategies are more salient regarding windows market, the bigger perception of the tax credit in case of window insulation could partly come from an "attractive argument" in these strategies. Considering the *EPD* as a signal for energy performance, the influence of the *EPD* in case of multiple retrofitting can also be linked to the importance attached to the green value for those investments.

Contextual factors

In Table 1, *Recent move-in or ownership* are important drivers for multiple-measures retrofitting (>30%) but not for single-measure retrofitting (<13% all together except for regulation and ventilation systems). In the econometric estimates (Table 2), the recent access to *ownership* and the fact to *move* into a new dwelling increases the probability of investing in global retrofitting by respectively 16 and 17 percentage points. In Table 1, *wear and tear* is a major driver for the heating system replacement by a conventional one (66.3%) but interestingly not for an innovative one (11.3%). In a minor way, we find the same difference for respectively glazed (18.8%) and opaque surface insulation (5.7%). In Table 2, the *wear and tear* dummy significantly increases the probability of investing in conventional system by 12.8 percentage points (4 percentage points for window insulation but only at the 10% level). *Other retrofitting*, i.e. the opportunity to realize energy efficiency retrofitting in the same time as a non-energy renovation (“cosmetic” ones or extensions), appears as a secondary driver (always below 10%, Table 1). However, it favors relatively more opaque surface insulation and multiple retrofit increasing the probability by respectively 10.3 and 6.7 percentage points (Table 2). Therefore, different retrofitting investments are impacted by different exogenous dynamics: the lifetime and the age of the systems in case of conventional systems; the opportunity created by non-energy retrofitting investment, a new move-in/access to ownership in case of building envelope insulation and multiple-measures retrofitting. Finally, the co-ownership's decision is a very minor driver (always <4%, Table 1).

Table 1. Summary statistics over 2007/2012

	Glazed surfaces insulation	Opaque surfaces insulation	Conventional heating systems	Innovative heating systems	Heating regulation & ventilation	Opaque & glazed surfaces insulation	Glazed surfaces insulation & conventional heating system	Multiple retrofitting combination	Total sample investors and non-investors
N	1567	1058	437	419	271	360	362	229	32343
Row % among investors	33.3	22.5	9.3	8.9	5.8	7.7	7.7	4.9	
Mean HDD	2044	2079	2056	2040	2051	2078	2038	2005	2032
Column %:									
Annual income of the dwelling									
<18500 euros	18.5	20.0	18.3	10.3	12.9	17.7	14.8	18.2	22.5
18500/36 300 euros	50.4	50.8	46.1	53.8	44.7	57.0	50.7	46.7	48.0
>36 300 euros	31.1	29.2	35.7	36.0	42.4	25.3	34.5	35.1	29.6
Socio-professional category									
Entrepreneur	4.5	5.4	5.6	8.1	4.3	11.2	7.5	14.3	6.4
Managers	28.7	27.4	26.8	28.0	42.5	26.9	38.0	32.9	26.8
Employees	20.8	27.9	24.5	34.5	25.0	30.5	26.6	30.2	23.4
Inactive	46.0	39.3	43.2	29.4	28.2	31.3	28.0	22.7	43.3
The head of household's age									
<35 years old	0.1	0.5	0.0	0.4	0.6	0.0	0.0	0.7	0.5
35-54 years old	39.7	42.7	42.0	58.2	54.7	49.0	55.7	63.9	41.7
>54 years old	60.2	56.9	58.0	41.4	44.7	51.0	44.3	35.4	57.8
Family size									
1 person	26.1	21.1	22.3	8.1	23.6	17.8	15.7	11.7	26.4
1 couple	39.1	38.3	40.3	35.9	34.1	38.5	33.5	34.9	36.9
>2 persons	34.9	40.6	37.4	56.0	42.4	43.7	50.8	53.4	36.7
Move_in date									
< 3 years	14.0	15.1	10.3	12.4	29.6	26.6	34.2	36.6	11.1
3 / 10 years	26.6	33.4	26.2	43.0	26.7	32.4	30.2	30.8	30.4
> 10 years	59.5	51.5	63.5	44.6	43.8	41.1	35.6	32.5	58.6
Building type									
Individual house	71.5	90.0	71.7	96.5	67.2	91.3	80.5	96.5	73.1
Collective flat	28.5	10.0	28.3	3.5	32.8	8.7	19.5	3.5	26.9
Building completion date									
< 1974	66.2	67.8	70.4	44.4	42.8	77.6	71.7	66.7	57.0
1975/1988	27.2	20.2	17.2	23.3	31.4	18.7	20.5	20.4	22.1
1989/last year	6.6	12.0	12.4	32.3	25.9	3.7	7.9	12.8	21.0
Category of city									
Parisian agglomeration	14.1	8.1	13.7	4.6	15.5	6.0	11.5	4.1	13.1
> 20.000 inha.	40.5	31.2	45.4	23.6	41.2	31.9	40.0	28.8	38.8
<20.000 inhab./rural	45.4	60.7	40.9	71.9	43.4	62.1	48.6	67.1	48.1
Individual preferences									
Unemployment	68.5	66.1	69.2	63.0	67.9	64.1	67.5	60.1	67.0
Climate change	25.3	25.4	26.4	25.7	29.9	29.1	25.2	22.3	26.5
Energy savings	22.4	23.6	25.0	24.1	22.6	24.4	27.6	29.8	22.2
Retrofitting drivers									
Among the following list, what was the main reason why you invested in retrofitting?									
Savings on the Energy Bill	20.8	32.6	32.4	73.6	39.0	35.9	30.4	53.2	
Comfort	32.0	24.3	11.3	23.0	44.4	33.9	33.1	31.4	
Thermal insulation	35.9	44.4	0.2	0.8	2.6	36.1	25.8	11.5	
Acoustic insulation	5.7	1.2	0.0	0.0	0.0	1.5	2.4	0.0	
Wear and tear	18.8	5.7	66.3	11.3	25.0	7.5	27.3	13.3	
Green Value	3.9	5.5	1.2	3.3	1.9	6.1	4.0	5.2	
In addition with this first motivation, what were the two main supplementary incentives among the second list below?									
Tax credit	39.6	15.4	30.4	64.0	4.6	24.3	26.5	50.7	
Reduced VAT	27.7	14.8	18.9	19.4	12.9	13.6	16.2	14.0	
Other financial support	7.2	5.4	10.1	11.6	0.7	11.0	12.5	18.5	
Recent ownership	9.9	9.3	4.9	5.1	14.4	22.5	25.2	20.2	
Recent move-in	3.3	3.0	2.1	2.4	9.4	8.0	15.5	11.0	
Other retrofitting	4.6	11.9	4.0	3.6	10.1	9.6	6.5	5.4	
Institutional info. (EIE)	1.6	3.8	3.3	4.7	1.5	2.0	2.5	5.8	
EPD	2.2	4.3	4.9	3.1	1.9	6.3	4.9	3.3	
Advertisement	4.0	3.5	2.1	3.0	5.7	1.7	1.4	2.2	
Advice	9.8	16.2	19.7	16.2	20.1	9.4	13.3	8.8	
Co-ownership's decision	1.2	4.0	4.1	0.4	2.6	2.1	2.5	2.4	

Note: Innovative systems include heat-pump and equipment producing renewable energy (wood stove, solar heater water, etc.). Conventional heating systems refer to boilers and radiators.

Interpretation example: as regards the households and housing characteristics, 18.52% of households investing in glazed surfaces insulation belongs to the first income level. As regards households' declarations on the drivers, 20.75% of households investing in glazed surfaces insulation declares that the savings in the energy bill is the main motivation.

Table 2. Multinomial logit's average marginal effect estimates.

	Glazed surf. insulation	Opaque surf. insulation	"Conventional" systems	"Innovative" systems	Multiple retrofitting
HDD	-0.001	0.044**	0.01	-0.006	-0.047***
Annual income of the dwelling (<i>ref</i> : <18500 euros)					
18500/36 300 euros	-0.009	-0.019	0.007	0.026***	-0.005
>36 300 euros	-0.011	-0.044**	0.023	0.034***	-0.002
Building completion date (<i>ref</i> : < 1974)					
1975/1988	0.054***	-0.021*	0	0.023***	-0.056***
1989/last year	-0.104***	0.02	0.099***	0.098***	-0.114***
Building type (<i>ref</i> : individual house)					
Collective flat	0.187***	-0.144***	0.111***	-0.051***	-0.104***
Category of city (<i>ref</i> : Parisian agglomeration)					
> 20.000 inhabitants	-0.005	-0.032	0	0.003	0.034*
<20.000 inhabitants / rural	-0.03	-0.011	-0.016	0.028**	0.029
Socio-professional category (<i>ref</i> : Entrepreneur)					
Managers	0.035	0.038*	0	0.016	-0.089***
Employees	0.004	0.047**	-0.009	0.033***	-0.074***
Inactive	0.08***	0.043**	0.01	0.005	-0.139***
Family size (<i>ref</i> : 1 person)					
1 couple	-0.049***	0.005	-0.022*	0.023**	0.043***
>2 persons	-0.036*	-0.001	-0.024*	0.03***	0.031*
General concern:					
Unemployment	0.024*	0.009	0.005	-0.012*	-0.026**
Climate change	-0.008	0.007	0.013	-0.015*	0.003
Energy savings	-0.02	-0.003	0.004	-0.008	0.028**
Stated preferences:					
Savings on the Energy Bill	-0.129***	-0.011	-0.004	0.071***	0.074***
Comfort	0.038**	-0.056***	-0.062***	-0.001	0.081***
Thermal insulation	0.21***	0.149***	-0.313***	-0.187***	0.14***
Acoustic insulation	1.049	0.421	-1.395	-0.674	0.599
Wear and tear	0.04*	-0.246***	0.128***	0.001	0.077***
Green Value	-0.016	0.071***	-0.14***	0.018	0.067**
Ownership	-0.034*	-0.038**	-0.051***	-0.035**	0.158***
Move	-0.078***	-0.068**	0.017	-0.041**	0.17***
Other retrofitting	-0.163***	0.103***	-0.003	-0.004	0.067***
Other financial support	-0.01	-0.104***	-0.012	0.016	0.11***
Institutional information (EIE)	-0.14***	0.056**	-0.016	0.034**	0.065**
Tax credit	0.097***	-0.153***	-0.065***	0.076***	0.045***
Reduced VAT	0.076***	-0.042***	-0.008	-0.009	-0.017
EPD	-0.117***	0.044	-0.002	-0.013	0.087***
Advertisement	0.065**	0.006	-0.009	0.009	-0.072*
Advice	-0.099***	0.024*	0.046***	0.019*	0.01
Co-ownership's decision	-0.29***	0.213***	-0.043	-0.005	0.125***
Nb of observations	4038			Log likelihood	-6818.1213
Market shares (row %)	33.32	22.5	15.05	8.91	20.22

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%). (Std errors not reported)

Note : Innovative systems include heat-pump and equipment producing renewable energy (wood stove, solar heater water, etc.). Conventional heating systems refer to boilers, radiators, heating regulation and ventilation systems. The sum in row of all marginal effects is zero. Due to different market shares, a given value of Interpretation example: to be in the highest income bracket (>36300 euros) rather than in the lowest one (<18500 euros) increases the probability to invest in "innovative" systems by 3.4 percentage points.

Table 3. Summary of the econometric results.

	Gazed surf. insulation	Opaque surf. insulation	"Conventional" systems	"Innovative" systems	Multiple retrofitting
Revealed preferences					
Building characteristics					
Collective flats compared to individual house	++	--	++	-	--
Relatively recent building (> 1989 compared to <1974)	--		+	+	--
HDD (energy needs due to climatic conditions)		+			-
Relatively small city category (<20 000 inhab. compared to Paris)				+	
Households characteristics					
Relatively high income household		-		+	
Relatively large family size (>1 person compared to 1)	-		-	+	+
Socio-professional category:					
Inactive compared to Entrepreneur	+	+			--
Employees compared to Entrepreneur		+		+	--
Stated preferences					
Future economic benefits					
Savings on the energy bill	--			+	+
Green value		+	--		+
Future non economic benefits : Comfort	+	-	-		+
Economic incentives decreasing up-front costs					
Tax credit, reduced VAT	++	--	-	+	+
Other financial support (e.g. loan, inheritance)		--			++
Information provision					
Public sector (EPD and EIE)	--	+		+	++
Private sector (Advertisement)	+				-
Interpersonal (Advice)	-		+		
Contextual factors					
Recent ownership or move-in	-	-	-	-	++
Wear and tear		--	++		+
Other non-energy renovation	--	++			+
Co-ownership decision	--	++			++
General concern					
Energy savings					+
Unemployment	+			-	-

Note: ++ = the stated preferences has a significant positive marginal effect above 10 percentage points (or that several variables inside the category are significantly positive), + = that the stated preferences has a significant positive marginal effect between 0 and 10 percentage points. -- = the stated preferences has a significant negative marginal effect below -10 percentage points (or that multiple modalities are significantly positive), - = that the stated preferences has a significant negative marginal effect between -10 and 0 percentage points.

Note 2: Innovative systems include heat-pump and equipment producing renewable energy (wood stove, solar heater water, etc.). Conventional heating systems refer to boilers, radiators, heating regulation and ventilation systems.

6. Discussion and conclusion

Results summary

Using data coming from the French EM survey over 2007/2012, we estimate a multinomial logit model with both revealed (household and housing characteristics) and stated (households' declarations) preferences in order to assess how investment determinants vary with the retrofitting type.

A first distinction should be made between investment in energy systems and investment in building envelope insulation given the heterogeneous influence of hidden non-economic benefits (e.g. comfort) and of "wear and tear". In terms of households and housing profile, the difficulties inherent to multi-family dwellings and dense urban areas like the Parisian agglomeration especially affect investments in building envelope insulation (and consequently multiple-measures retrofitting). Second, some drivers are specific to multiple-measures retrofitting: the opportunities created by recent move-in/ownership or by other non-energy retrofits, the expectations regarding the green value and the importance of financial supports other than subsidies. These specificities are often shared with investment in opaque surfaces insulation, which suggests that in case of multiple-measures retrofitting, it is the determinants of the investment in opaque surface insulation that lead the decision. Among systems, additional distinction should be made between investments in "conventional" and "innovative" systems given the importance attached to "wear and tear" for "conventional" systems and to economic profitability for "innovative" ones. In terms of households' and housing profile, high income households and entrepreneurs are more prone to invest in innovative systems. Finally, investments in glazed surfaces insulation share more similarities with investments in conventional heating systems than with investments in opaque surface insulation given the importance attached to wear and tear or private information provision (advertisement). As regards socio-economic characteristics, Inactive (Elderly) people also tend to invest more in windows and conventional systems.

Implications in terms of investment decision modelling and public policy design

Regarding investment decision modelling, the heterogeneous influence of the technological dynamics (“wear and tear”) and of the housing market dynamics (occupancy or ownership switch) suggests to explicitly take into account these two dynamics and make them appropriately interact with specific energy efficiency investment types. On one side, the pace of changes in the housing market is essential regarding global retrofitting investments or building envelope insulation. This means that the imperfections or the frictions in the housing markets have implications on the dynamics of residential energy efficiency. On the other side, systems’ life duration and age are key factors for the investments in conventional heating system replacement.

In terms of policy implications, rather than considering these two dynamics as “ancillary conditions”, i.e. “are any factors that affect the individual’s choices but are not relevant to what the social planner would choose” (Gillingham & Palmer 2013), we should wonder how to take into account these two dynamics in order to improve the cost-efficiency of the policies.

Assuming that investments in systems are mainly driven by replacements after break could notably explain why economic instruments such as tax credits could not affect the investment decision on the extensive margin for systems (see chapter 2). Besides, given the heterogeneity of investments drivers, the implementation of a uniformed policy scheme among all energy efficiency investments types as it has been planned for 2015 does not seem to be the most appropriate strategy.

The consideration of the housing market dynamics in the regulation process has already been started. The principle of an obligation to retrofit existing dwellings in case of transactions in the housing market associated with specific financial support through extra mortgage with low-interest rate has been proposed by the non-profit organization négaWatt and the consortium of building industries and businesses “Insulate Earth against CO (Salomon et al. 2005) and has been discussed during the *Grenelle de l’Environnement* (Pelletier 2008), though

with little success.⁵² Alternatively, the new law project for 2015⁵³ has enforced the obligation to invest in energy conservation measures in case of opportunities created by non-energy works such as outdoor wall insulation in case of façade restoration, roof insulation in case of roof repair and indoor wall insulation in case of new rooms furnishing. Considering that such non-energy works are often undertaken in case of transfer in occupancy/ownership, this can be viewed as an appropriate first step for this type of regulation. More importantly, this obligation only bears on opaque surface insulation measures, which is well targeted, as we have seen that the investment in non-energy works is a specific driver to opaque surface insulation. Therefore, as the specific driver for energy durable goods is “wear and tear”, why not imagine the implementation of energy efficiency standards on heating systems investments in case of replacement?

Apart from regulation, these two dynamics have been slightly considered in the tax credit design with the tax credit rate increase from 25% to 40% in case of recent move-in over 2006/2009 and with the tax credit rate increase from 25% to 40% for investments in wood stove only in case of replacement after 2009. This implies higher subsidization for households facing lower investment barriers. This is in contradiction with the principle sated by Allcott (2014) to implement “consumer-specific subsidies tailored to each consumer’s bias”. Moreover, while the Tax Credit was purposely implemented to promote energy savings, we notice that windows insulation in the investment category the most favored by the Tax Credit but also the least favored when considering the influence of future energy savings. We notably wonder why windows have been reintroduced in the CIDD scheme for 2015 after having been removed since 2012.

Besides, we should pay attention to the consequences of public policies on the housing markets. In a study conducted by the Ministry of Ecology the implementation of a bonus/malus proportional to building energy efficiency introduced either on the property tax or on the transfer tax, Kieffer (2013) highlights the risk of lock-in in case of implementation on the

⁵² See Giraudet et al. (2011) for an academic assessment.

⁵³ Projet de loi relatif à la transition énergétique pour la croissance verte, <http://www.assemblee.nationale.fr/14/projets/pl2188.asp> puis <http://www.senat.fr/leg/pjl14-016.html> (article 5)

transfer tax. Indeed, it could act as a disincentive to sell highly energy intensive buildings, which would be counterproductive given our results on the influence of occupancy/ownership switch on investment decisions.

Finally, if we consider that the biggest energy efficiency potential lies in global retrofitting, results show that we should pay more attention to financial support able to solve financial/liquidity constraints, to the promotion of a perceived and effective green value on the housing market and to the implementation of a widely available public information provision.

7. Appendix

A1. L'enquête ADEME-TNS-SOFRES « Maîtrise de l'énergie » : une revue critique.⁵⁴

L'enquête ADEME-TNS-SOFRES « Maîtrise de l'énergie » (MDE), Energy Management (EM) survey dans sa traduction anglaise, que la TNS-SOFRES réalise annuellement pour le compte de l'ADEME depuis 1986, nous informe sur les travaux de maîtrise de l'énergie réalisés par les ménages français dans leur logement. L'objet de cet article est de présenter l'enquête, de faire l'analyse critique de sa construction et de certains résultats ainsi que de retracer l'historique de la construction du panel utilisé dans cette thèse.

1. L'enquête « Maîtrise de l'énergie » : description, et principaux résultats et évolutions

Rappels historiques, questionnaire et échantillon

Chaque année, environ 10 000 ménages tirés du panel TNS- SOFRES Métascope⁵⁵ sont interrogés sur leurs pratiques en termes de consommation énergétique dans leur logement ainsi que sur leurs investissements dans des travaux de rénovation énergétique et, plus récemment, dans les énergies renouvelables.

La richesse de cette enquête réside dans le niveau de détail des informations collectées sur les travaux de rénovation énergétique. Après avoir longuement détaillé les consommations et les pratiques du ménage en matière de consommation énergétique des ménages dans leur logement ainsi que l'équipement du logement, l'enquête demande au ménage s'il a réalisé ou fait réaliser des travaux de maîtrise de l'énergie (efficacité énergétique et/ou énergie renouvelable). Auquel cas, le ménage est invité à remplir un second questionnaire quelques mois plus tard. Les travaux réalisés y sont alors décrits de façon relativement fine par type: isolation de l'enveloppe du bâtiment, et si oui quelle partie (toiture, parois non-vitrées, parois vitrées, etc.) ; amélioration de la production de chaleur (appareil de régulation du chauffage,

⁵⁴ Se reporter aux synthèses de la TNS-Sofres pour une présentation générale de l'enquête (TNS Sofres & ADEME 2012).

⁵⁵ Cf section 2.

pompe à chaleur, chaudière, chauffage au bois, etc.) ; ventilation et eau-chaude sanitaire; enfin, énergie renouvelable (eau chaude solaire thermique). Pour chaque type de travaux, l'enquête fournit le montant, les conditions de paiement et de réalisation des travaux. Enfin, l'enquête tente de mettre en lumière les motivations des ménages à investir (ex: volonté de réaliser des économies d'énergie, désir de confort, etc.), ainsi que, plus récemment, l'importance du recours à des instruments d'aide au financement des travaux (ex: Crédit d'Impôt Développement Durable). De façon analogue et non moins intéressante, celle-ci les interroge sur les barrières à l'investissement (ex: montant de l'investissement trop important, réalisation des travaux compliquée et/ou perturbante, etc.).

Bien que certaines questions aient été modifiées, ajoutées ou supprimées depuis la naissance de l'enquête⁵⁶, la structure générale de l'enquête s'est maintenue au moins depuis 2000, ce qui permet de construire des séries temporelles sur une dizaine d'années.

Résultats principaux

Chaque année, environ 10% des ménages français enquêtés puis pondérés déclarent avoir effectué ou fait réaliser des travaux de maîtrise de l'énergie. Ce chiffre, relativement élevé si on le compare par exemple aux résultats de l'enquête Logement 2006 (4% d'après Charlier 2012), concerne l'ensemble des travaux réalisés, quel que soit leur importance. En effet, l'enquête ne distingue pas au sein d'un même type de travaux (ex: isolation des murs par l'intérieur), les « petites » rénovations des « grosses » rénovations, contrairement à l'enquête ménage d'OPEN par exemple. Or certains montants de travaux indiquent que chaque catégorie de travaux inclue des travaux de rénovation mineurs (ex: une isolation partielle), bruit dont il faut donc tenir compte lorsqu'on s'intéresse aux rénovations énergétiques d'ampleur.

Le taux de rénovation est très hétérogène selon le type de ménage (Figure 4). Contrairement à l'enquête ménage d'OPEN qui interroge uniquement les propriétaires sur les travaux entrepris (qu'il soit propriétaire occupant ou bailleur) et qui ne fournit des statistiques de rénovation énergétique que sur le parc de logements privé, l'enquête MDE interroge

⁵⁶ Certaines questions étant par exemple d'un intérêt ponctuel pour l'Ademe, comme celle renvoyant à la campagne de sensibilisation « Faisons vite, ça chauffe » entre 2004 et 2006.

l'ensemble des ménages occupants. De ce fait, l'enquête MDE fournit des statistiques de rénovation sur le parc locatif social et privé. Néanmoins, dans le cas d'un logement loué, la question posée aux ménages étant la suivante « *Entre le 1er janvier [de l'année n] et le 31 décembre [de l'année n], avez-vous réalisé ou fait réaliser des travaux ayant pour but de réduire votre consommation d'énergie ou d'améliorer votre confort (chauffage, eau chaude, isolation, ventilation, etc.) dans le logement que vous occupez actuellement?* », les travaux de rénovation énergétique entrepris par le propriétaire bailleur ne sont pas systématiquement comptabilisés⁵⁷, ce qui conduit à une sous-estimation du taux de rénovation énergétique des logements dans le parc locatif.

Si l'on se restreint aux propriétaires de maisons individuelles, pour lesquels l'échantillon de travaux est le plus grand, il semble que le taux de rénovation énergétique global ait augmenté entre 2005 et 2008, avant de se stabiliser voire de diminuer ensuite (Figure 4). Le champ de travaux de rénovation énergétique pris en compte dans l'enquête a cependant évolué au cours de la période. L'introduction en 2005 de la mention de nouveaux équipements (pompe à chaleur et chauffe-eau solaire) dans le périmètre des travaux de l'enquête peut conduire à l'augmentation artificielle de ce taux de rénovation d'ensemble (voir le chapitre 2 de la thèse pour une analyse du taux de rénovation).

⁵⁷ Ils le sont parfois, car le ménage indique dans certains cas que les travaux ont été décidés par un tiers, mais cela reste à la discrétion du répondant.

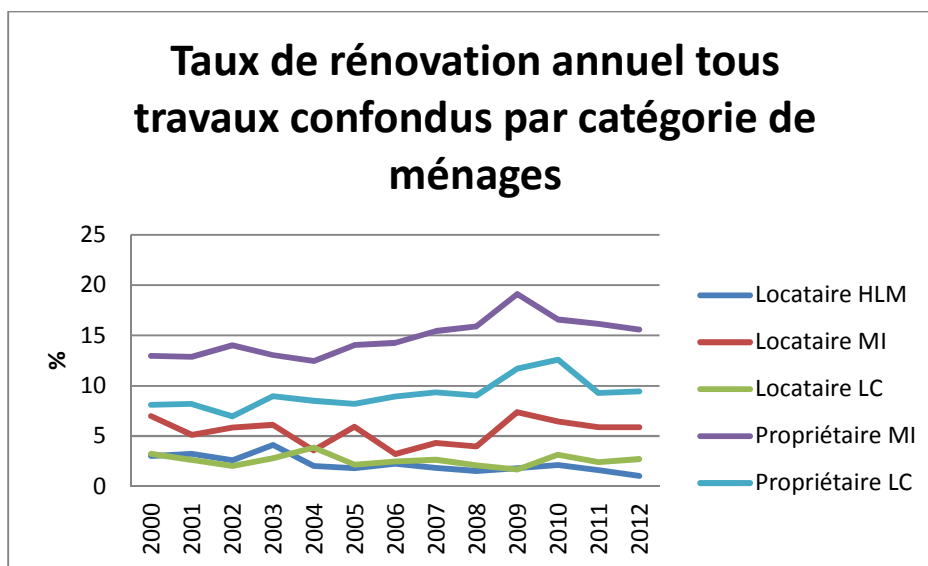


Figure 4. Evolution 2002-2011 du taux de rénovation selon le statut d'occupation et le type de logement.

Note : MI : Maison individuelle, LC : Logement collectif ; HLM : Habitation à loyer modéré.

Limites de l'enquête

La fonction première de cette enquête étant de fournir un observatoire généraliste sur la maîtrise de l'énergie par les ménages dans le logement, la première limite porterait sur le manque d'anticipation dans la conception des questionnaires en vue d'une évaluation statistique ex-post de l'efficacité des politiques publiques. Le cas de l'ajout en 2005 des pompes à chaleur et des chauffe-eau solaire suite à l'introduction de ces équipements dans le périmètre du CIDD est à ce titre particulièrement illustratif. La concomitance du début de la mesure avec l'introduction de la politique à évaluer ne permet pas la mise en place d'analyses statistiques appropriées (même les plus simples telles que l'estimation en différence utilisée dans le chapitre 2 de la thèse). Un autre exemple dans la dimension transversale cette fois concerne l'inégalité des traitements selon différentes sous-populations. Entre 2005 et 2008, l'enquête demande de renseigner le type de chaudière installée uniquement pour les investissements bénéficiant du CIDD, ce qui ne nous permet notamment pas d'utiliser l'exclusion des chaudières basse-température du dispositif en 2009 afin d'estimer l'effet du CIDD sur les systèmes de chauffage, réforme qui nous fournissait pourtant un bon cadre d'expérience quasi-naturelle.

La seconde limite de l'enquête porterait sur le périmètre et le niveau de détail des travaux que l'on pourrait juger insuffisant. Concernant le périmètre, on pourrait regretter que l'enquête ne comptabilise pas également les travaux non énergétiques, contrairement à l'enquête OPEN. En particulier, cela nous aurait permis de prendre en compte plus facilement les effets macroéconomiques, tels que la crise de 2008 sur les travaux de rénovation. En outre, il aurait été intéressant de mesurer les travaux de rénovation sur parois opaques dépourvus d'isolation (ex : ravalement de façade sans isolation) afin de calculer le taux de renouvellement des éléments de l'enveloppe du bâtiment. Concernant le niveau de détail, on pourrait regretter que l'enquête ne fournisse pas davantage d'informations sur le niveau de performance énergétique des travaux, tel que l'épaisseur de l'isolant ou le nombre de m² d'isolant posé. Néanmoins, au vue des tailles d'échantillon, un plus grand niveau de détail n'aurait sûrement pas permis de produire des tests statistiques robustes.

2. Construction du panel

Généralités

Le panel utilisé pour l'enquête « Maîtrise de l'énergie » est constitué chaque année d'une dizaine de milliers de ménages, allant de 6345 en 2005 à 8855 en 2009 pour la période 2000/2012 (Table 4). Les panelistes ont un mois pour répondre à chaque volet de l'enquête. Environ 10% des répondants de phase 1 déclarent réaliser des travaux et se trouvent réinterrogés en phase 2 quelques mois plus tard. La saisie des questionnaires se fait en auto-administré, à titre volontaire. La sortie du panel provient le plus souvent du souhait du ménage de ne plus participer aux enquêtes. La TNS-SOFRES dispose d'un Panel consommateurs, appelé METASCOPE, parmi lequel elle puise pour construire des panels représentatifs de la population française. Les critères de représentativité correspondent, d'une part, à des variables « ménage », à savoir la région (répartition conforme à celle des régions UDA⁵⁸), la zone climatique, la catégorie d'agglomération, la taille du foyer et la catégorie socio-professionnelle et l'âge du chef de ménage, et d'autre part, à des caractéristiques du logement, à savoir le type de logement, son année de construction et son mode de chauffage principal. Une pondération annuelle est enfin construite par la TNS-SOFRES pour redresser les biais d'échantillonnage et la

⁵⁸ <http://www.uda.fr/chiffres-et-documents/regions-uda/>

non-réponse. Celle-ci est calée sur les enquêtes Emploi de l'INSEE pour les variables « ménages » et sur les enquêtes CEREN pour les variables « logements » et aboutit à une taille d'échantillon pondérée en phase 1 de 10000 ménages. Une seconde pondération permet de fusionner les réponses de la phase 2 à celles de la phase 1.

Le roulement du panel et biais d'attrition

Les ménages sortent volontairement de l'enquête, ce qui signifie que l'enquête MDE constitue une base de données de panel non cylindrée. Sur la période 2000/2012, 29339 ménages furent interrogées, dont 41,7% sur une seule année et 21% sur cinq années ou plus (Table 4). En outre, environ 4000 personnes sont observés plusieurs années mais non continument. Puisque le renouvellement du panel est en grande partie déterminé par la sortie volontaire des panélistes au fil du temps, les données de panel collectées peuvent contenir des biais d'attrition. En effet, l'attrition, à savoir est la perte d'individus de l'échantillon au cours du temps, risque de distordre l'échantillon des ménages suivis dans le temps et de le rendre non représentatif de la population totale si celle-ci est corrélée avec un certain profil socio-économique.

Table 5 présente la distribution des enquêtés en fonction des principales caractéristiques sociodémographiques du ménage et de celles du logement sur l'ensemble de l'échantillon pondéré (échantillon national représentatif, colonne1) ou non (colonne 2) et sur le sous-échantillon des ménages suivis sur au moins 5 années (« panel longue durée », colonne3). Les profils surreprésentés dans l'enquête sont ménages en couple, âgés et inactifs. Par effet de structure, les foyers propriétaires habitant en maison individuelle sont relativement plus présents que les foyers d'une seule personne, que les jeunes ou les locataires. Les agriculteurs, les chefs d'entreprises (y compris artisans et commerçants) ainsi que les cadres supérieurs sont également sous-représentés. Cette distorsion sur le profil sociodémographique du ménage s'accroît lorsqu'on restreint l'échantillon sur les ménages observés sur longue période uniquement. La distribution des variables caractéristiques du logement de l'échantillon «panel longue durée» est en revanche assez peu biaisée par rapport à la distribution nationale.

Il est probable que les méthodes de fidélisation employées par la TNS-SOFRES influencent le profil socio-économique des panélistes. Les ménages présents dans les panels SOFRES entretiennent en effet un lien particulier avec l'institut de sondage. Ils sont sollicités tous les mois pour répondre à différentes enquêtes sur des sujets aussi diverses que les vacances, le téléchargement sur internet, les placements financiers, etc. En outre, le lien de fidélisation entretenu par la TNS-SOFRES est important. Des systèmes de cumul de points cadeaux à chaque questionnaire rempli sont mis en place. La valeur économique des incitations est assez faible (le barbecue étant le présent le plus onéreux) et la TNS-SOFRES essaye de jouer également sur la conscience citoyenne des panélistes (lettres d'info) pour augmenter le taux de réponse⁵⁹. Les individus sensibles aux compensations proposées, disposant de temps libre important, sont par conséquent surreprésentés dans le panel. Cependant, la spécificité des profils socio-économiques suivis sur longue période et donc l'attrition n'est pas corrélée aux variables d'intérêt de l'enquête « Maîtrise de l'énergie ». La réalisation de travaux n'influence en effet notamment pas la sortie de l'enquête⁶⁰, ce qui a pu notamment être testé dans le chapitre 2. La pondération et le renouvellement régulier du panel permettent en outre de redresser cette distorsion. Les biais de recrutement sont d'ailleurs moins problématiques étant donné que la TNS-Sofres recrute les nouveaux enquêtés en proportions des enquêtés sortant de manière à maintenir un échantillon annuel représentatif.

Enfin, le traitement statistique de la non-réponse n'a pu être systématiquement effectué sur les données (absence de distinction entre la modalité « Ne sait pas » et la non-réponse pour certaines années par exemple). Néanmoins, nous supposons que les répondants et les non-répondants n'ont pas des comportements divergents au vue des variables d'intérêt. En effet, la thématique « travaux de rénovation » ne contient pas de caractère sensible qui inciterait les ménages à ne pas répondre. Le taux de répondants à la phase 1 de l'enquête est en outre assez

⁵⁹ Un nouveau programme de fidélisation a été mis en place entre 2007 et 2008 mais ce changement n'a pas eu de conséquences sur les résultats de l'enquête (contrairement à leur enquête tourisme par exemple : ce nouveau programme a eu un effet sur le taux de départ en vacances déclarés car il a augmenté le taux de réponse des questionnaires longs à remplir et le temps de réponse est corrélé avec les départs en vacances).

⁶⁰ L'attrition n'est pas non plus liée aux déménagements, car les ménages communiquent leur nouvelle adresse.

élevé pour ce genre d'enquête postale⁶¹, de 70.3% en moyenne sur 2002/2012, et stable sur la période (écart type : 4.4). Le taux de retour de la phase 2 est encore plus fort (moyenne: 83.5%, écart-type : 2.5).

Table 4. Nombre d'observations annuelles et structure du panel.

Année	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total
Nombre d'observations	7234	6999	6888	6730	6635	6345	7021	8422	8546	8855	7990	6955	7114	95734
Nombre d'années d'observation par ménage	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Nombre de ménages	12225	5351	3241	2318	1604	996	661	557	462	468	481	458	517	29339
%	41.67	18.24	11.1	7.9	5.47	3.39	2.25	1.9	1.57	1.6	1.64	1.56	1.76	

⁶¹ Les taux de retour des enquêtes TNS Sofres pour les enquêtes concernant les pratiques internet et le téléchargement illégal par exemple sont nettement plus faibles.

Table 5. Profil des ménages et des logements suivant la période d'observation.

	Population total		Echantillon "panel longue durée (≥5 ans)"		Population total		Echantillon "panel longue durée (≥5 ans)"
	Pondéré	Non pondéré			Pondéré	Non pondéré	
	%	%	%		%	%	%
Age du chef de ménage				Type de logement			
Moins 25 ans	2.1	1.2	0.3	maison	56.7	66.0	67.9
25-34 ans	16.4	14.0	7.1	appartement	43.2	33.8	32.0
35-44 ans	18.6	18.8	15.9	autre	0.2	0.2	0.2
45-54 ans	18.9	17.5	16.5	Année de construction du logement			
55-64 ans	16.3	17.9	20.3	avant 1949	27.5	24.9	24.6
65 ans et plus	27.7	30.7	39.8	1949/1974	32.7	29.6	31.7
Nombre de personnes au foyer				Entre 1975/1981	13.4	15.6	16.5
1 habitant	31.8	25.8	28.7	1982/1988	8.8	10.2	10.4
2 habitants	34.0	38.8	42.8	1989/an dernier	16.8	18.8	16.2
3 habitants	14.8	14.2	11.9	année en cours	0.8	0.9	0.6
4 habitants	13.1	14.6	11.6	Zone climatique d'hiver			
5 habitants et plus	6.3	6.5	5.0	H1	58.9	59.6	60.0
PCS du chef de ménage				H2	30.4	29.7	29.5
Agriculteur exploitant	1.5	1.0	0.6	H3	10.8	10.7	10.6
Commerçant, Artisan, Chef d'entrep.	4.2	2.5	1.7	Catégorie d'agglomération			
Prof. libéral/Cadre sup	11.0	10.4	7.7	Ile de France	15.4	15.1	14.4
Prof. Intermédiaire	14.2	14.7	11.9	>100.000 hab	29.3	29.3	29.6
Employé	11.4	11.6	10.5	20.000/100.000 hab	13.2	13.7	14.1
Ouvrier	17.3	17.1	14.5	2.000/20.000 hab	17.6	17.6	18.4
Inactif	40.4	42.8	53.1	Ruraux	24.4	24.2	23.4
Revenu du foyer				CCC gaz	53.0	53.0	55.0
Moins de 18500 euros	35.3	31.2	33.3	CCC fioul	27.1	26.0	25.2
18500 à 36 300 euros	45.0	47.1	46.9	CCC électricité	4.7	5.0	4.4
Plus de 36 300 euros	19.7	21.7	19.8	CCC chauffage urbain	11.8	12.8	13.6
Statut d'occupation				CCI gaz	62.5	62.7	62.1
Locataire HLM	13.6	11.4	10.9	CCI fioul	27.4	27.5	28.6
Locataire non HLM	19.1	15.5	12.7	CCI électricité	3.5	3.5	3.3
Proprio	64.2	70.2	73.7	CEI	27.2	27.2	26.0
Autre	3.2	2.9	2.7	Indépendant gaz	2.4	2.1	2.2
				Indépendant fioul	3.9	2.9	2.9
				Indépendant électricité	17.7	17.5	17.3
				Indépendant bois	73.2	74.0	74.1

Note: CCC : chauffage central collectif; CCI : chauffage central individuel; CEI : chauffage électrique individuel; Indépendant : système de chauffage indépendant.

Historique de la construction de la base de données.

Les données de l'enquête MDE furent mise à disposition à des fins de recherche depuis 2010 grâce aux démarches de Laurent Meunier, économiste au Service Economie et Prospective de l'ADEME. De 2010 à fin 2013, un important travail de récupération, d'harmonisation et de vérification des données (à partir des tris à plat et des synthèses fournis par la TNS Sofres) a été entrepris en collaboration avec la TNS Sofres et l'ADEME. Fin 2013/début 2014, une réunion s'est tenue avec l'ADEME afin de discuter des limites de l'enquête du point de vue des méthodes statistiques l'évaluation des politiques publiques et de son avenir. Une réunion s'est tenue avec la TNS-Sofres pour valider certaines hypothèses de travail et discuter de la possibilité de travailler sur les bases de données archivées d'avant 2000. Enfin, un fichier fut constitué afin de permettre la transmission de ce travail, contenant :

- un recensement de l'ensemble des questions des questionnaires sur la période 2000/2012,
- un historique des corrections effectuées sur les bases 2000/2012 depuis 2010,
- les bases de données 2000/2012 vérifiées et corrigées pour les variables utilisées dans la thèse, les scripts permettant de reconstruire la base de données constituée pour la thèse ainsi qu'un dictionnaire des variables et des modalités et les formats.

L'objectif de ce travail de transmission est de permettre à d'autres chercheurs d'utiliser et poursuivre ce travail de constitution d'une base de données de panel complète et corrigée. Cette thèse s'est concentrée sur l'investissement des ménages dans l'efficacité énergétique mais l'enquête fournit par ailleurs de l'information sur les modes de consommations énergétiques des ménages qu'il serait intéressant d'exploiter.

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Chapter 2 Free-riding on tax credits for home insulation in France: an econometric assessment using panel data.

Preliminary remark:

The core of the chapter has been published in Nauleau (2014) and is presented in the same way as in the article. In appendix A4 and A5, this chapter extends the analysis of the CIDD tax credit. In appendix A4, it focuses on the CIDD effect on the intensive margin of the investment. In addition to the analysis on the extensive margin of the investment, it allows the computation of the average BFTB multiplier of the policy, i.e. the amount of private investment triggered per euro of public spending. In appendix A5, it deals with the CIDD effect on the arbitrage between “Do it Yourself” and professional works.

Abstract

This econometric study assesses the efficiency of the income tax credit system introduced in France in 2005 on investment decisions for household retrofits, focusing on insulation measures. A logit model with random individual effects is estimated using an unbalanced panel of 23,879 households surveyed over the period 2002-2011. An estimation in difference is performed to identify the impact of the policy. The tax credit is found to have had no significant effect during the first two years, suggesting a latency period related to inertia in households' investment decisions, possibly due to the complexity of the tax credit scheme. The tax credit had an increasing, significant positive effect from 2007 to 2010, before slightly decreasing in 2011. This is in line with changes in the tax credit rates, suggesting a correlation with the level of subsidy. Defined as the situation in which the subsidized household would have invested even in the absence of the subsidy, free-ridership progressively decreased over the period, was lower for insulation of opaque surfaces (roofs, walls, etc.) than for insulation of windows and depended on individual characteristics. The estimated average proportion of free-riders varies between 40% and 85% after 2006. In addition, we assess the potential bias caused by time-varying unobservable variables and conclude that our estimates of the impacts of the policy are conservative.

JEL: Q48, R22, D12

Keywords: Energy conservation, residential sector, tax credit, free-riders, difference estimation, panel data

1. Introduction⁶²

In the current context of climate change and given the weight of the residential sector in industrialized countries' energy end use and CO₂ emissions, the promotion of energy efficiency investments in the existing building stock is a major issue in climate policy. This sector is all the more targeted as it is considered one of the sectors with the highest energy savings potential (Levine & al. 2007), although this potential has been questioned (Allcott & Greenstone 2012). Consequently, incentives such as income tax credits have been introduced in many countries to encourage households to invest in energy-efficient retrofitting of their dwellings. In some countries the first wave of tax credit implementation occurred in the 1970's, in the post oil-crisis period, and led to a first group of empirical studies, mainly dealing with the US tax credit system from 1977 to 1986.

Among all the barriers to action faced by households who want to retrofit their dwellings (Jakob 2007), the presence of market imperfections may provide justification for instruments such as tax credits. Called "investment inefficiencies" by Allcott and Greenstone (2012), these market failures mainly refer to imperfect information and may cause households not to undertake privately profitable investments in energy efficiency. Moreover, in the case of negative externalities related to fossil fuels and the political difficulties of implementing first-best solutions such as pigouvian taxes, energy efficiency policies might be a reasonable second-best substitute (Allcott & Greenstone 2012). Such policies can also address behavioral failures, even if they are imperfect when consumers are heterogeneous (Gillingham & Palmer 2013).

In public economics, policy assessment occurs relative to social welfare, in a framework of cost-benefit analysis taking into account all the significant direct and indirect effects of the policy on the economy and society. Empirical papers however tend to adopt a cost-effectiveness perspective due to the limitations of empirical cost-benefit analysis, which lentile & Mairesse write is "as difficult as it is ambitious" (2009).

⁶² Abbreviations in the article: CIDD stands for *Credit d'Impôt Développement Durable* (Sustainable Development Tax Credit), which is the French name of the tax credit scheme studied; EcoPTZ stands for *Eco Prêt à Taux Zéro* (Interest-Free Loan for Environmentally-Friendly Projects), which is the French name of the currently-available zero interest rate loan.

In order to measure cost-effectiveness, we first have to assess the extent to which households respond to the policy. There is no consensus in the literature, in particular regarding studies of the first US tax credit scheme: results differ depending on data and methodology. Dubin and Henson (1988) studied the scheme for the 1979 tax year, using fiscal data aggregated by Internal Revenue Service (IRS) district and audit class. They assessed the tax credit's effects on both the probability of declaring energy conservation investment and the amount of expenditure, and found no significant incentive effects (1988). Neither did Walsh (1989) using micro data from the 1982 Residential Energy Consumption Survey, nor Cameron (1985) using a nested logit model. On the other hand, using micro panel data covering 1979/1981, Hassett and Metcalf (1995) found a significant positive incentive effect of the tax credit on the likelihood of performing energy-efficiency improvements. However, they could not assess free-ridership,⁶³ which is defined as behavior occurring “when the agents targeted by the policy take the incentives but would have made the investment anyway” (Alberini et al. 2014)

Free-ridership has to be taken into account to avoid overstating a policy's efficiency in terms of additional energy savings. Moreover, free-ridership leads to a net social cost in the presence of administrative costs (to attract, to monitor, etc.)⁶⁴. Public revenues could have been allocated to other expenditure and subsidies may cause price distortions and have anti-redistributive effects. To our knowledge, Joskow and Marron (1992) were the first to discuss free-ridership in the literature related to domestic energy conservation. They conducted a meta-analysis by reviewing evaluations of demand-side management (DSM) programs implemented by U.S. utilities, in which estimates of free-ridership varied between 4% and 55%. Recent literature studying subsidies implemented to trigger domestic energy efficiency investment has focused on the assessment of free-ridership. Using a discrete choice model on German cross-section data, Grösche and Vance (2009) designated potential free-riders as those whose estimated marginal willingness to pay for a particular retrofit option is higher than the observed investment cost without subsidy, and found the proportion of free-riders approached

⁶³ The term of “windfall gains” could be more appropriate in order not to emphasize households' “intention to free-ride” but the use of the terms “free-riding, free-rider, or free-ridership” is the most common in energy efficiency literature.

⁶⁴ Such welfare loss is theoretically formalized by Boomhower & Davis (2014).

50%. Using the same database, Grösche, Schmidt, and Vance (2013) applied a more flexible discrete choice model to generate predicted choice probabilities for each retrofit option. They found that, as the size of the subsidy increases, the share of program funds allocated to free-riders decreases even as the overall cost of the program increases. Using discontinuity analysis regression to examine the adoption of energy efficient appliances, Boomhower & Davis (2014) found similar results. Alberini et al. (2014) studied the effects of an Italian tax credit implemented in 2007. Taking into account geographical heterogeneity, they found that the tax credit made the rate of window replacement increase by 37 to 40 percent in colder climates. They also found that increased free-ridership is more likely in the case of heating system replacement than window replacement.⁶⁵ Mauroux (2012) studied the French tax credit, called CIDD, implemented in 2005 in order to trigger households' investment in energy conservation and renewable energy equipment in their dwellings. The author analyzed the effect of the 2006 reform, which increased the CIDD rate from 25% to 40% for investments in old buildings after a recent housing transfer using fiscal data over the period 2006/2008. Her results suggested the presence of significant free-ridership: around two thirds of the CIDD beneficiaries would have applied for the subsidy even without the reform. The effect of the reform was also found to increase over time. In these two papers however, free-ridership assessment was not complete as data did not provide the share of subsidized retrofits on the whole of energy-efficiency retrofitting investments.

In this paper, we assess the same French income tax credit (CIDD) as Mauroux (2012). Our approach in this paper is first to assess the impact of the CIDD on energy-saving investments on the extensive margin at the time of its introduction in 2005. The extensive margin corresponds to the number of retrofit investments that were triggered by the implementation of CIDD, in other words the effect of CIDD on the probability of retrofitting. Second, the paper assesses how the effect of the CIDD evolved over the period 2005/2011. Third, those estimations enable an assessment of the proportion of free-riders and what individual and housing characteristics influence free-riding. An unbalanced panel of individual

⁶⁵ A possible explanation is that heating system replacement only happens when the old equipment breaks down beyond repair.

data coming from the “Energy Management” (EM) annual survey conducted over the period 2002/2011 and dedicated to households’ energy-efficiency investments in their dwellings is used since behavior-based estimates are more reliable than self-reports (Malm 1996). In the absence of a control group, a difference estimator relying on time and policy-design change is performed, as in Alberini et al.(2014). This estimation focuses on insulation measures (windows, walls, roofs, etc.).⁶⁶ Control variables are included in the model and a test for pre-trends over the period 2002/2004 is conducted in order to avoid ascribing to CIDD effects that are due to exogenous unobserved time-varying variables. We also include individual effects to control for unobserved time-constant variables. Risch (2013) has already studied the effect of the CIDD on the extensive and intensive margin of the investment based on the same data used in this paper. Using matching methods, she finds higher effects on the intensive margin than on the extensive margin but without distinguishing between different retrofitting types and without taking into account the longitudinal dimension in the data such as the panel structure of the data or the potential presence of trend.

Our results suggest a significant and positive effect of CIDD on householders’ investment decisions but with a lag of two to three years depending on the category of retrofits. After the initial lag, the estimated average marginal effects of CIDD rise progressively, especially in 2009, before slightly decreasing in 2011. These changes are consistent with actual changes in the tax credit rates and with the slowness of the investment decision-making process. As regards the assessment of free-riders, the estimated share of free-riders among CIDD beneficiaries varies between 40% and 85% in years for which the effect of CIDD was significant. This is consistent with the range of values found in the literature and confirms that free-riding is an important phenomenon. Free-ridership is found to have decreased gradually over the period, to be lower for measures relating to opaque surface insulation than those related to glazed surface insulation and to depend on socio-economic variables such as the dwelling move-in date or the socio-professional category of households.

⁶⁶ Information on other retrofitting investments, such as efficient heating systems and equipment producing renewable energy, is too scanty to introduce them in the analysis, as discussed below Figure 6.

In section 2 we first review the French context and describe the tax credit scheme being studied. Section 3 presents the data, the variables and descriptive statistics. Econometric methods are explained in section 4. Section 5 presents the results, which are discussed in section 6, with conclusions in section 7.

2. Description of the French context and tax credit scheme⁶⁷.

France is committed to a 75% reduction in greenhouse gas emissions by 2050 compared to the 1990 level, and to improving final energy intensity by 2% a year from 2015 onwards (French Climate Plan and Energy Program Act of 13 July 2005). The residential sector consumed 30% of the total French energy supply in 2011 (in final energy),⁶⁸ mainly for space heating and hot water. The French policy package called “Grenelle de l’Environnement” (voted in 2009) aims at cutting energy consumption in the existing building stock by at least 38% by 2020, compared to the 2008 level.

The French tax credit scheme CIDD started in 2005.⁶⁹ The tax credit was initially implemented for the period from 2005 to 2009 and was extended until 2015. The purchase of energy efficient equipment and materials for main dwellings⁷⁰ is eligible for income tax credits. All households, regardless of their level of income, can apply for the CIDD tax credit. For households who pay income tax, the CIDD takes the form of an income tax reduction. For households who do not pay income tax, the CIDD tax credit is converted into a direct payment proportional to the amount of income tax one would save for a similar measure. The differences

⁶⁷ This review of the French tax credit scheme is based on information from several Official Tax Bulletin publications (BO n°147, September 2005; BO n°183, May 2006; BO n°88, July 2007; BO n°38, April 2009; BO n°65, June 2009; BO n°77, August 2010; BO n°84, December 2011) and public reports or publications (Mauroux et al. 2010), (Pelletier 2011), (Mauroux 2012).

⁶⁸ Source: “Le bilan énergétique de la France en 2011” <http://www.developpement-durable.gouv.fr/IMG/pdf/LPS130.pdf>

⁶⁹ Earlier legislation allowing fiscal deductions already existed (since 2001 for thermal insulation material) but did not specifically target energy efficiency renovations and its scope was not comparable with that of CIDD: public expenses were around ten times lower (<http://www4.minefi.gouv.fr/budget/plf2004/somble04.htm>), due to lower level of subsidies and a lower proportion of beneficiaries, especially for insulation measures (according to households’ declarations in the EM survey).

⁷⁰ The Tax Credit had only subsidized owner-occupiers and tenants but in 2009 it was extended to landlords renting their dwellings.

between the CIDD and a direct subsidy are a one year-delay in the reimbursements and that households have to have made a tax declaration. These can affect have different effects on households, given liquidity constraints. The tax credit subsidy is capped at 8,000€ for a one-person dwelling, 16,000€ for a two-person dwelling (with an additional allowance of 400€ per child) for a period of five consecutive years.

Eligible investments include both energy conservation measures, such as opaque and glazed surface insulation⁷¹ and heating system improvements⁷², and renewable energy systems, such as wood-heating appliances, photovoltaic panels, solar heaters and domestic wind turbines. Renewable energy production systems and heat pumps are eligible for all types of buildings, whereas insulation measures and other heating system improvements are only eligible for buildings more than two years old. The tax credit rates range from 15 to 50% of investment cost and are specific to each category and are based on energy performance criteria. Table 6 gives details for tax credit rate changes. Changes in the tax credit rates, as well as in energy performance eligibility criteria, result from a compromise between the aim of targeting the most energy-efficient systems, the desire to limit public expenditure, and lobbying from the supply side.⁷³ Whereas the tax credit base has generally only subsidized material costs of measures, a reform in 2009 included labor costs of installation for the insulation of opaque surfaces. A further amendment occurred in 2011 where the tax credit was cut by 10% due to the economic crisis and concerns about the public deficit.

According to statistics from the “Energy Management” (EM)⁷⁴ survey on households’ intentions to apply for the available economic incentives,⁷⁵ French households have benefited

⁷¹ Opaque surface insulation refers to the insulation of the attic, the walls (indoor or outdoor) or the floor (or a combination of different types of insulation) while glazed surface insulation refers to the installation of more energy-efficient windows and/or shutters.

⁷² Heating system improvements are: the installation of heating regulation systems (thermostatic valves, heat cost allocators, ambient thermostat, programming equipment) and the installation/replacement of energy efficient heating systems (boilers, heat-pumps).

⁷³ Heat-pumps are a good example: air-air heat-pumps were only eligible between 2006 and 2008 whereas thermodynamic heat-pumps for water heating started to be eligible in 2010.

⁷⁴ The Energy Management survey is supervised by the French Agency for Environment and Energy Management (ADEME) and conducted by the French market research institute TNS-Sofres. More information in section 3.

from CIDD far more than from other contemporary instruments.⁷⁶ Since 2005, more than half of the households investing each year in retrofitting their homes have used the CIDD, this proportion having reached nearly 70% since 2007, whereas less than 7% of them used other subsidies over the same period. Moreover, according to the same survey, CIDD is widely known (56.9% of households were aware of it in 2005, steadily increasing to 85.2% in 2009) and has been considered by households as the most decisive incentive since 2006 (see **Figure 5**). Due to its success, CIDD has led to large public expenditures: 985 M€ in 2005, 1.9 Bn€ in 2006, 2.2 Bn€ in 2007, 2.8 Bn€ in 2008, 2.6 Bn€ in 2009, 1.96 Bn€ in 2010 and 1.1 Bn€ in 2011⁷⁷.

After the implementation of CIDD, another economic instrument was created. When households invest in a combination of at least two retrofitting measures taken from an options list, an interest-free loan (known as EcoPTZ) could have been combined with CIDD for the same investment since 2009 (except in 2011) but has been used much less than CIDD.⁷⁸ A total of 70,933 EcoPTZ were issued in 2009 (resp. 78,484 in 2010 and 40,755 in 2011), while by contrast, more than 1 million households have benefited from CIDD every year since 2006. Statistics based on the EM survey show that EcoPTZ has never been perceived as a key incentive, while CIDD has (see **Figure 5**). Finally, in the case of insulation measures, EcoPTZ has benefited households much less than CIDD: the proportion of investors intending to apply for CIDD was 49.1% and 84.5% for opaque and glazed surface insulation respectively whereas the proportion of investors intending to apply for EcoPTZ was 3.1% and 3.3% for opaque and glazed surface insulation respectively.

⁷⁵ In this paper, households' declared intentions to apply for the different economic incentives are used to determine the proportion of corresponding beneficiaries, which means assuming that the proportion of applicants who would not be subsidized is negligible.

⁷⁶ Available subsidies include regional or local subsidies, national subsidies delivered by the ANAH (National Housing Agency), for which the modalities can vary with income, retrofitting performance, etc.

⁷⁷ Data from the Public Finances general Directorate (DGFIP). Public expenses (in million €) for opaque and glazed insulation were estimated at 518 in 2005, 741 in 2006, 948 in 2007, 811 in 2008, 902 in 2009, 417 in 2010 and 363 in 2011 mainly for windows (CGDD 2012).

⁷⁸ This has been mainly due to the reluctance of the banking sector to propose such loans (Pelletier 2011). Eligibility criteria have also been tightened.

Table 6. Tax credit rates changes

	2001/2004	2005	2006-2007	2008	2009	2010	2011-2012
Insulation							
Roof and wall	0%	25%	25%/40%*	25%/40%*	25%/40%*	25%	22%
Floor	0%	25%	25%/40%*	25%/40%*	25%/40%*	25%	22%
Ceiling	0%	0%	0%	25%/40%*	25%/40%*	25%	22%
Window, shutter	0%	25%	25%/40%*	25%/40%*	25%/40%*	15%	13.50%
Energy production							
Heating regulation syst.	0%	25%	25%/40%*	25%/40%*	25%/40%*	25%	22%
Low-temperature boiler	0%	15%	15%	15%	0%	0%	0%
Condensing boiler	0%	25%	25%/40%*	25%/40%*	25%/40%*	15%	13.50%
Wood heating appliance	0%	40%	50%	50%	40%	25%/40%**	22%/36%**
Specific heat-pump	0%	40%	50%	50%	40%	25%/40%	22%/36%
Renewable energy	0%	40%	50%	50%	50%	25%/50%***	22%/45%***

(*) 25% in the general case, 40% for housing transfer (move-in date less than 3 years before retrofitting) in old constructions (built before 1977).

(**) 25/22% in the general case, 40/36% in the case of replacement.

(***) 25% for photovoltaic panels, 50% for others (solar heater, domestic wind turbines, ...)

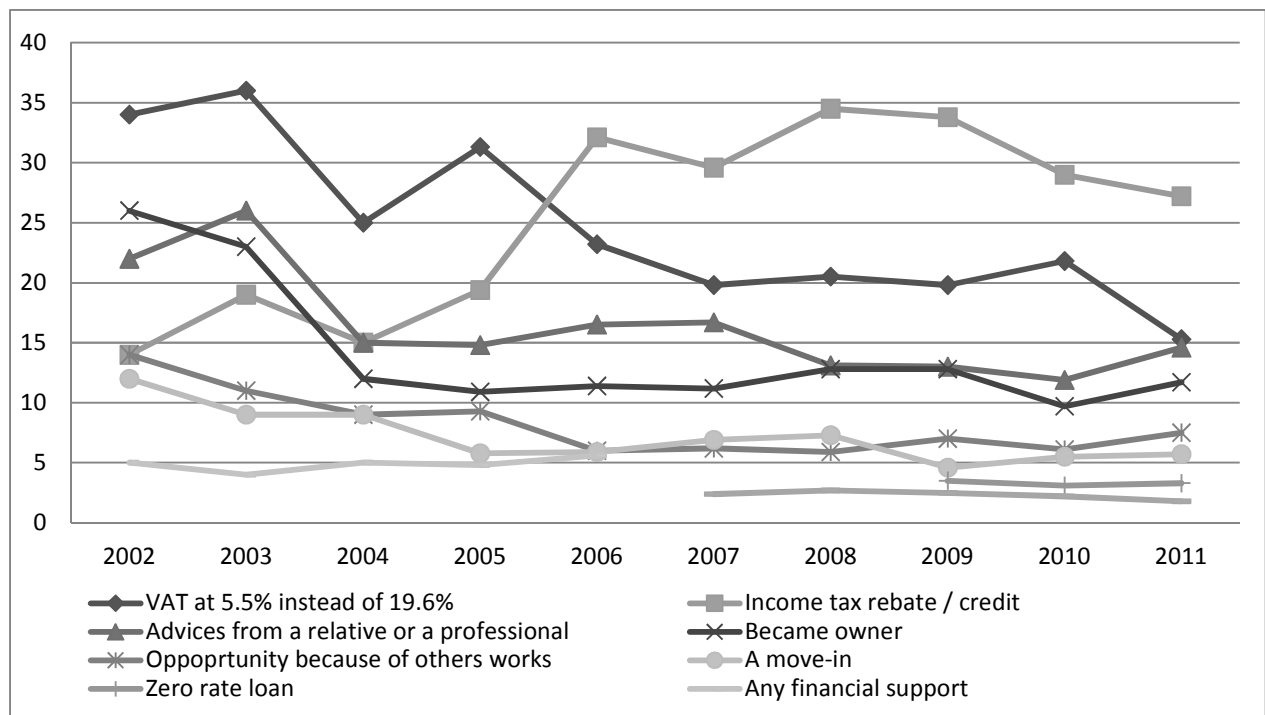


Figure 5. Main incentives/opportunities in the decision to retrofit for the households.

3. Data

3.1 Dataset description

The data used in this paper come from the annual EM) survey,⁷⁹ which provides detailed information on the retrofitting decision process, retrofit options, the characteristics of households and dwellings, and on the subsidies they received. We use data collected from 2002 to 2011⁸⁰ and treat this as an unbalanced panel.⁸¹ Over the period 2002/2011, 23,879 households were surveyed with an average turnover rate between two successive years of 49%. Households were observed for 2.4 years on average, with 40.5% of the sample observed only once. The number of annual observations goes from 6,148 households in 2005, to 8,498 in 2009. Every year, households are asked about their residential energy consumption and the investments they have or have not made, in order to improve the energy efficiency of their dwelling. A first questionnaire provides data on socio-economic variables, housing information (type of building, heating energy source, building date, etc.), and information about dweller's situation (occupation status, move-in date). Those who have invested in retrofitting their home during the last year (7-12% each year) answer a second questionnaire to provide information on retrofitting categories, investment costs, means of payment, the economic or non-economic incentives investors have benefited from (including tax credit), as well as other pieces of qualitative information such as their motivation, personal context, satisfaction, etc. In this second questionnaire, each investment is described by one to four items taken from an options list.

⁷⁹ The datasets are not in open access. Any researcher who wants to use the data has to sign a convention with ADEME and TNS-SOFRES. Contact the author for more information.

⁸⁰ The survey has been conducted since 2000 but we restricted the sample to the period 2002/2011 for the econometrics because some explanatory variables such as Individual Preferences are unavailable for 2000 and 2001. Robustness checks run over 2000/2011 do not change the results.

⁸¹ Annual recruitment is carried out by TNS-Sofres to ensure representation of all socio-economic profiles after the departure of households wishing to leave the survey. Attrition will be discussed in section 5.

3.2 Selection of variables

In order to estimate the effect of CIDD on the investment decision on the extensive margin, the dependent variable is the *retrofitting investment decision*, equal to one if the respondent has invested in retrofitting during the past year. We restricted our analysis to opaque and glazed surface insulation measures.⁸² Finally, we chose to keep “undeclared works” (carried out by an unregistered professional) or “DiY works” (carried out by the household) in the study, even though only retrofits made by a registered professional can be subsidized. Indeed, aside from the fact this is the major reason for receiving no subsidy in the case of insulation of opaque surfaces,⁸³ the households’ choice between having work carried out by a declared professional, an undeclared one, or themselves is endogenous to CIDD and excluding some alternatives from the choice set would bias the results.⁸⁴

The explanatory variables are selected on the basis of the literature on household investment modeling in residential energy. The basics of those models consist of calculating the return on retrofitting investment by comparing initial cost with future economic savings in a cost-benefit analysis, in which technological, socio-economic and contextual constraints can interact.

The **socio-demographic variables** influencing the investment decision in the model are the *Annual income of the household*, the *Socio-professional category*, the *Family size* and the *Age of the head of the household*. The *Annual income of the household* reflects the households’ financial status and their opportunity cost of time⁸⁵. This variable can also reflect the households’ discount rate, included in each profitability calculation. Indeed, several studies have shown that the discount rate decreases with income (Train 1985). Besides, this variable can reflect the impacts of the overall economic variations on individual situations. Given the life cycle theory, the *Age of the head of the household* or the *Family size* may reflect the financial

⁸² See the note below Figure 6

⁸³ On the basis of households’ declarations reported in the EM survey, 75% of households who invested in opaque insulation and did not benefit from CIDD declared that was due to DiY or undeclared works (as opposed to 15% in the case of boiler replacement). See Appendix A2 for more details.

⁸⁴ Data were however inappropriate to explicitly estimate this first sequence in the decision making.

⁸⁵ Since the information collection and implementation phases of a retrofitting project are time-consuming.

and situational constraints of the dwelling. Distinguishing between a *Business* category (in a wide sense including *company directors, farmers and shopkeepers*), *Professionals* (including *liberal professionals and executive managers*), *Employees* and the *Inactive*, the *Socio-professional category* captures aspects linked to education and the opportunity cost of time. We use the *status of occupation (rental or ownership)*, which is a key variable to characterize the important barrier linked to the split incentives between tenants and owners. In the econometrics model, we restrict the analysis to homeowners. Indeed, the question in the EM survey about retrofit investment is ambiguous in the case of tenants since it is not clear what answer a tenant of a dwelling in which retrofitting has been undertaken by the owners should give, which can lead to potential measurement bias. Moreover, even if tenants were potentially concerned by the program, statistics show that CIDD has only impacted home-owners. The *move-in-date* (the duration since the last move) is also included as a recent change in occupancy can indicate a likely time to retrofit (Gans 2012).

In order to capture changes in **individual preferences** about the environment and the economic context, possibly linked to either macroeconomic or social changes, we also include data on households' main concerns. In the EM survey, households are asked every year to rank, in order of importance, their concerns about environmental (e.g. pollution, climate change, renewable energy...) and economic issues (unemployment). *Environmental concern* and *Economic concern* are included as dummy variables equal to one if the household has identified pollution, and, respectively, unemployment, as one of the main concerns.

The *Building completion date*, the *Building type*, the *Dwelling size (surface area in square meters)* and the *Heating energy sources* are the **home characteristics** variables included in the model to describe the energy performance and the level of energy consumption, conditioning the profitability of the investment. The *Building type* variable, which differentiates between single-family homes and multi-family buildings, also characterizes the potential barriers raised by a collective decision-making process. Translating energy savings into economic gains, changes in energy prices can also impact the investment decision. We include the average

current⁸⁶ *heating energy price* determined on the basis of the main energy source declared by each household (electricity, gas, fuel, wood, district heating and a mix between electricity and wood).^{87,88} Dwellings heated by wood and district heating have been omitted from the sample in the econometrics estimation since energy prices have only been available since 2003 for these two energy sources.

The *Heating degree days (HDD)* and the *Location Category* are used to represent the **climatic and spatial characteristics of the dwelling**. The regional *HDD* variable, taken from an external data source⁸⁹, influences the energy performance of a retrofitting investment, as the energy needs vary according to the outside temperature. The *Location Category*, allows for the differentiation between urban and rural regions, and captures aspects such as storage space availability or the supply-side structure of the residential energy efficiency market. Finally, the probability of investing in retrofitting is affected by former retrofitting investments. We deal with dynamic aspects in the retrofitting investment decision including the *Former retrofitting* variable. Since 2004, households have been asked about their former retrofitting projects, which reveals whether households did not undertake such investment because insulation measures had already been taken. This variable is only used in robustness checks as it compels us to omit 2002 and 2003. However, since the implementation of the dynamic panel data model is impossible due to the unbalanced nature of the panel and the short time that people stay in it, this last estimation allows us to identify any potential bias due to neglecting this time dependency in former estimations.

⁸⁶ "current price is a sufficient statistic value for the present discounted value of the future stream of prices" (Hassett & Metcalf 1995).

⁸⁷ From statistics produced by the French Ministry of Ecology. [http://www.statistiques.developpement-durable.gouv.fr/energie-climat/r/industrie-1.html?tx_ttnews\[tt_news\]=21083&cHash=fb5b458ff78e44f761db201e5f4a2641](http://www.statistiques.developpement-durable.gouv.fr/energie-climat/r/industrie-1.html?tx_ttnews[tt_news]=21083&cHash=fb5b458ff78e44f761db201e5f4a2641).

⁸⁸ Even if the EM survey provides data on households' energy bills, we chose not to use it due to the number of missing values and the fact that we do not know if the reported energy bills correspond to the pre or post-retrofitting period for households who retrofitted during the previous year.

⁸⁹ From statistics produced by the French Ministry of Ecology. http://www.statistiques.developpement-durable.gouv.fr/energie-climat/r/statistiques-regionales.html?tx_ttnews. Heating degree day (HDD) is a measurement based on the gap between outside temperatures and a comfortable inside temperature. The heating requirements for a given structure at a specific location are considered to be directly proportional to the number of HDD.

3.3 Descriptive statistics

In order to contextualize the results, **Figure 6** shows retrofitting rates in the main dwellings among all homeowners for all the main retrofitting categories. Retrofitting categories are here accounted for separately, even if the same households have undertaken several measures belonging to different categories. As for *the installation or replacement of standard heating systems with non-renewable energy*, we do not observe any trend. This suggests that CIDD would only potentially impact the decision to invest at the intensive margin (leading to choose more energy-efficient equipment), since the retrofitting rate seems unresponsive to the introduction of CIDD. Unfortunately, as explained below Figure 6, this cannot be properly measured as the data do not provide the precise energy performance characteristics of each system (see appendix A3 for a discussion on the heating systems). No increasing trend appears for heating regulation/ventilation systems either. We cannot say anything for *equipment producing renewable energy* as the series start in 2005. An exception could be *wood stove installation or replacement* (observed since 2000), whose installation rate seems to slightly increase after 2005 but statistical tests cannot be performed due to limited sample size and low rates of installation.

Focusing on insulation measures, **Figure 6** shows investment rates separately for opaque and glazed surface insulation.⁹⁰ Investment rates for both insulation types follow similar changes, which indicate some correlations between these retrofitting measures and the necessity to study them all together. We do not see any particular trend for either before 2005. After 2005, we see a slight increase until 2008, especially for glazed surface insulation, then a peak in 2009 and a decline thereafter. This suggests that there was a differentiated effect during two sub-periods of the implementation of CIDD's: 2005/2008 and 2009/2011. Finally, the average CIDD rate for all insulation measures shown on the right axis of Figure 6 seems correlated with the retrofitting rates for insulation, especially from 2007. The peak in 2009 is due to the reform relating to the inclusion of labor costs, and shows a large increase in the tax

⁹⁰ We use "window" with an extensive meaning of all glazed surfaces.

credit rate.⁹¹ Figure 7 in appendix A1 also shows that the increase in the retrofitting rate for opaque surface insulation has been mainly driven by single roof insulation and that investments in a combination of opaque insulation measures have stayed in minority.

We pooled all opaque surface insulation measures into one category in order to ensure the statistical validity of the test. Indeed, as shown in Table 7, which gives the results of a Pearson's chi-squared test for each insulation measure, the power values prevent us from testing the equality between the investment rates during the pre (2001-2004) and post (2005-2011) CIDD periods for each insulation measure separately (except for roofs), and even more so at the annual level. The power values for the category "all insulation" and "all opaque surface insulation" are respectively 4,686 and 3,998, which are in the range of values of the annual subsample sizes on which the econometrics estimations are based. The equality of the detailed opaque surface investment rates (null hypothesis) is then rejected for both opaque surface insulation and window insulation.

⁹¹ Considering that labor costs represent at least 30% of the total cost (based on the EM survey over the period 2008/2011, since no data were available making the distinction between labor and material costs before 2008, labor costs as a percentage of total costs go from 32% for roofs to 39% for ceilings), this reform is equivalent to an increase of at least 50% in the tax credit rate.

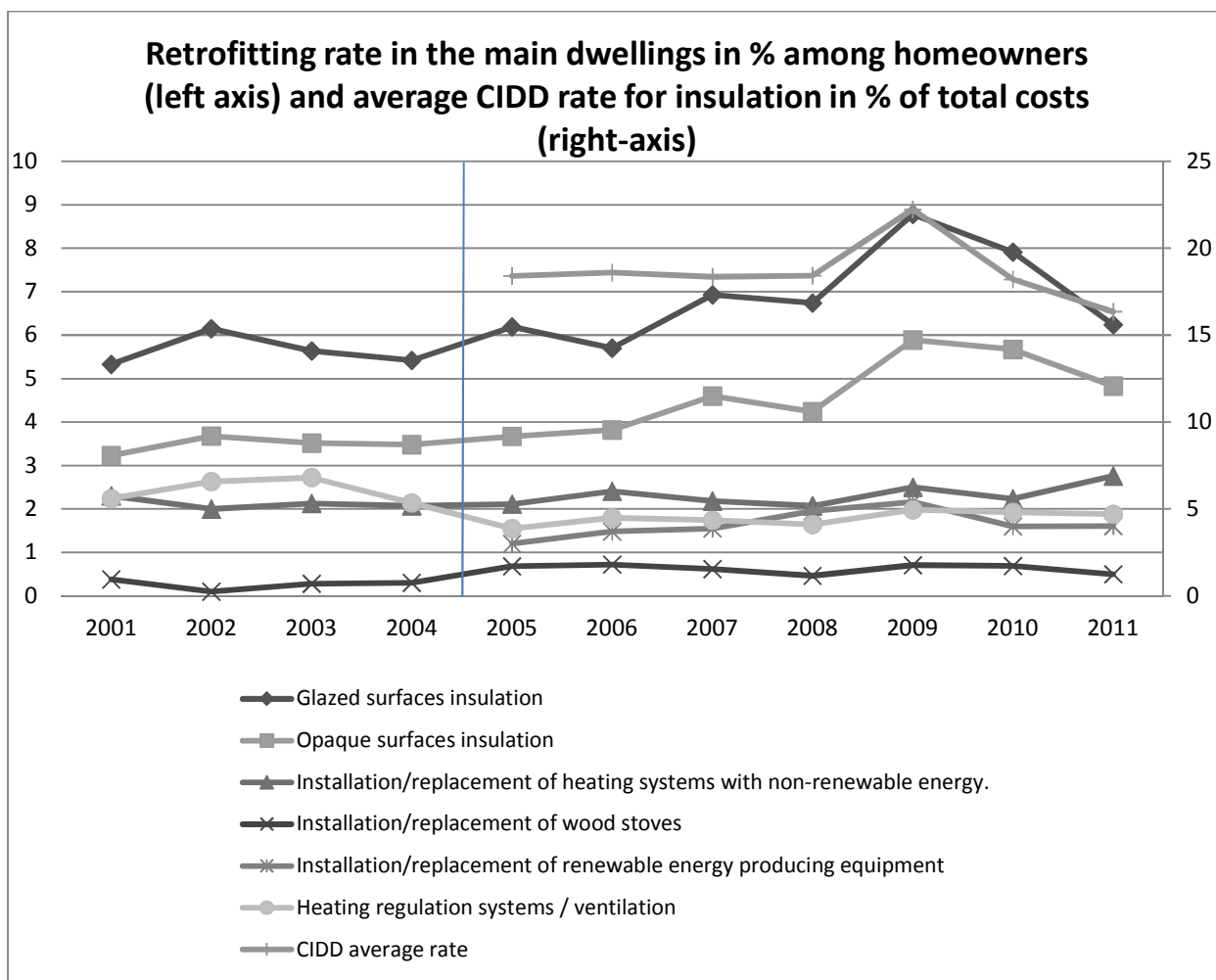


Figure 6. Retrofitting rate in % among occupying homeowners.

Note: Data are inappropriate to estimate the CIDD effect on retrofit measures other than opaque and glazed surface insulation. As for the category “installation/replacement of heating systems with non-renewable energy”, we do not observe the energy performance of each system, on which CIDD eligibility is based.⁹² As for “heating regulation/ ventilation systems” and “installation/replacement of wood stoves”, the sample size cannot provide robust statistics given their low retrofitting rates. Equipment producing renewable energy and heat-pumps are excluded from the analysis since the EM survey does not mention these systems in the list of retrofitting options before the introduction of CIDD. The average CIDD rate is weighted by the market shares of the different types of insulation and takes into account the repartition between material and labor costs for each type of insulation (based on statistics from the EM survey over 2009/2011).

⁹² Unlike heating systems, we assume that available information is sufficient to consider insulation measures without leading to significant measurement bias since the non-eligibility of the material based on technical criteria is a minor reason for subsidies being refused.

Table 7. Pearson chi-test statistic.

	Investment rate (in %)		Test power*	Statistic	P Value**
	2001/2004	2005/2011			
All Insulation measures	6.62	8.38	4686	41.13	0
All opaque surfaces	2.63	3.91	3998	46.8	0
Internal wall	1.07	1.3	45436	4.09	0.04
External wall	0.3	0.38	126510	1.33	0.25
Roof	1.36	2.43	3442	52.78	0
Floor	0.35	0.34	5550427	0.01	0.92
Window insulation	4.58	5.34	16969	11.41	0
Total sample size (N)***	14,171	29,585			

The null hypothesis H0 is the equality between the two investment rates over 2001/2004 and over 2005/2011.

* The power of the test gives the minimum number of observations required in each group to provide robust test statistics given a Type I error probability fixed at 5%.

** H0 is rejected when the p-value is less than the predetermined significance level (5%).

*** Subsample restricted to home-owners of dwellings heated by fuel, gas and electricity.

Table 8 presents the summary statistics of the households' socio economic variables and dwellings characteristics. It first shows the distribution of household statistics over 2001-2004 (before the introduction of CIDD) and 2005-2011 (the CIDD period). Second, statistics over 2005-2011 are displayed as regards: i) the share of households aware of the existence of CIDD, ii) the share of households investing in insulation, iii) the share of investors applying for the CIDD subsidy and iv) the share of CIDD beneficiaries declaring themselves to be "free-riders". Home owners dominate the categories of CIDD beneficiaries as they retrofit more and apply more for the CIDD than those who rent, with a renovation rate and a share of subsidized retrofit of 8.3% and 66.7% respectively for owners, and of 1.3% and 21.1% for tenants. Lower-income households are under-represented among investors and CIDD beneficiaries, as their renovation rate is 4.2% (or 59% for the share of subsidized retrofit), compared to 7.2% among the highest income bracket (or 68% for the share of subsidized retrofit). The gap is more prevalent when households are divided by the age of the household head: the renovation rate is 6.1% (or 73.4% for the share of subsidized retrofit) for household where the head is older than 55 years, compared to 3% for the households where the head is younger than 34 years (or 29% for the share of subsidized retrofit). In the same way, inactive people benefit more from the CIDD (73.8%) than other socio-professional categories (49.8% for Employees, 59% for Business and

65.9% for professionals). Environmental concern was higher between 2001 and 2004 than during the 2005-2011 period (54.8% of the households' top priority was the environment in 2001/2004, 51.5% in 2005/2011). Conversely, economic concern increased during the 2001-2011 period (unemployment was the top priority of 58.2% and 63.3% of the households during the 2001-2004 and 2005-2011 periods respectively). Annual national surveys indicate that the environmental concern of French households started to decline after 2008, while employment became the main concern, coincident with the economic crisis.

As regards *Building characteristics*, the retrofitting rate increases with the age of the building. Buildings built in the 1949 to 1981 period benefit more from the CIDD (more than 70% of subsidized retrofit compared to 58% for building built before 1948). Multi-family buildings are relatively under-represented in the retrofitting subsamples. Households living in single-family homes clearly retrofit more (8.3%) than those in multi-family buildings (2.8%). Dwellings heated by fuel are over-represented among investors (retrofitting rate of 8.2%) compared to those heated by electricity and district heating (retrofitting rate of 4.5% and 2.6% respectively). This can be related to correlation between dwelling types and energy sources since electricity and district heating are mostly used in multi-family buildings. The share of dwellings heated by fuel decreases between 2001/2004 and 2005/2011. Heating energy prices increase between 2001/2004 and 2005/2011, especially fuel, then gas prices. Households living in rural areas invested more in energy efficiency (8%) than those in urban areas (<5% for cities over 100 000 inhabitants) but benefited less from CIDD (56.2% compared to more than 68% for bigger cities). This might be due to the fact that rural dwellers have more ability to retrofit by themselves than urban dwellers. The average heating degree days (HDD) is greater in the retrofitting subsample than in the total sample, meaning that households invest more in retrofitting in colder regions. These statistics are in accordance with other empirical studies, providing confidence in our database.

Finally, the share of households declaring themselves to be "free-riders", i.e. for which the CIDD has had no effect on their decision, ranges from 40% to 70% of CIDD beneficiaries but is more important for households with higher income, relatively older (or Inactive) householders

and for those having occupied their home for many years or those living in houses built before 1948.

Table 8. Statistics on socio-economic variables and characteristics of dwellings.

	2001/2004 (% in columns)	2005/2011 (% in columns)	CIDD awareness*	Renovation rate*	Subsidized retrofit*	Declared free-riding*		2001/2004 (% in columns)	2005/2011 (% in columns)	CIDD awareness*	Renovation rate*	Subsidized retrofit*	Declared free-riding*
Annual income of the household							Building completion date						
<18500€	39.32	33.69	60.12	4.23	59.02	57.07	<=1948	28.49	26.85	71.06	7.6	57.96	62.29
18500 /36 300€	43.60	44.77	75.81	6.54	64.07	53.84	1949/1974	33.73	32.34	69.25	6.71	70.27	54.7
>36 300€	17.08	21.54	83.49	7.24	68.02	58.62	1975/1981	14.05	13.15	72.54	6.73	73.04	49.54
The age of household head							1982/1988						
34 years old	2.66	2.44	66.92	2.99	28.63		1989/last year	9.44	8.44	74.02	5.39	67.93	49.45
35-54 years old	46.56	43.82	72.97	5.82	58.91	54.08	current year	13.53	18.37	75.93	2	42.28	56.71
> 55 years old	50.78	53.74	69.56	6.1	73.44	58.04	Building type						
Family size							single-family home						
1 person	29.60	32.74	65.52	4.26	75.1	59.25	multi-family housing	58.22	55.91	76.65	8.33	61.91	55.5
1 couple	34.84	33.69	75	6.5	66.38	55.08	Main heating energy source						
>2 persons	35.56	33.57	74.79	6.92	56.7	53.99	gas	41.45	42.93	70.3	5.61	70.58	56.03
Socio-professional category							fuel						
Business	5.39	5.81	79.26	6.47	58.97	59.03	district heating	21.19	18.04	74.56	8.2	64.15	55.29
Professionals	25.03	25.21	79.36	6.42	65.87	54.65	wood	2.34	2.28	65.71	2.58	83.74	61.31
Employees	29.84	28.02	69.37	5.51	49.79	52.39	electricity	4.95	3.55	74	8.4	50.43	60.52
Inactive	39.74	40.95	67.85	5.76	73.81	57.6	mix wood electricity	26.32	28.89	71.68	4.45	61.22	58.5
Move in date							3.76						
< 3 years	19.78	18.60	72.97	6.57	59.53	50.36	Location category						
3 / 10 years	31.88	32.57	74.53	5.5	56.86	56.69	Parisian area	15.88	15.19	69.56	4.04	73.27	57.59
> 10 years	48.34	48.83	70.19	6	71.33	57.64	>100.000 inhab.	29.53	29.00	69.39	4.82	68.71	53.76
Status of occupation							20.000/100.000						
renter	32.63	32.80	61.29	1.3	21.13	62.08	2.000/20.000 inhab.	13.18	13.18	70.47	5.73	74.63	54.93
owner	64.12	63.96	77.57	8.32	66.65	55.36	Rurals	17.45	17.70	72.02	6.47	60.52	52.75
other	3.25	3.24	67.66	4.4	55.65	70.28	Means of heating energy prices (€/kWh)						
Individual preferences/concerns							Gas						
Environmental	54.83	51.50	71.98	5.92	62.18	56.66	Fuel	0.04	0.06				
Economic	58.19	63.32	71.9	5.87	64.76	56.47	Electricity	0.04	0.07				
Means of HDD**							Wood						
2025.41	2021.67	2021.05	2044.81	2028.31	2034.98		District heating	0.03	0.04				
							0.05						

* CIDD awareness : % of households aware of CIDD over 2005/2011; Renovation rate : % of households having invested into insulating the dwelling over 2005/2011; Subsidized retrofitting: share of households applying for CIDD in % of households who have invested in insulation over 2005/2011; Declared free-riding : share of households claiming that CIDD did not affect their decision-making in % of households benefiting from CIDD for their insulation retrofit over 2005/2011.

** means of HDD respectively for: households over 2001/2004 (col 1), households over 2005/2011 (col 2), households aware of CIDD over 2005/2011 (col 3), households investing in insulation over 2005/2011 (col 4), households applying for CIDD over 2005/2011 (col 5), households claiming themselves as free riders over 2005/2011 (col 6).

4. Econometric methodology.

We aim to determine the impact of the CIDD tax credit on the probability of investing. In the absence of a control group or any appropriate exogenous variable to identify the impact of the CIDD, the identification strategy presented in section 4.1. relies on the comparison of the dependent variable before and after the CIDD introduction. Section 4.2 presents the econometric specification.

4.1 Identification strategy: the difference estimation.

Let $\hat{\Delta}_0$ be the “naive” difference estimator:

$$\hat{\Delta}_0 = \overline{I_{it}^{CIDD_t=1}} - \overline{I_{it}^{CIDD_t=0}} \quad (1)$$

with I_{it} the dependent variable, i.e. the *retrofitting investment decision*, $\overline{I_{it}^{CIDD_t=1}}$ and $\overline{I_{it}^{CIDD_t=0}}$ the empirical mean of I_{it} respectively before and after the implementation of CIDD. Let $CIDD_t$ be a dummy variable equal to one after the implementation of CIDD and zero before. $\hat{\Delta}_0$ captures the average effect of the introduction of CIDD on the dependent variable. $\hat{\Delta}_0$ is identified by the marginal effect of $CIDD_t$ on I_{it} and is unbiased if all unobserved explanatory variables are constant over time (Crépon & Jacquemet 2010). The situation where all unobserved explanatory variables had changed over time would be captured by $CIDD_t$. Therefore, in order to avoid ascribing to CIDD effects that are due to exogenous unobserved time-varying variables, the model implementing the difference estimator Δ has to include all the relevant variables that are likely to change over time. Second, the eventual presence of trends in unobservable potential time-varying variables is checked over the period before the implementation of CIDD. Third, temporal changes in the tax credit rate will be integrated in the model in a second step to improve the identification.

The difference estimation might not eliminate all sources of bias. We will discuss in section 6 potential shocks in unobservable variables over the period after the implementation of CIDD in order to see to what extent identification could have been biased. However, it is the only applicable method to assess the CIDD effect using our data. Other identification strategies are inappropriate. First, there can be no control group since all households are potentially eligible for the CIDD. Second, there is no appropriate exogenous variable to identify the CIDD effect. As regards the awareness of tax credit for example (provided by households' declarations in the EM survey), the use of such a variable to separate households likely to be influenced by the CIDD from the others would be biased by inverse causality⁹³ and omitted variables.⁹⁴ Moreover, the use of the cross-section heterogeneity in the tax credit rates mainly relates to different retrofitting categories. Therefore, due to the presence of substitution/complementarity effects between some retrofitting categories, the tax credit rate determination would be endogenous to households' choices. Besides, a difference estimation allows us to consider the potential two-fold effect of the tax credit, combining the "price effect" with an "announcement effect"⁹⁵ (Kooimey 2002), which is not possible when tax credit is only identified with its subsidy rate.

4.2. Econometrics specification.

To estimate the effect of CIDD on the probability of investing, the difference estimator Δ is implemented in a Random effect (RE) dichotomous logit model.⁹⁶ The first specification is as follows:

⁹³ Bias due to inverse causality occurs if the decision to retrofit also makes households aware of CIDD. From the Open survey, 16 to 17% of investors stated that they had learned of the existence of tax credit after having decided to undertake a retrofitting project.

⁹⁴ Bias due to omitted variables occurs if unobservable factors influence both the probability of investing in energy conservation and the probability of knowing about tax credits. People's unequal awareness of fiscal incentives can be related to their socioeconomic profile (age, socio-professional category, income but also the social network e.g. word of mouth), the place where they live, etc. These factors can also impact on their investment decision.

⁹⁵ Through the announcement effect, the tax credit would act as a label, conferring credibility on certain goods through the approval of the regulator.

⁹⁶ The conditional fixed effects logit model is not used since it is estimated only on individuals having variation in the outcome, which excludes too many observations. Indeed, among the 23,879 households surveyed over 2002/2011, only 2,674 households are observed for at least two years and have variation in the outcome as

$$P(I_{it} = 1 | CIDD_t, X_{it}, u_i) = \frac{e^{\alpha + \sum_{t=2002}^{2004} \gamma_t T_t + \sum_{t=2005}^{2011} \delta_t CIDD_t + \beta X'_{it} + u_i}}{1 + e^{\alpha + \sum_{t=2002}^{2004} \gamma_t T_t + \sum_{t=2005}^{2011} \delta_t CIDD_t + \beta X'_{it} + u_i}} \quad (2)$$

with $P(I_{it} = 1 | X_{it}, u_i)$ the probability of investing in retrofitting for household i at time t , $X_{it} = (x_{1it}, \dots, x_{kit})$ the exogenous observed covariates presented in section 3.2, β the vector of coefficients to be estimated and u_i the unobserved individual effect. We model u_i as a random individual effect, $u_i | X_i \sim Normal(0, \sigma_u^2)$, assuming that c_i and x_i are independent. The individual error terms e_{it} are assumed to follow a standard logistic distribution with mean 0 and variance $\sigma_e^2 = \pi^2 / 3$ giving the latent intra-class correlation $\rho_{logit} = \frac{\sigma_u^2}{\sigma_u^2 + \pi^2 / 3}$ (Rodriguez & Elo 2003). $(T_t)_{t=2002, \dots, 2004}$ are annual dummies referring to the period before the introduction of CIDD. Their corresponding coefficients γ_t have to be insignificant in order to ensure the absence of trend before the implementation of CIDD, a necessary condition of the difference estimation. As regards the identification of the effect of CIDD, $(CIDD_t)_{t=2005, \dots, 2011}$ are the annual dummies referring to the period after the implementation of CIDD. We make the *CIDD* dummy interact with annual dummies in order to allow for temporal heterogeneity in the effect of CIDD. The model is estimated by maximum likelihood.

Contrary to a linear model, the difference estimator Δ is not directly derived from δ but from the marginal effects of $CIDD_t$ on $P(I_{it} = 1 | X_{it}, u_i)$:

$$\frac{\partial P(I_{it} = 1 | X_{it}, u_i)}{\partial CIDD_t} = \delta_t (1 - P(I_{it} = 1 | X_{it}, u_i)) P(I_{it} = 1 | X_{it}, u_i). \quad (3)$$

In order to estimate Δ , we compute the average of all the individual marginal effects. Temporal variations in the tax credit rates are then added in a second model specification to

regards retrofitting investments in opaque and glazed surface insulation (1,425 considering only retrofitting investments in opaque surface insulation).

test if the CIDD effect is correlated with the tax credit rate. As for robustness checks, we also estimate linear probability models with random individual effects⁹⁷. Finally, based on the same RE logit model as in equation 2, two last models are estimated in order to isolate the effects of CIDD from those of EcoPTZ and to control for path dependency in the retrofitting investment decision.

From those estimates, we derive the share of free-riders. It should be recalled that free-riding is defined as the situation in which the subsidized household would have undertaken the energy saving investment even in the absence of the subsidy. The free-riders share is defined as:

$$FRS = \frac{Invest_{Subsidized} - \hat{\Delta}}{Invest_{Subsidized}} \text{ (equation 4), where } Invest_{Subsidized} \text{ is the total number of renovations for}$$

which an incentive was requested. $Invest_{Subsidized}$ can be broken into two components: $\hat{\Delta}$, the renovations for which an incentive was requested and where the availability of the incentive was critical for the decision to do the renovation; and $Invest_{Subsidized} - \hat{\Delta}$, the number of investments for which an incentive was claimed, but the household would have made the renovation anyway. $Invest_{Subsidized} = \alpha_{CIDD} * \tau_R$, with τ_R the retrofitting rate among owner-occupiers and α_{CIDD} the proportion of retrofitters applying for CIDD, assuming that the measurement error caused by identifying households benefiting from CIDD with those applying for it can be ignored.⁹⁸ FRS confidence intervals are computed with the delta method.

In order to investigate what factors influence free riding, the RE logit model is re-estimated including interaction variables between the CIDD dummy and some individual and housing characteristics. Contrary to the case with linear models, statistical significance of the coefficient of the product term between two variables is neither necessary nor a sufficient

⁹⁷ For the same reasons as for the conditional fixed effects logit model, the linear probability model with individual fixed effect is not used since the identification is based only on individuals having variation in the outcome.

⁹⁸ More information is unavailable. But in 2011 for example, 1408.5 thousands of households applied for the CIDD and 1 363.50 thousands of households finally benefited from it, meaning a gap of 3% (fiscal data).

condition for concluding that there is meaningful interaction. In fact, the marginal effect of x_{it} on $P(I_{it})$ is

$$\frac{\partial P(I_{it} = 1)}{\partial x_{it}} = \left[\frac{\partial P(I_{it} = 1)}{\partial I_{it}^*} \right] \left[\frac{\partial I_{it}^*}{\partial x_{it}} \right], \quad (5)$$

with I_{it}^* being the unbounded latent dependent variable of the logit model. The first term of equation 6 is the marginal effect of I_{it}^* on $P(I_{it})$. The second term is the marginal effect of x_{it} on I_{it}^* . The product term only captures the interaction between the two variables present in the second term. However, the logit function may capture another interaction between the two variables present in the first term by what is known as compression.⁹⁹ This phenomenon is not an artefact of the statistical model but is a feature of the data (Berry et al. 2010). Therefore, we have to check both types of interactions. The selection of the most likely discriminating variables is based on two criteria: i) when the proportion of investors benefiting from the CIDD varies between the different modalities of the variable and/or ii) when the share of CIDD beneficiaries declaring themselves to be free-riders varies between the different modalities of the variable.

5. Results

5.1. The difference estimation

Table 9 and Table 10 show logit estimates for the full model over the period 2002-2011 for, respectively, opaque & glazed insulation and opaque insulation only. The tables provide estimates for logit models with (column 3) and without (column 2) random individual effects (RE) plus a preliminary logit model without any covariate except the policy variable interacted

⁹⁹ Compression is the phenomenon in which the marginal effect of a variable on $\Pr(Y)$ is strongest at some value of $\Pr(Y)$, and declines in strength as $\Pr(Y)$ gets either smaller or larger. Compression is present in any statistical model with a link function mapping an unbounded index I_{it}^* into a bounded $P(I_{it})$. Compression acts in the marginal effect of I_{it}^* on the $P(I_{it})$, which is equal to the instantaneous slope of the logit curve at the values of the covariates. See Berry et al. (2010).

with the year dummies (column 1). It should be recalled that the sample is restricted to owner-occupiers of dwellings heated by fuel, gas or electricity. New buildings and buildings other than single-family homes or multi-family buildings are also omitted from the sample. The *heating energy price* variable is introduced as a rate of variation in the regression. Otherwise, it would capture differences between energy sources to a greater extent than changes in the price of each source of energy. At year y , the *energy price variation* variable is the growth rate between $y-4$ and $y-1$. We notably assume a certain inertia in the decision-making process, which is why there is a lag in the prices considered and why the growth rates considered are calculated over several years¹⁰⁰. 2001 has been omitted from the sample since a few variables were not available for that year.

Looking first at the full model for insulation of both glazed & opaque surfaces (Table 9 column 3), the estimated marginal effects of the control variables reveal significant determinants of the investment decision. As regards household variables, being relatively wealthy has a positive impact on the retrofit decision. *Professionals, Employees* (and to a minor extent the *Inactive*) are more likely to invest than the *Business* category (including company directors, farmers and shopkeepers). The *family size* variable is insignificant. The *age of household head* variable was dropped due to correlation between covariates. Households having recently moved in also invest significantly more in energy efficiency. *Environmental preferences* have a significant positive effect on the investment decision whereas the *economic concerns* variable is insignificant. As regards variables relating to the dwelling, households living in old buildings and/or in single-family homes are more prone to invest than those living in more recent and/or multi-family buildings. Larger surface area, which implies higher energy consumption for the same behavior in respect of energy use, significantly increases the probability of investing. As for the *energy price variation* variable, its effect is positive though insignificant. Regarding geographic patterns, households living outside Paris, and in particular in small cities or in rural areas, invest more in energy efficiency. The *regional average heating degree days (HDD)* variable, also positively correlated with energy consumption, impacts

¹⁰⁰ We choose the specification maximizing the log-likelihood. Other specifications have been tested giving the same results (not reported in the paper but available on request).

positively though insignificantly on the retrofit decision. Turning to models restricted to the insulation of opaque surfaces (Table 10 column 3), we find similar results, except that the effect of the *Economic concerns* variable and the *HDD* variable become significantly negative for the former and positive for the latter.

As regards the effect of CIDD, it should first be recalled that we use a difference estimator. The insignificance of annual dummies before 2005 confirms the absence of a temporal trend before the implementation of CIDD, which is a necessary condition for this estimation method. Then, looking first at the insulation of both glazed & opaque surfaces (Table 9 column 3), we find that, after a three-year latency period (2005-2007) with no significant effect, the effect of CIDD on the investment decision starts to be significantly positive in 2008 at the 10% level. This positive effect strongly increases after 2009: becoming significant at the 1% level, it goes from 0.8 percentage points in 2008 to 3.1 in 2009 decreasing to 2.5 percentage points in 2010 and 1.5 percentage points in 2011. Looking at opaque surface insulation only (Table 10 column 3), we have the same temporal pattern in the results (tripling from 0.4 percentage points in 2008 to 1.3 in 2009). The effect of CIDD becomes positively significant slightly earlier (at the 10% level in 2007 and the 5% level in 2008). Comparing columns 1 and 2 with column 3 in both samples, the introduction of the covariates and the RE in the logit models changes the coefficients, mainly lowering the magnitude of the average marginal effects of the CIDD (and other covariates).

Table 9. RE logit's estimated marginal effects for opaque & glazed surface insulations

Variables	logit (1)		logit (2)		logit RE (3)	
	M.E.	S.E.	M.E.	S.E.	M.E.	S.E.
Annual dummies (ref:2002)						
2003	0.002	(0.0065)	0.001	(0.0062)	0	(0.0046)
2004	-0.004	(0.0069)	-0.002	(0.0067)	-0.006	(0.0045)
CIDD dummy*2005	0.001	(0.0069)	0.002	(0.0068)	0	(0.0048)
CIDD dummy*2006	-0.001	(0.0067)	-0.002	(0.0063)	-0.004	(0.0045)
CIDD dummy*2007	0.012*	(0.0066)	0.011*	(0.0065)	0.006	(0.0046)
CIDD dummy*2008	0.01	(0.0067)	0.013*	(0.0066)	0.008*	(0.0047)
CIDD dummy*2009	0.037***	(0.0073)	0.043***	(0.0074)	0.031***	(0.0054)
CIDD dummy*2010	0.027***	(0.0072)	0.038***	(0.0075)	0.025***	(0.0053)
CIDD dummy*2011	0.008	(0.0066)	0.018***	(0.0066)	0.015***	(0.005)
Environmental concerns			0.006*	(0.0034)	0.005**	(0.0024)
Economic concerns			-0.001	(0.0034)	0	(0.0024)
HDD			0	(0.006)	0.005	(0.0043)
Energy price variation			0.008	(0.0102)	0.008	(0.0075)
Dwelling size			0.001**	(0.0005)	0.001**	(0.0004)
Building completion date (ref: < 1974)						
1975/1988			-0.027***	(0.0045)	-0.022***	(0.0033)
1989/last year			-0.087***	(0.0033)	-0.065***	(0.0029)
Multi-family housing (ref: single-family home)			-0.041***	(0.0044)	-0.031***	(0.0029)
Annual income of the dwelling (ref: <18500 euros)						
18500 /36 300 euros			0.01**	(0.0046)	0.01***	(0.003)
>36 300 euros			0.007	(0.0057)	0.008**	(0.0038)
Move in date (ref: < 3 years)						
3 / 10 years			-0.071***	(0.0076)	-0.062***	(0.0067)
> 10 years			-0.095***	(0.0078)	-0.082***	(0.007)
Category of city (ref: Parisian agglomeration)						
> 20.000 inhabitants			0.004	(0.0059)	0.008**	(0.0037)
<20.000 inhabitants / rural			0.008	(0.0062)	0.009**	(0.004)
Socio-professional category (ref: Entrepreneur)						
Managers			0.029***	(0.0092)	0.023***	(0.006)
Employees			0.026***	(0.0091)	0.018***	(0.006)
Inactive			0.021**	(0.0091)	0.014**	(0.0058)
Family size (ref: 1 person)						
1 couple			0.008*	(0.0048)	0.004	(0.0035)
>2 persons			0.01	(0.0063)	0.004	(0.0041)
sigma_u					1.111	0.047
rho					0.273	0.017
Nb of observations	36367		36367		36367	
Nb of individuals	13116		13116		13116	
Log likelihood	-12411.527		-11714.13		-9432.6265	

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

col (1): logit estimates without covariates; (2) logit estimates; (3) RE logit estimates

Table 10. RE logit's estimated marginal effects for opaque surface insulations only

Variables	logit (1)		logit (2)		logit RE (3)	
	M.E.	S.E.	M.E.	S.E.	M.E.	S.E.
Annual dummies (<i>ref:2002</i>)						
2003	0	(0.0043)	0.001	(0.0041)	0	(0.0019)
2004	0	(0.0045)	0	(0.0043)	-0.001	(0.0019)
CIDD dummy*2005	0.002	(0.0046)	0.003	(0.0044)	0.001	(0.002)
CIDD dummy*2006	0	(0.0045)	-0.001	(0.0041)	-0.001	(0.0019)
CIDD dummy*2007	0.009**	(0.0044)	0.007*	(0.0043)	0.003*	(0.002)
CIDD dummy*2008	0.007	(0.0043)	0.008*	(0.0043)	0.004**	(0.002)
CIDD dummy*2009	0.021***	(0.0049)	0.025***	(0.0051)	0.013***	(0.0025)
CIDD dummy*2010	0.017***	(0.0048)	0.023***	(0.0051)	0.011***	(0.0025)
CIDD dummy*2011	0.011**	(0.0045)	0.016***	(0.0044)	0.009***	(0.0024)
Environmental concerns			0.005*	(0.0023)	0.002**	(0.0011)
Economic concerns			-0.006***	(0.0023)	-0.002**	(0.0011)
HDD			0.005	(0.0041)	0.004*	(0.002)
Energy price variation			0.002	(0.0071)	0.001	(0.0034)
Dwelling size			0	(0.0004)	0	(0.0002)
Building completion date (<i>ref: < 1974</i>)						
1975/1988			-0.017***	(0.0032)	-0.009***	(0.0016)
1989/last year			-0.037***	(0.0024)	-0.019***	(0.0017)
Multi-family housing (<i>ref: single-family home</i>)			-0.038***	(0.0024)	-0.017***	(0.0014)
Annual income of the dwelling (<i>ref: <18500 euros</i>)						
18500 /36 300 euros			0.005	(0.003)	0.003**	(0.0014)
>36 300 euros			0.004	(0.0038)	0.003	(0.0018)
Move in date (<i>ref: < 3 years</i>)						
3 / 10 years			-0.043***	(0.006)	-0.024***	(0.0038)
> 10 years			-0.061***	(0.0061)	-0.034***	(0.0041)
Category of city (<i>ref: Parisian agglomeration</i>)						
> 20.000 inhabitants			0.001	(0.0038)	0.002	(0.0018)
<20.000 inhabitants / rural			0.008*	(0.004)	0.004**	(0.0019)
Socio-professional category (<i>ref: Entrepreneur</i>)						
Managers			0.011*	(0.0062)	0.006**	(0.0028)
Employees			0.011*	(0.0061)	0.005*	(0.0028)
Inactive			0.003	(0.0061)	0.001	(0.0027)
Family size (<i>ref: 1 person</i>)						
1 couple			0.005	(0.0035)	0.002	(0.0017)
>2 persons			0.006	(0.0044)	0.002	(0.0019)
sigma_u					1.556	0.075
rho					0.424	0.024
Nb of observations	36367		36367		36367	
Nb of individuals	13116		13116		13116	
Log likelihood	-6866.6968		-6266.76		-5129.0113	

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

col (1): logit estimates without covariates; (2) logit estimates; (3) RE logit estimates

Thus, the results relating to the effect of CIDD reveal an initial latency period of two or three years with no significant effect, followed by an increasing, positive effect on the probability of retrofitting, especially from 2009, although with a decrease in the positive effects at the end of the period. As regards the first years of latency, the first column of Table 13 (in Appendix) shows the estimated marginal effects of CIDD in two sub-periods (2005/2007 and 2008/2011) both for opaque and glazed surface insulation¹⁰¹. The null hypothesis of equality between the coefficients of the two sub-periods policy variables is significantly rejected. Focusing on the period in which the effect of CIDD is significant, the average effect of CIDD is an increase of 2.1 percentage points in the probability of investing over the period 2008/2011. Given an average retrofitting rate of 9% over the period 2008/2011, the effect of CIDD represents 23% of the retrofitting rate¹⁰². We can deduce the existence of some inertia in households' response to the policy. This could first be due to the intrinsic temporality of such an investment decision, known to be a long process.¹⁰³ This inertia can also be related to the time such a policy requires to become widely known and to the complexity of the CIDD scheme (see section 2).

Second, the increase in the positive effect in 2009 may be linked to the reform carried out in that year (the addition of the installation expenditure to the tax credit base in 2009 for opaque surface insulation measures).¹⁰⁴ In this case, the CIDD effect acted as a price shock, as households' awareness of CIDD did not change much in the meantime.¹⁰⁵ Finally, the decreasing trend in the positive effect of CIDD at the end of the period can be related to the decrease in the CIDD rate for glazed insulation (and secondarily for opaque surfaces, see Table 6).¹⁰⁶ The

¹⁰¹ Dealing with additional model specifications, Table 13 only shows estimates for the marginal effect of the CIDD. As regards other covariates, these additional regressions provide similar results with slight changes in the levels of estimates. The full results are available on request.

¹⁰² Not reported in the paper, we did the same for opaque surface insulation only: the average effect of CIDD is an increase of 0.87 percentage points in the probability of investing over the period 2007/2011, representing 21% of the respective retrofitting rate (given an average retrofitting rate of 4%).

¹⁰³ The average maturation period of a renovation project is more than 6 months, according to the OPEN¹⁰³ database, even more for a project including insulation measures (OPEN 2008).

¹⁰⁴ The fact that the retrofitting subsample including glazed surfaces presents the same increase is not contradictory due to the fact that most insulation projects on opaque surfaces also include glazed surfaces.

¹⁰⁵ On the basis of the EM survey, the proportion of households surveyed only once that were aware of CIDD is 56.9% in 2004, 62.9% in 2006, 76% in 2007, 79.4% in 2008, 85.2% in 2009 and 83.4% in 2010.

¹⁰⁶ The fact that households can only benefit once from a CIDD subsidy over a five-year period can also contribute to a

decrease suggests that the effect of CIDD is sensitive to the level of subsidy. Column two of Table 13 (in Appendix A1) shows the estimated marginal effects of an interaction variable between the CIDD dummy over the second sub-period (after the latency period) and a tax credit rate variable. The tax credit rate variable is the difference between the annual tax credit rate in % of total costs (material and installation costs) and the average rate, equal to 18.7% over 2005/2011. We see that both the CIDD dummy and the interaction variable have a significant positive effect on the investment decision over the second period. A one percent increase in the CIDD rate above the average is found to equate to an increase of 0.3 percentage point in the probability of investing over the period 2008/2011, representing 3.3% of the retrofitting rate.

5.2. Free-ridership assessment

Annual estimates of the share of free-riders (FRS) along with their confidence intervals are presented in Table 11, in addition to annual statistics on τ_R (the retrofitting rate among owner-occupiers), α_{CIDD} (the share of retrofitters applying for CIDD) and households' declarations about free-ridership provided in the EM survey. It does not provide estimates of the proportion of free-riding for those years for which the estimated marginal effect of CIDD was not significant, suggesting that free-riding would have been ubiquitous during these years. As regards all insulation measures, annual rates of free-riding decrease from 85% in 2008 to 61% in 2010, with a new increase to 70% in 2011. When focusing on opaque surface insulation, annual rates of free-riding rates steadily decrease from 77% in 2007 to 42% in 2011. Estimates indicate that free-riding is more significant in the case of glazed surface insulation than opaque surface insulation. We remark that households' intentions to benefit from CIDD also decline at the end of the period, probably linked to the fact that more and more potential CIDD beneficiaries had already undertaken works and also to the decrease in subsidy rates. The percentage of households having benefited from CIDD and declaring themselves as free-riders decreased from 61.4% in 2006 to 52.4% in 2010 before going up again to 61.8% in 2011¹⁰⁷.

diminishing effect of CIDD in the long run too. Indeed, the CIDD subsidy being capped for a period of 5 consecutive years (see section 2), households having invested at the beginning of the CIDD implementation period (2005), or households having reached the subsidy cap, were no longer eligible in 2011, which might have contributed to the 2011 decrease in CIDD effects.

¹⁰⁷ The question did not exist in 2005.

Statistics for opaque surface insulation follow the same trend: from 66.9% in 2006 to 48.7% in 2010 and rising to 65.1% in 2011. Compared to our estimates, rates of declared free-riding display the same decreasing trend until 2010, with a new increase in 2011, but are lower in magnitude.

Table 11. Estimation of free-ridership

All retrofit incl. Insulation (opaque and glazed surfaces)							
	2005	2006	2007	2008	2009	2010	2011
Observed retrofitting rate*	6.77	6.59	8.22	7.99	10.91	9.61	7.8
Observed CIDD recourse rate**	62.88	67.57	67.52	68.46	74.29	73.43	64.79
Estimated CIDD M.E.	0	-0.004	0.006	0.008	0.031	0.025	0.015
Standard errors	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Estimated FRS	-	-	-	0.85	0.62	0.65	0.7
FRS 95% Confidence interval	-	-	-	[0.69 - 1]	[0.49 - 0.75]	[0.5 - 0.79]	[0.51 - 0.9]
Declared FRS***	-	61.4	56.2	48.8	55.1	52.4	61.8
(N)****	-	255	310	335	425	398	275

Opaque Insulation							
	2005	2006	2007	2008	2009	2010	2011
Observed retrofitting rate*	2.91	2.83	3.7	3.51	4.93	4.6	3.89
Observed CIDD recourse rate**	.	29.96	36.29	39.37	48.83	42.02	39.95
Estimated CIDD M.E.	0.001	-0.001	0.003	0.004	0.013	0.011	0.009
Standard errors	0.002	0.002	0.002	0.002	0.003	0.003	0.002
Estimated FRS	-	-	0.74	0.68	0.48	0.43	0.43
FRS 95% Confidence interval			[0.45 - 1]	[0.4 - 0.97]	[0.27 - 0.68]	[0.18 - 0.69]	[0.13 - 0.73]
Declared FRS***	-	66.9	60.6	60.1	58.3	48.7	65.1
(N)****	-	123	169	142	227	224	167

(*) the renovation rate for insulation in % among occupying homeowners, (**) the % of households having invested in retrofitting who apply for CIDD, (***) % of CIDD beneficiaries stating that CIDD had no effect on their decision, (****) Number of respondents to the question "What was the CIDD effect on your decision to retrofit?"

Note : Confidence intervals are computed with the delta method.

Table 12 shows the estimates of the RE logit models including interaction variables between the CIDD dummy and the individual and housing characteristics found to be discriminating as regards the share of subsidized retrofits and the declared free-riding (Table 8). For simplicity and parsimony, we show results in which the CIDD variable has not been interacted with annual dummies and the interaction variables have been estimated separately.¹⁰⁸ Column 1 shows the estimated coefficients of the RE logit model for the CIDD variable, the covariate alone and the interaction between CIDD and the covariate. Column 2 shows the estimated marginal effect of the CIDD on the probability of investing for each

¹⁰⁸ A RE logit model including all the interaction variables has also been estimated and provides the same effects but we prefer to present separated estimates to compute free-riding share separately. Covariates estimates are not reported but all results are available on request.

modality of the variable put into interaction. Corresponding free-rider shares are presented in column 5. As regards the *socio-professional category*, the interaction variable coefficients are significant, meaning that interaction effects occur in the latent model. FRS is found to be higher for people in Business (65% of CIDD beneficiaries) than for Professionals and Employees (35%) or for Inactive (50%). For the *move-in date* and the *income* variables, interaction variables coefficients are insignificant. The heterogeneity of the estimated CIDD marginal effects is only due to compression. FRS increases with income, from 44% for the lowest income bracket to 65% for the highest income bracket and also increases with tenure from 64% among households having occupied their home more than 3 years compared to only 27% for households having recently moved into a new dwelling. As regards the building completion date, the interaction variable coefficients are significant. But given differences in the retrofitting rate and in the share of subsidized retrofits, estimated FRS are homogenous (46-47%) for the different periods of construction. The estimated CIDD marginal effect is higher for smaller cities, but, still given differences in the retrofitting rate and in the share of subsidized retrofits, FRS is slightly higher for smaller cities (55% for rurals dwellings and cities <20.000 inhabitants compared to 48-49% for bigger cities). Similarly, whereas the estimated CIDD effects are very different between single and multi-family houses, their FRS estimates are close. As regards income and city category, the coefficients of the covariate alone turn into insignificant ones compared to the full model in Table 9 providing less confidence in these specifications.

Table 12. RE logit's estimated marginal effects and FRS interacted with socio-economic variables and housing characteristics. Opaque & glazed surface insulations sample.

Variable	Est. Coeff. (1)	Est. CIDD M.E. (2)	Renovation rate (3)	Subsidized retrofit (4)	Estimated FRS (5)	FRS Confidence interval (6)
Annual income of the dwelling						
<i>CIDD</i>	0.335***					
<i>CIDD * <18500 euros</i>	-0.163	0.014***	4.23	59.02	0.44	[0.11 - 0.77]
<i>CIDD * 18500 /36 300 euros</i>	-0.048	0.017***	6.54	64.07	0.59	[0.35 - 0.83]
<i>CIDD * >36 300 euros</i>	<i>ref</i>	0.017***	7.24	68.02	0.65	[0.43 - 0.87]
<i><18500 euros (ref: >36 300 euro)</i>	-0.086					
<i>18500 /36 300 euros (ref: >36 300 euro)</i>	0.049					
Building completion date						
<i>CIDD</i>	0.394***					
<i>CIDD * <=1948</i>	-0.432***	0.023***	7.60	57.96	0.47	[0.29 - 0.65]
<i>1949/1988</i>	<i>ref</i>	0.024***	6.50	70.67	0.47	[0.29 - 0.65]
<i>CIDD * 1989/last year</i>	0.11	0.005***	2.00	42.28	0.46	[0.26 - 0.66]
<i><= 1948 (ref: 1949/1988)</i>	0.378***					
<i>1989/last year (ref: 1949/1988)</i>	-1.943***					
Socio-professional category						
<i>CIDD</i>	0.443***					
<i>CIDD * Business</i>	-0.744**	0.013***	6.47	58.97	0.65	[0.49 - 0.81]
<i>CIDD * Professionals & Employees</i>	-0.294***	0.022***	5.95	58.41	0.35	[0.13 - 0.57]
<i>CIDD * Inactive</i>	<i>ref</i>	0.021***	5.76	73.81	0.50	[0.32 - 0.68]
<i>Business (ref: Inactive)</i>	0.229					
<i>Professionals & Employees (ref: Inactive)</i>	0.366***					
Move-in date						
<i>CIDD</i>	0.304***					
<i>CIDD * < 3 years</i>	-0.18	0.029***	6.57	59.53	0.27	[0 - 0.54]
<i>CIDD * > 3years</i>	<i>ref</i>	0.014***	5.80	65.70	0.64	[0.5 - 0.78]
<i>< 3 years (ref: > 3years)</i>	1.088***					
Category of city						
<i>CIDD</i>	0.371***					
<i>CIDD * Parisian agglomeration</i>	-0.221	0.015***	4.04	73.27	0.48	[0.25 - 0.71]
<i>CIDD * > 20.000 inhabitants</i>	-0.15	0.018***	5.10	70.80	0.49	[0.28 - 0.7]
<i>CIDD * <20.000 inhabitants / rural</i>	<i>ref</i>	0.019***	7.37	57.76	0.55	[0.35 - 0.75]
<i>Parisian aggro (ref: <20.000 inhab./rural)</i>	-0.022					
<i>> 20.000 inhab (ref: <20.000 inhab./rural)</i>	0.11					
Building type						
<i>CIDD</i>	0.287***					
<i>CIDD * Multi-family housing</i>	-0.075	0.008***	2.82	73.40	0.60	[0.44 - 0.76]
<i>CIDD * Single-family home</i>	<i>ref</i>	0.016***	8.33	61.91	0.68	[0.55 - 0.81]
<i>Multi-family housing (ref: single-family home)</i>	-0.688***					

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

(1): estimated coefficient; (2) Estimated marginal effect of the CIDD; (3) retrofitting rate for insulation in % of occupying homeowners; (4) % of subsidized retrofit; (5) Estimated free-riders share; (6) Free-riders share 95% Confidence interval (delta-method).

5.3 Robustness checks

Table 13 (in Appendix) provides complementary estimation results for robustness checks for the opaque & glazed surface insulation sample. A RE logit model is estimated in which retrofitting observations satisfying EcoPTZ eligibility criteria are omitted from the sample over the period 2002/2011 in order to isolate the effects of CIDD from those of EcoPTZ (column 3)¹⁰⁹. Insignificant in the first period, the estimated effect of the CIDD is a significant increase of 1.7 percentage points in the probability of investing in the second period, representing 21.4% of the retrofitting rate of this sub-sample, similar to the 23% of the model on the entire insulation sample (column 1). It is the same timing and magnitude as in the entire model which confirms our assumptions that this increase in 2009 is not due to the introduction of EcoPTZ. In order to identify any potential bias resulting from neglecting this time dependency in former estimations, another RE logit model is estimated in which we introduce a *Former retrofitting* variable indicating whether households have already invested in retrofitting (column 4). Results show that the *Former retrofitting* variable has a negative, though insignificant, effect on the investment decision and higher effects of CIDD compared to the RE logit model's estimates in column 1. Therefore, ignoring the time dependency would potentially understate the effect of CIDD. However, we do not place too much confidence in this result given the number of omitted observations (as we explained in section 4.2, the variable is only available from 2004). Column 5 shows estimates for a RE linear probability models¹¹⁰, which give similar CIDD effects to the RE logit model, albeit somewhat higher.

Finally, compared to the national situation, couples of elderly and inactive homeowners are over-represented in the EM survey, all the more so if we consider people who are present in the survey over a long time period. Therefore, in estimations not reported in this paper but

¹⁰⁹ If the 2009 increase in the estimated CIDD effect is an upward bias due to a positive effect of the EcoPTZ captured by the CIDD variable, such an increase would have to disappear when excluding the retrofitting observations potentially impacted by the EcoPTZ. These observations are all the investments combining at least two retrofitting measures present in the EcoPTZ options list. For simplicity, Table 13 shows estimates of the CIDD effects on the relevant two sub-periods as found previously.

¹¹⁰ Not reported in this paper, the linear probability (LP) model without individual effect gives higher estimated CIDD effects. The LP model with fixed effects gives insignificant CIDD effects even for the second sub-period. But, as seen in section 4.2., the identification relies on too few individuals to be considered.

available on request, we test for attrition¹¹¹ in two ways (Gans 2012): by including for each household (i) the number of periods they appear in the sample, and (ii) a dummy variable indicating whether they are present for all periods in the sample. The coefficients on these additional regressors are insignificant, which means that attrition is not a concern¹¹².

6. Discussion.

After being cautious about explanatory variable selection and conducting successful pre-trend tests, some uncertainties still remain as regards the difference estimator's ability to capture CIDD effects exclusively. In particular, unobserved time-varying factors linked to macroeconomic shocks, especially related to the economic crisis of 2008, still potentially exist. We have been careful to introduce individual subjective declarations in order to capture changes in environmental preferences and the economic conjuncture but other crisis-related time-varying factors could remain unobservable, such as budget and liquidity constraints, precautionary saving, etc. However, another data source can help to assess to what extent the omission of the impact of the economic crisis from the regression could have biased the estimates. OPEN, a French institutional watchdog for renovation provides two surveys about all households' retrofitting investments, also including retrofitting measures outside the scope of CIDD - contrary to our dataset - covering the observation periods 2007/2009 and 2009/2011 respectively. Considering the retrofitting rates for categories excluded from the CIDD scheme,¹¹³ we can see the impact of the economic crisis independent of the effects of CIDD, assuming that the economic crisis has had the same repercussions on both retrofit categories and that there is

¹¹¹ Attrition exists in the panel. However, it does not lead to a significant selection bias since it is not correlated with specific households' investment in residential energy efficiency and new recruitment compensates for attrition.

¹¹² The variable indicating the number of periods they appear in the sample has a small negative effect on the retrofitting investment decision in the case of opaque surface insulation, though only significant at the 10% level.

¹¹³ Retrofitting measures are grouped into 7 categories: 1) Electricity, lighting, etc., 2) Painting, wallpaper, curtains, etc., 3) Sanitary, plumbing and bathroom furniture, 4) Kitchen furniture and appliances, 5) Stairs, elevators, etc., 6) Furniture, storage and bedding material, 7) Retrofitting relating to the garden.

no substitution between them. Transformed into a normalized indicator for the year 2009,¹¹⁴ average retrofitting rates weighted by market share are 0.99 in 2007, 1.55 in 2008, 1 in 2009, 1.2 in 2010 and 1.52 in 2011 suggesting that the economic crisis had a negative, immediate, and temporary impact on the retrofitting rate, which seems to have stopped an increasing trend on these specific retrofitting categories. Therefore, it is reasonable to assume that the economic crisis would have had a similar negative, immediate, and temporary effect as regards insulation measures, which means that our CIDD effect estimates are likely underestimated after 2008 and especially in 2009. Moreover, the econometric study does not take into account the evolution of the retrofitting costs. If we assume that such costs have increased over the period (see the IPEA index in Appendix A1), our estimates would be even more underestimated.

As explained in section 4.1., in the absence of a control group or any appropriate exogenous variable to identify the effect of CIDD, the difference estimation is the only applicable method to assess the CIDD effect using our revealed preferences data. Further steps could be the estimation of a structural choice model, but this would require using other data. In fact, contrary to choice experiment data, our data do not provide information about all of the alternatives of the choice set faced by the decision maker. Therefore, to estimate a choice model would require building the choice-attributes for all the non-chosen alternatives. This cannot be done due to the lack of relevant information available in the data set and the intrinsically high level of heterogeneity among retrofitting investments.

¹¹⁴ The two surveys do not have the same scope, providing justification for normalization on the common year 2009. Author's own calculations.

7. Conclusion

This paper assesses the effects on households' retrofit investments of the most prominent incentive implemented in France: the CIDD tax credit introduced in 2005. Focusing on glazed and opaque surface insulation measures, we use an unbalanced panel of individual data from the EM annual survey over the period 2002/2011 in order to estimate the effects of CIDD on the extensive margin of French households' retrofit investments. In the absence of a control group, we use a difference estimator in a random individual effect dichotomous logit model.

Results reveal a significant positive effect of CIDD on the probability of investing in retrofitting, though after an initial latency period of two or three years with no significant effect. Focusing on the period in which the effect of CIDD is significant and given an average retrofitting rate of 9% over 2008/2011, the effect of CIDD represents respectively 23% of the retrofitting rate. As regards the first years, we can deduce the existence of some inertia in households' response to the policy, probably due to the intrinsic temporality of such investment decisions, to the time required for CIDD to become widely known and to the complexity of the CIDD scheme. The marginal effect of CIDD increases in 2009, which may be linked to the 2009 reform (the addition of installation costs to the tax credit base in 2009 for opaque surface insulation measures) suggesting that the effect of CIDD is sensitive to the level of subsidy. A decreasing trend in the positive effect of CIDD then appears at the end of the period, which can be related to the decrease in the tax credit rates and to the fact that the majority of potential CIDD beneficiaries had already entered the scheme. Accordingly, the estimated annual proportion of free-riders among CIDD beneficiaries has globally decreased over the period: from 85% in 2008 to 61% in 2010 for all insulation measures (70% in 2011), from 77% in 2007 to 42% in 2011 when focusing on opaque surface insulation (after quasi-ubiquitous free-riding over the period 2005/2007). Therefore, free-riding is an important phenomenon, higher for insulation of glazed surfaces than for opaque surfaces. Free-ridership is found to decrease in cases of recent housing transfer, to depend on the socio-professional category and to possibly increase as income rises.

We took care not to attribute to CIDD effects that are due to exogenous unobserved time-varying variables, such as the presence of pre-trends in the model or the introduction of EcoPTZ in 2009. We also assess the potential bias caused by the impossibility of including variables reflecting the effects of the economic crisis in 2008 and information on past retrofitting investments. We conclude that our estimated effects of CIDD on households' decision to invest are conservative, possibly underestimated.

In terms of policy implications, the existence of inertia in households' response to the policy invites the implementation of consistent and simple tax credit design, accompanied by good communication. The sensitivity of households' response to the level of subsidy suggests that increasing the level of subsidy while strengthening the eligibility requirements would trigger more additional private investment for the same level of public expenditure. The heterogeneity found in the FRS also suggests targeting subsidies towards groups where the number of likely free-riders is low.

8. Appendix

A1. Supplementary Tables and Figures

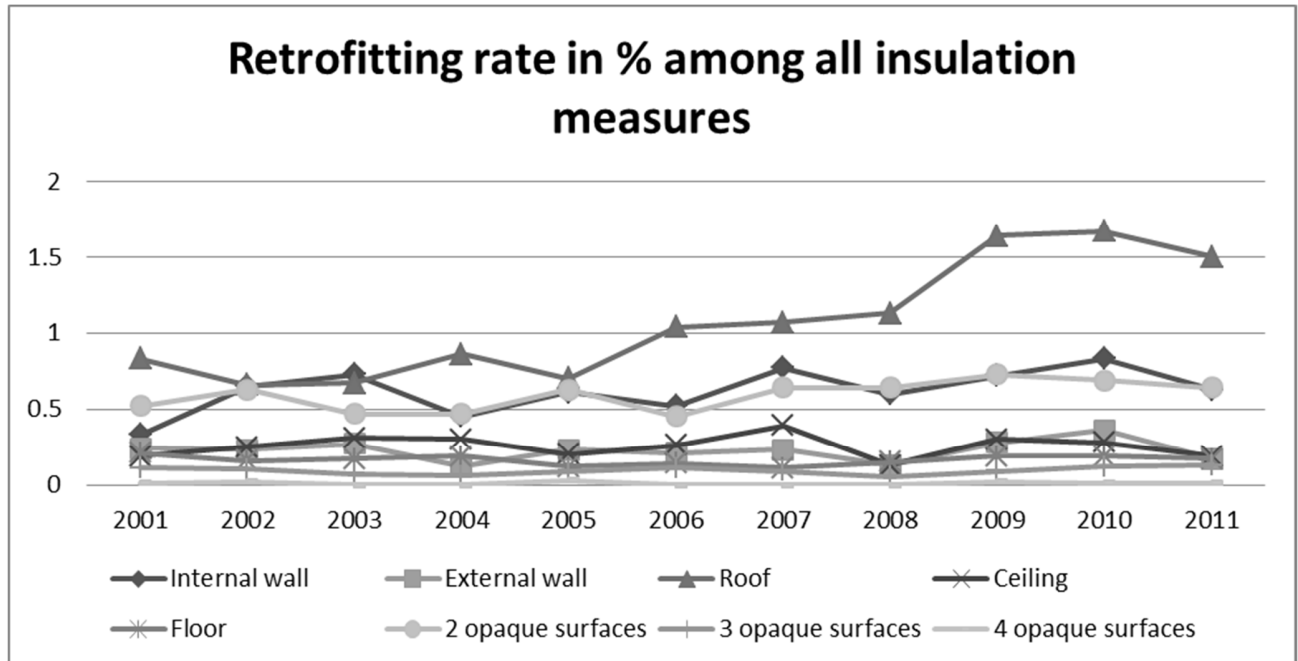


Figure 7. Detailed retrofitting rate for opaque surfaces insulation measures.

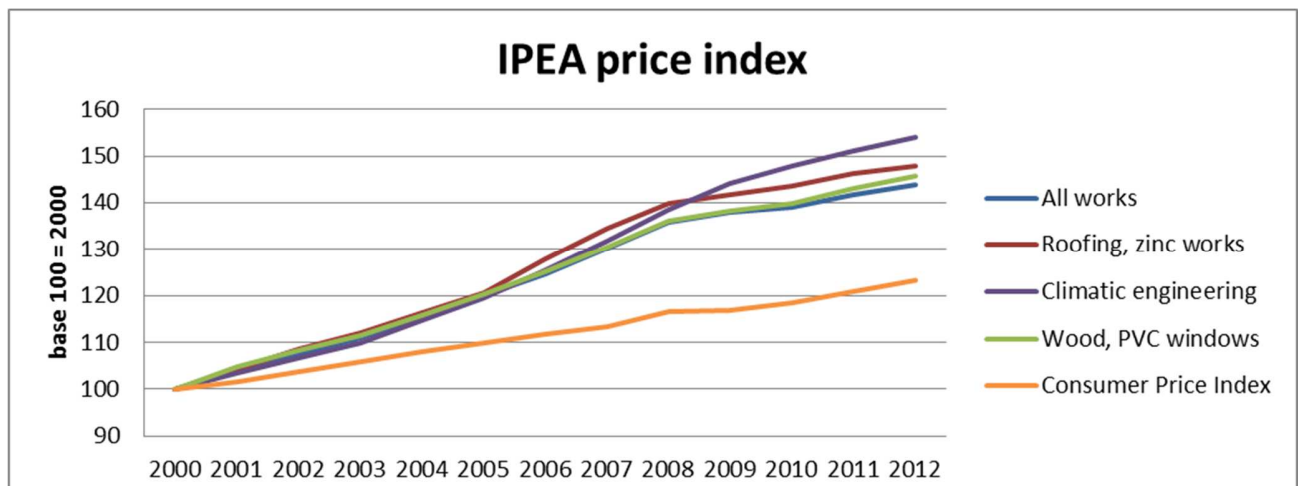


Figure 8. Annual IPEA price index compared to the consumer price index

Note: The IPEA (Indice des Prix Entretien-Amélioration) price index is based on a survey formerly conducted by the statistic office of the Ministry of Ecology (SOES, and then by INSEE). It includes the prices (both labor and material costs) of all the energy and non-energy retrofitting works made in the residential buildings except the insulation measures. Notably, it includes: Climatic engineering (heating and air-conditioning systems (code NAF 2008 43.22B); Roofing, zinc works (code NAF 2008 43.22B); Wood and PVC windows (code NAF 2008 43.32B). The IPEA suggests that the retrofitting prices have increased over the period. However, given its high level of aggregation, the fact that it excludes the insulation measures and the fact that it does not control for technological change, such index is unable to give precise insights as for the investments subsidized by the CIDD.

Table 13. Full model 1. Opaque & glazed insulation. Other specifications.

	logit RE (1) (2 sub periods)	logit RE (2) (1 + CIDD rate)	logit RE (3) (1 + EcoPTZ excl.)	logit RE (4) (1 + past retrofit)	LP RE (5)
Variables	M.E.	M.E.	M.E.	M.E.	M.E.
<i>CIDD dummy_1st period (2005/2007)</i>	0.004	0.004	0.001	0.006	0.004
<i>CIDD dummy_2nd period (2008/2011)</i>	0.021***	0.021***	0.017***	0.032***	0.026***
<i>CIDD rate * CIDD dummy_2nd period</i>		0.003***			
Former retrofit				-0.992	
Nb of observations	36367	36367	35977	29392	36367
Nb of individuals	13116	13116	13023	11333	13116
Log likelihood	-9448.9157	-9442.788	-8629.989	-6012.8457	
R2: within					0.0033
between					0.0532
overall					0.0309

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

col (1) RE logit estimated marginal effects (M.E.) with CIDD period divided in two sub-periods; col (2) same model as col 1 with an interaction effect with the CIDD rate for the 2nd sub-period; (3) same model as col 1 excluding retrofitting measure eligible to EcoPTZ; (4) same model as col 1 including the Former retrofit variable estimated over 2004/2011; (5) same sample as col 1 but estimated with a linear probability (LP) model with random individual effects (RE).

A2. Households' declarations on the effect of CIDD per retrofitting type¹¹⁵

Les deux raisons principales et contrastées entre les types de travaux sont d'une part le choix d'équipements ou de matériaux standards qui ne vérifient pas les critères de performance imposés par le CIDD, et, d'autre part, l'installation par un professionnel non déclaré ou par le ménage lui-même (autoproduction). Le choix de l'autoproduction est plus important pour l'isolation thermique des parois opaques (motif évoqué par 75 % des ménages n'utilisant pas le CIDD), travaux pour lesquels les coûts de main-d'œuvre sont plus importants, tandis que le choix d'équipements non « CIDD » concerne davantage les chaudières (motif évoqué par 58 % des ménages n'utilisant pas le CIDD).

Dans l'enquête MDE, les ménages qui ont bénéficié du CIDD sont interrogés sur l'effet que le dispositif a eu sur leur décision de réaliser des travaux de rénovation thermique. Dans le cas de travaux d'isolation et de remplacement des systèmes de chauffage conventionnels

¹¹⁵ Les statistiques de cette partie sont extraites de l'article « Les travaux de rénovation thermique dynamisés par le crédit d'impôt développement durable » coécrit par Daussin-Benichou, Mauroux et Nauleau, publié dans La Revue du CGDD (2015).

(chaudière gaz et fioul), plus d'un tiers des ménages évoque directement l'effet du CIDD sur la prise de décision (« *entreprendre des travaux* », « *ne plus différer les travaux* »). Pour l'installation d'appareils de régulation de chauffage, les ménages déclarent très majoritairement que le CIDD n'a eu aucun impact. Dans les deux cas, la proportion de ménage déclarant que le CIDD n'a eu aucun effet décroît de 2006 à 2010. Au contraire, pour l'installation de systèmes de chauffages moins courants (chauffage au bois et PAC), le CIDD a accéléré le processus de décision de presque un ménage sur deux. Dans une moindre mesure, le CIDD a conduit les ménages à recourir à des professionnels pour des travaux qu'ils auraient sinon réalisés eux-mêmes.

Table 14. Taux de subvention, raisons de non recours et effets évoqués du CIDD par travaux.

	Isolation de parois vitrées	Isolation de parois opaques	Système de régulation de chauffage	Chaudière (gaz, fioul)	Chauffage au bois	Pompe à chaleur
% des travaux pour lesquels le ménage recourt au CIDD	85	47	47	71	86	89
Raisons de non recours au CIDD (2006-2011, N=761)						
% dans l'échantillon	24	48	7	16	3	2
<i>Inéligibilité des équipements/matériaux</i>	22	28	46	58	29	56
<i>Auto-production</i>	40	75	53	15	77	4
<i>Paiement par un tiers</i>	18	4	1	18	0	0
<i>Montants peu élevés</i>	12	18	27	6	21	0
Effets évoqués du CIDD sur la décision d'investissement en % des ménages bénéficiaires du CIDD (2006-2011, N=2014)						
% dans l'échantillon	51	17	2	15	8	7
<i>Entreprendre des travaux non envisagés</i>	8	11	3	10	7	27
<i>Ne plus différer la décision d'entreprendre des travaux envisagés.</i>	37	25	7	29	41	51
<i>Faire réaliser les travaux par un professionnel</i>	5	9	11	2	12	2
<i>Aucun</i>	54	62	81	61	48	28

A3. Discussion on the CIDD impact on the heating systems investments.

Pieces of evidence suggest that the CIDD tax credit and other similar subsidies cannot impact households' investment in heating systems installation/replacement on the extensive margin of the investment. First, chapter 1 shows investment in heating systems is mainly triggered by "wear and tare", at least for "conventional" systems (boilers, radiators, regulation systems). Second, in the literature, Bigano & Alberini (2014) look at the effect of a subsidy on the decision to retrofit looking at its effect on the age of replaced equipment. "About 585 of the 841 recent changers provided information sufficient to compute the age of the previous heating system when it was replaced (in 2007 or more recently). On average, homeowners who received incentives retired their heating systems when they were 17.28 years old. Homeowners who replaced their heating system during the same period (2007 or later) but did not receive an incentive report an average age at retirement of 16.61 years. These averages are not statistically different from one another at the conventional levels (t statistic -0.89). This suggests that the incentives have had only minimal effect in getting people to replace old and inefficient equipment earlier than they would have otherwise (Bigano & Alberini 2014)."

Based on the EM survey data, we cannot compute the same statistics as Bigano & Alberini since most of households who invest in a new heating system report the age of the new system instead of the old one.¹¹⁶ More importantly, we cannot assess the effect of the tax credit policy on investment in systems with the methodology used for the insulation measures. Indeed, the installation of heat-pump has not been mentioned in the retrofitting list of the EM survey before 2005. Therefore, since conventional heating systems, such as electric radiators or boilers in case of fuel switch, can be potentially replaced by heat-pumps, we cannot correctly measure the evolution of the heating systems replacement rate. A solution is to look at the retrofitting rate on a sub-sample in which the installation of heat-pumps is very unlikely. Looking at the profile of dwellings with installed heat-pumps, we see that small dwellings in dense urban cities¹¹⁷ do not have any heat-pumps. Figure 9 looks at the whole heating systems

¹¹⁶ Due to the formulation of the EM survey.

¹¹⁷ Cities over than 100 000 inhabitants and dwellings bigger than 75 m2.

replacement / installation¹¹⁸ excluding heat-pumps in the full EM survey sample and in a subsample only including small dwellings in dense urban cities. The rate of installation/replacement of heating systems did not increase after the introduction of CIDD in both samples, which would confirm our assumption that the dynamic of heating systems replacement is not impacted by the CIDD. However, the lack of observations in the subsample prevents us from having too much confidence in this result.

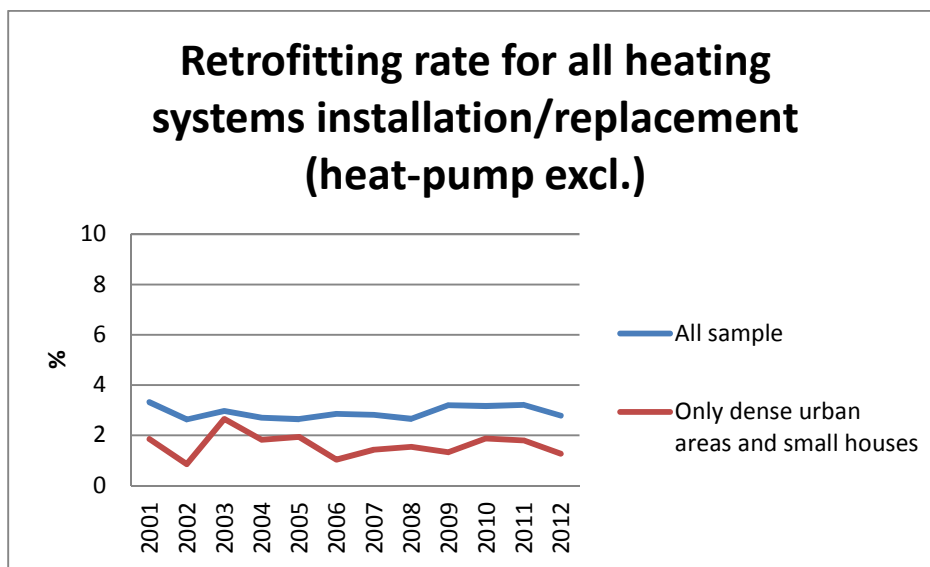


Figure 9. Retrofitting rate for heating systems.

¹¹⁸ Installation/replacement of boilers, wood stove, radiators.

A4. An estimation of the impact of the CIDD tax credit on the intensive margin of households' retrofitting investments and the computation of the BFTB multiplier.

Method

Using the same sample¹¹⁹ and the same identification strategy as in the main study of chapter 2, namely the estimation in difference, we aim at determining the amount by which the households that invested in energy efficiency adjusted their investment after the implementation of the CIDD. To estimate this CIDD's effect on energy saving investment on the intensive margin,¹²⁰ we fitted a linear model by Ordinary Least Squares (OLS) on the subsample of people who invested in retrofitting:

$$Y_{it} = \alpha + \sum_{t=2002}^{2004} \gamma_t T_t + \sum_{t=2005}^{2011} \delta_t CIDD_t + \beta X'_{it} + u_{it} \quad (6)$$

,with Y_{it} the total investment costs (including both material and labor costs, in constant euros deflated by the INSEE Consumer Price Index¹²¹) of each retrofitting measures of household i at time t , $(T_t)_{t=2002, \dots, 2004}$ the annual dummies referring to the period before the introduction of CIDD, $(CIDD_t)_{t=2005, \dots, 2011}$ the annual dummies referring to the period after the implementation of CIDD and u_{it} the residuals. Contrary to the analysis on the extensive margin, we do not use the data in panel since there are very few households present more than one period among retrofitting observations. In such linear model, the difference estimator Δ is directly identified by the CIDD coefficient δ_t . $X_{it} = (x_{1it}, \dots, x_{kit})$ gathers the same exogenous observed covariates as in the study on the extensive margin (presented in section 3.2) in addition with dummies for each retrofitting type, for households' declarations based on invoices (*Invoice dummy*) and for "DiY" works (*DiY dummy*), i.e. works that are "undeclared" (carried out

¹¹⁹ Namely the occupying homeowners of existing buildings mainly heated by electricity, gas or fuel.

¹²⁰ We refer to the intensive margin effect but the appropriate term would be a "gross intensive margin effect" since a strict definition of the intensive margin would be the variation of the average amount spent by the households who would have invested even without the tax credit introduction. But at the individual level, we cannot identify in the data the households who would have retrofitting even without the CIDD. See Daussin-Benichou & Mauroux (2014) for a more complete discussion.

¹²¹ The data do not provide labor and material costs separately before 2008.

by an unregistered professional) or "Do it Yourself" (carried out by the household).¹²² Although "DiY" works cannot apply for CIDD, we choose to include them in the sample since the arbitrage between "DiY" works and professional ones can be impacted by the CIDD subsidy. Indeed, the subsidy can turn professional works into more profitable investments than "DiY" ones, especially after the 2009 reform including labor costs in the tax credit base for opaque surface insulation (see appendix A5). Moreover, we cannot control in the econometrics for the precise eligibility of an investment to the CIDD subsidy since this information is only available after 2005.¹²³ However, we consider the Professional works variable as a good proxy since it nearly identifies the retrofitting observations eligible to CIDD. The share of subsidized retrofit among professional works is 85% and the average investments costs are similar between declared works and subsidized ones (see Figure 10). Finally, we only include observations for which households report investments they entirely paid for, in order to avoid the inclusion of shared (with the owner, the co-owners...) investments costs.

From estimates of the CIDD average effect on both the extensive and intensive margins of the investments, we can compute the amount of additional private investment triggered by one euro of public spending at the aggregated level, which is called the "Bang For The Buck (BFTB)" multiplier (Ientile & Mairesse 2009). Such metric assesses the policy efficiency from a budgetary perspective. In first approximation, we can consider that a BFTB multiplier below one would point to an inefficient policy on the argument that since one euro of forgone tax receipt generates less than one euro of additional private investment, direct public investment or transfer would be a better instrument (see Ientile et Mairesse 2009 for a critical review of the literature on the R&D tax credit).

Let V_{obs} be the aggregated economic value of retrofitting investments observed during the CIDD period, V_{CIDD} the additional aggregated economic value generated by CIDD and

¹²² We cannot distinguish between the works carried out by an unregistered professional and those carried out by households.

¹²³ This information could be derived from data on the precise energy efficiency level of the material (windows or insulation layers) but the EM survey does not provide such information. After 2005 however, households can explain why they do not apply for the CIDD tax credit.

V_{noCIDD} the aggregated economic value that would have been observed in absence of CIDD :

$V_{CIDD} = V_{obs} - V_{noCIDD} \cdot V_i$ can be written as $V_i = Q_i * v_i, \forall i = Obs, NoCIDD, CIDD$, with :

$-Q_{obs} = Q_{noCIDD} + Q_{CIDD}$ the quantity of professionally-produced retrofitting works, the sum of Q_{noCIDD} the quantity that would have been in the absence of CIDD and Q_{CIDD} the CIDD effect on the extensive margin,

$-v_{obs} = v_{noCIDD} + \Delta_{Intensive}$ the observed average investment cost, the sum of v_{noCIDD} the average investment cost that would have been in the absence of CIDD and v_{CIDD} the CIDD effect on the intensive margin.

We have $V_{CIDD} = v_{noCIDD} * Q_{CIDD} + v_{CIDD} * Q_{noCIDD} + v_{CIDD} * Q_{CIDD}$, the first term represents additional investments on the extensive margin only, the 2nd term represents additional investments on the intensive margin only, and the 3rd term additional investments on both margins. The BFTB multiplier is the ratio between V_{CIDD} and PS the CIDD-related public spending. Data on public spending able to isolate expenses for insulation measures come either from a non-public ministerial report (CGDD 2012) based on experts' estimates or from internal estimation in which $PS = \overline{\%_{CIDD}} * V_{obs}$, with $\overline{\%_{CIDD}}$ the CIDD rate averaged over the retrofitting mix and over the period. Finally, assuming that the rise in expenditures triggered by the CIDD entirely correspond to a rise in the energy efficiency of the retrofitting (and not to a price increase), we can get an estimation of the theoretical energy savings or CO2 emissions reduction per euro of public spending in turning investments expenditures into physical values. We use official data coming from the French Energy Performance certificate scheme¹²⁴ as regards conventional energy savings in order to translate each retrofitting measure into conventional energy savings. Energy savings are specific to each retrofitting type and depend on the climatic zone, the building type and the heating energy source of the dwelling (available

¹²⁴ <http://www.developpement-durable.gouv.fr/1-le-secteur-du-batiment.html>

information in the EM survey). They are expressed in kWh cumac.¹²⁵ For insulation measures, energy savings data are most often expressed in kWh cumac per square meter of insulated surfaces or per window. As the EM survey does not provide such information, we use the total investment cost, available in the EM survey, to estimate the number of insulated surfaces or windows thanks to OPEN data on cost per window per m² of insulating layers for each insulating measures (OPEN 2009)¹²⁶. The conversion from conventional energy savings to CO₂ emissions reductions is based on the main heating energy source.¹²⁷

Results

Figure 10 presents the average annual investment cost for all insulation measures and for glazed surface insulation. The average investment for all insulation has remained stable, around 2700/3000€ 2009 over 2001/2004 before progressively increasing until 2009 to reach an average of 3500€ 2009. Excluding the DiY works, the level of costs is higher of 1000€ 2009 but we observe the same evolution, albeit with an earlier increase. On the second graph, we see that the positive trend after 2005 seems to disappear when deflating by the IPEA¹²⁸ price index. We can only deflate the glazed surfaces insulation since opaque surface insulation is not included in the IPEA index (see Figure 8 in Appendix A1). Table 15 gives the t-test statistic of the mean comparison between the two periods before and after the CIDD introduction. Results confirm that the means of investments costs before and after the CIDD introduction are not significantly different when deflating by the IPEA price index whereas they are significantly different otherwise. Therefore, assuming no technological change, this would suggest that the rise in expenses is not caused by a rise in energy efficiency (through a quantitative or a qualitative effect in the investments) but by economics effects. However, since the IPEA cannot control for technological change, this assumption cannot be verified (see the note below Figure

¹²⁵ Cumulative over the life expectancy of the equipment (around 15 years for systems producing heat or renewable energy and 35 years for insulation measures on the building shell) discounted at 4%.

¹²⁶ OPEN is a survey similar to the EM survey, carried out less frequently and more detailed as regards the retrofitting measures.

¹²⁷ A conversion factor of 206g CO₂/ kWh (resp. 268 and 180) for the gas (resp. the fuel and the electricity).

¹²⁸ The IPEA (Indice des Prix Entretien-Amélioration) price includes the prices (both labor and material costs) of all the energy and non-energy retrofitting works made in the residential buildings except the insulation measures. See Figure 8 in Appendix A1.

8 in appendix A1). Moreover, if we focus on the value of the BFTB multiplier, no matter if the additional expenses made by households correspond or not to additional energy savings. The sample size for opaque surface insulation only is too small to be studied separately, with an average annual number of observations of 145 (56 for DiY works) compared to 337 (228 for DiY works) for the full sample, especially given such high standard deviations (see Table 15).

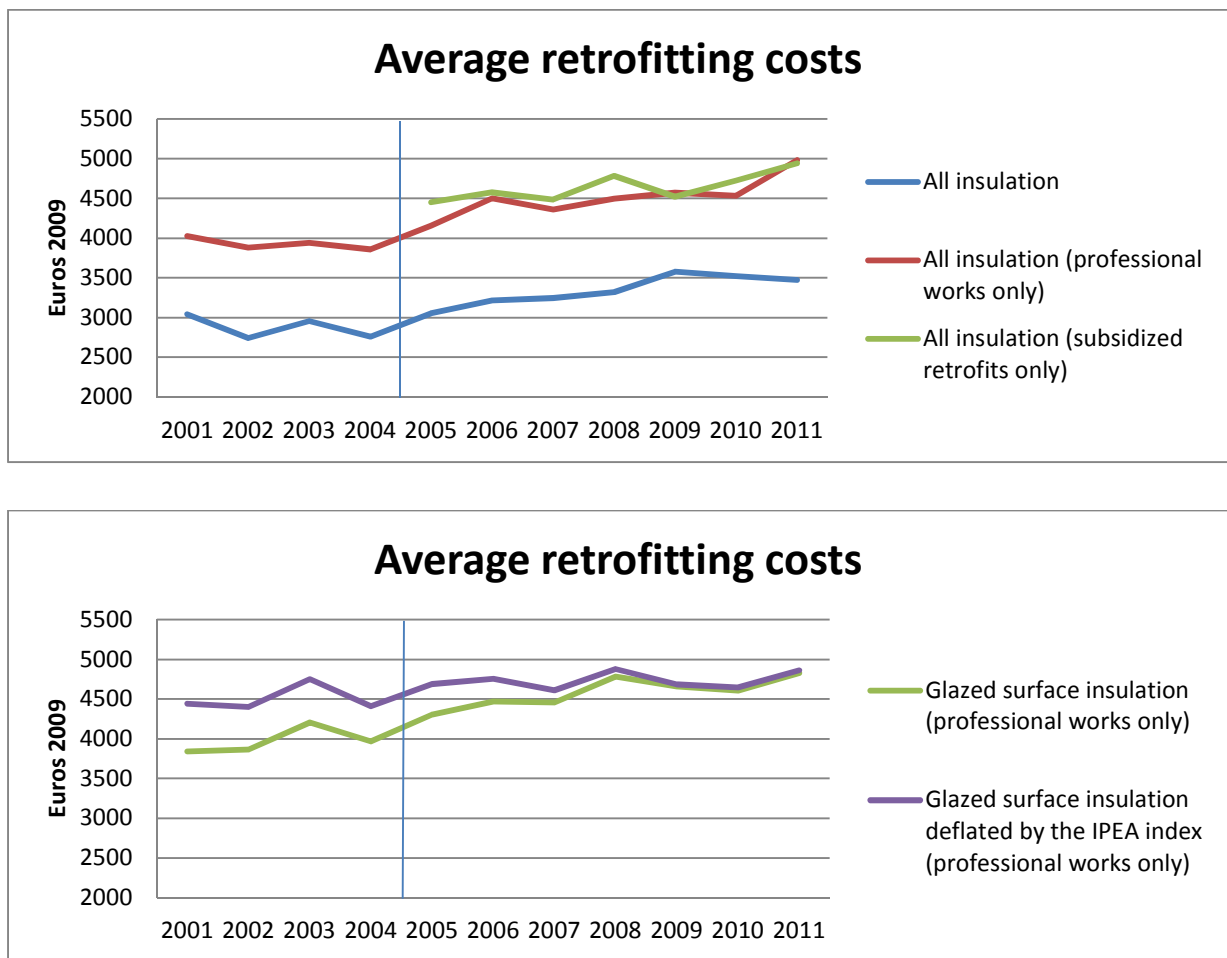


Figure 10. Annual average retrofitting costs for all insulation measures and for glazed surfaces insulation only.

Note: The investments costs include both labor and material costs. The subsample used in the same as the one in the econometric study. Professional works only excludes the DiY works.

Table 15. Mean comparison (T test) between the investment costs of the two periods before and after the CIDD introduction.

	N		Mean		Standard Deviation		t Statistic	P Value**
	2001/2004	2005/2011	2001/2004	2005/2011	2001/2004	2005/2011		
All Insulation	1016	2699	2970.3	3405.8	2905.0	3520.6	-3.52	0.0004
All Insulation (professional*)	669	1845	4007.5	4552.0	2952.7	3592.3	-3.51	0.0004
Glazed surfaces insulation (professional*)	534	1354	4039.4	4652.8	2862.2	3466.9	-3.63	0.0003
Glazed surfaces insulation IPEA (professional*)	534	1354	4583.6	4775.2	3248.9	3550.5	-1.08	0.2797

The null hypothesis H0 is the equality between the two means of investments costs over 2001/2004 and over 2005/2011. The subsample restricted to home-owners of existing dwellings heated by fuel, gas and electricity for investments entirely paid by the households. * DIY works excluded. ** H0 is rejected when the p-value is less than the predetermined significance level (5%).

Table 16 shows econometric results. Considering all insulation measures and annual dummies for the period pre and post-CIDD introduction (column 1), we first see the absence of trend before 2005, which is required by the difference estimation. Then, the insulation measure dummies' estimates show that the outdoor wall insulation are the most expensive retrofits, before the window installation, then roof insulation and finally the indoor walls and floor insulation. The positive effects of the Heating Degree Days (*HDD*) and of a new move-in are highly significant. The dwelling size, the age of the building and the income level of the household significantly increase the level of expenditures. Investment costs are also slightly higher in Paris. The estimate of the energy price variable is positive though insignificant. The coefficients of the *Building type* (Multi-family vs Single-family), the *Socio-professional category* and the *Family size* variables are not significant.

Regarding the CIDD dummies, we find the same timing in the effects that in the results on the extensive margin: the CIDD positive marginal effects start to be significant in a second period 2009/2011, which can be related to the inertia in the public efficiency or to the 2009 reform including labor cost in the tax credit base. Merging the CIDD dummies into the same two sub-periods as in the study on the extensive margin, namely 2005/2007 and 2008/2009, we find a significant positive effect of 230 euros over 2005/2007 (at 5%) and of 511 euros (at 1%) over 2008/2011. Considering an average retrofitting cost of 3215 €2009 over 2005/2007 (resp. 3504 €2009 over 2009/2011), it would represent an additional amount of expenditures of 7% over 2005/2007 (resp. 14% over 2009/2011) triggered by the CIDD. We find higher effects when considering only professional works (column 3) but with a drop in the R^2 from 28% to 6%.

When considering only the glazed surface insulation deflated by the IPEA index (column 5), we see that the coefficients of the annual dummies after the CIDD introduction turn into insignificant ones. This suggests that the efficiency of the CIDD in terms of energy efficiency would depend on what affected the retrofitting price increase after 2005. In case of technological change, the CIDD subsidy may induce technological change and lead to higher quality energy investment, which would be imbedded in the IPEA index. But the CIDD could also lead to a demand side increase, leading to an upward price adjustment from the supply side (especially in case of market powers, see chapter 4), which would also be imbedded in the IPEA index.

Mauroux and Daussin (2014) also studied the CIDD effect on the level of expenditures reported in the fiscal data using a 2006 reform increasing the tax credit rate (from 25% to 40%) in specific cases to perform a difference in difference estimation. They also observe the existence of inertia but find higher effects: “On average, in 2006, expenditures were 1% to 28% higher than if the tax credit has remained 25%, 23% to 47% in 2007 and 27% to 41% in 2008.” Moreover, using censored quantile regressions, they find that the price sensitivity is heterogeneous “lower at the top of the distribution and stronger for relatively well-off middle age couples with children living in Ile de France”. However, Mauroux and Daussin do not focus on insulation measures but gather all investment types concerned by the tax credit rate increase (insulation but also conventional systems such as boilers, heating regulation, etc.).

Table 16. OLS estimates

Variables	Investment costs in € 2009				Window insulation (professional works) (3)	Saved Kwh cumac (4)	Saved tons of CO2 emissions cumac (5)
	All insulation (1)	All insulation (professional works) (2)		All insulation (professional works)			
<i>Insulation measures fixed effect (ref: indoor wall insulation)</i>							
<i>Outdoor wall insulation</i>	2379.789***	2392.595***	3855.073***	3882.279***		136315***	31.416***
<i>Roof insulation</i>	345.224**	350.786**	1139.417***	1166.361***		-43875.24***	-9.91***
<i>Floor insulation</i>	-215.559	-217.077	217.679	228.033		39548.72***	9.293***
<i>Glazed surfaces insulation</i>	1008.149***	1007.774***	1651.279***	1666.31***		-69152.06***	-15.499***
<i>DIY dummy</i>	-2931.664***	-2931.91***					
<i>Invoice dummy</i>	-68.392	-68.254	-139.499	-150.969	-27.878	-1481.654	-0.426
<i>Annual dummies (ref:2002)</i>							
	2003	-62.201			304.718		
	2004	11.162	-104.612		100.46		
<i>CIDD dummy*2005</i>		182.358	415.389		541.841*		
<i>CIDD dummy*2006</i>		166.392	469.408*		161.856		
<i>CIDD dummy*2007</i>		273.571	517.352*		311.349		
<i>CIDD dummy*2008</i>		303.953	510.277*		205.995		
<i>CIDD dummy*2009</i>		455.924**	669.118**		182.982		
<i>CIDD dummy*2010</i>		519.819***	746.064***		387.092		
<i>CIDD dummy*2011</i>		675.717***	1137.229***		518.791		
<i>CIDD dummy_1st period (2005/2007)</i>		230.384**		473.955***		2516.421	0.334
<i>CIDD dummy_2nd period (2008/2011)</i>		511.026***		773.225***		6704.653***	1.338***
<i>CIDD rate * CIDD dummy_2nd period</i>		-24.963		-52.868		-649.647	-0.222*
<i>Environmental concerns</i>	24.801	13.56	-37.978	-47.854	5.56	-2141.875	-0.414
<i>Economic concerns</i>	63.537	62.147	-32.407	-21.069	-3.88	916.166	0.271
<i>HDD</i>	452.356***	449.322***	662.308***	649.794***	453.47*	21139.43***	4.96***
<i>Energy price variation</i>	196.226	154.181	528.289	487.075	844.779*	14909.15***	5.475***
<i>Dwelling size</i>	40.812***	39.6***	40.279**	39.076**	68.964***	311.544	0.133**
<i>Building completion date (ref: < 1974)</i>							
<i>1975/1988</i>	197.077*	190.633*	268.39*	257.462*	561.63***	-5519.792***	-1.578***
<i>1989/last year</i>	-402.888**	-389.266**	-589.467*	-529.288	385.498	-21107.15***	-5.168***
<i>Multi-family housing (ref: single-family home)</i>	-162.202	-159.56	-169.245	-157.831	-32.085	-278.902	0.329
<i>Annual income of the dwelling (ref: <18500 euros)</i>							
<i>18500 /36 300 euros</i>	-64.452	-67.425	-92.12	-91.61	11.959	-3439.698	-1.033*
<i>>36 300 euros</i>	312.559**	321.312**	472.936**	480.915**	516.663**	1187.234	-0.328
<i>Move in date (ref: < 3 years)</i>							
<i>3 / 10 years</i>	-662.938***	-665.077***	-1048.172***	-1057.562***	-1511.937***	-3800.344	-0.858
<i>> 10 years</i>	-467.395***	-462.544***	-765.023***	-759.075***	-1005.527***	-3984.269*	-0.939
<i>Category of city (ref: Parisian agglomeration)</i>							
<i>> 20.000 inhabitants</i>	-274.561**	-269.417*	-343.116*	-329.955*	-390.915*	-5126.545**	-0.955
<i><20.000 inhabitants / rural</i>	-196.967	-182.687	-250.907	-219.714	-412.964*	-4815.707*	-0.141
<i>Socio-professional category (ref: Entrepreneur)</i>							
<i>Managers</i>	-256.064	-254.847	-407.145	-412.893	-466.733	1037.485	0.58
<i>Employees</i>	-47.921	-55.105	-172.064	-176.128	-100.767	3114.95	1.281
<i>Inactive</i>	75.031	68.806	47.801	32.048	208.655	3988.7	1.413
<i>Family size (ref: 1 person)</i>							
<i>1 couple</i>	76.202	74.753	209.432	209.426	165.959	4159.276*	1.075*
<i>>2 persons</i>	108.124	109.604	211.271	211.43	21.776	6411.898**	1.562**
Constant	2364.358***	2373.723***	1439.21**	1460.906**	3610.972***	44936.84***	7.941***
Adj R-squared	4871	4871	3208	3208	2431	3208	3208
Nb of observations	0.2793	0.2796	0.0603	0.0606	0.0355	0.4693	0.4367

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

col (1): OLS estimates including all insulation measures; (2) OLS estimates excluding DIY insulation measures; (3) OLS estimates excluding DIY and opaque surfaces insulation measures and with costs deflated by the IPEA index; (4) (resp. (5)) : model (2) in which the monetary investments are turned into energy savings or CO2 emissions savings.

Note: The OLS regressions are weighted (giving higher number of observation that in the t-test mean comparison).

Table 17 presents the results on the BFTB multiplier computation over the two sub-periods 2005/2007 and 2008/2011 for all insulation measures. Over 2005/2007, the two public spending estimations highly diverge,¹²⁹ leading to a BFTB multiplier of either 30 or 1, which give poor confidence in the results for this first period. Over 2008/2011, the two public spending estimations are in the same range of values, with corresponding BFTB multipliers of respectively 3.4 and 2.2 € privately invested per € of public spending. In their study, Mauroux and Daussin (2014) find a multiplier of 1.5 in case of a 15% increase of the tax credit rate over 2007/2008. Using external data to extrapolate for the whole CIDD scheme, they find a multiplier of 2.2. As a benchmark, the empirical estimates of the BFTB multiplier for the R&D tax credit reviewed by Ientile et Mairesse (2009) range between 0.26 and 2.96 (mean:1.1, std:0.7, over 33 studies published between 1983 and 2009). In terms of additional CO2 emission reductions per € of public spending, we find a ratio of 0.007 / 0.005 of tons of CO2 emissions savings cumac per € of public spending over 2008/2011, which means that the additional ton of CO2 avoided cumac costs 139/220 euros of public spending. However, without any confidence intervals these results are just indicative.

¹²⁹ Recall (cf section Method) that data on public spending able to isolate expenses for insulation measures come either from a non-public ministerial report (CGDD 2012) based on experts' estimates or from internal estimation in which $PS = \%_{CIDD} * V_{Obs}$, with $\%_{CIDD}$ the CIDD rate averaged over the retrofitting mix and over the period. I have tried to get the reasons why the values of the experts' estimates in the non-public ministerial report (CGDD 2012) are so low during this first period but without success.

Table 17. BFTB multiplier computation

	Private investment (in euros)		Energy savings (in kWh cumac)		CO2 emissions reductions (in tons cumac)	
	2005/2007	2008/2011	2005/2007	2008/2011	2005/2007	2008/2011
Observed statistics						
v_obs (mean expenditures in euros, saved kwh or CO2 cuma	4351	4655	36885.87	41701.31	8.27	9.26
Realisation rate in % 2005/2007	7.2	9	7.2	9	7.2	9
CIDD rate	66	70	66	70	66	70
Q_obs (Ssubsidized retrofits in %)	4.752	6.3	4.752	6.3	4.752	6.3
Estimates						
Extensive margin effect	0.4	2.1	0.4	2.1	0.4	2.1
Intensive margin effect	230	511	2516.42	6704.65	0.33	1.34
Agregated values (in millions €, kwh cumac or tons of CO2 cumac)						
V_obs	3118.81	4423.68	26439.94	39629.10	5.93	8.80
V_CIDD = V_obs-V_noCIDD	413.51	1798.30	3877.53	17457.36	0.72	3.78
Public spending (millions €)						
External estimation*	14	527	14	527	14	527
Internal estimation**	575.69	832.04	575.69	832.04	575.69	832.04
Multiplier V_CIDD/ Public Spending						
External estimation*	29.54	3.41	276.97	33.13	0.051	0.007
Internal estimation**	0.72	2.16	6.74	20.98	0.001	0.005

* External estimation from CGDD report (2012), ** equal to V_CIDD x average CIDD rate

A5. An estimation of the impact of the CIDD subsidy on the arbitrage between DiY and professional works.

Method

One potential side-effect of the CIDD tax credit is its impact on the households' arbitrage between declared professional works and undeclared ones (undeclared professional or "Do it Yourself" works, what we will call DiY works), which can have important implications in terms of public finance and market structure. Indeed, the CIDD tax credit only benefit to declared professional works. Therefore, it can make declared works more profitable relatively to undeclared one compared to the situation before the introduction of the CIDD. This is particularly true for opaque insulation works, since the "DiY retrofitting" is the most important reasons why households do not apply for the CIDD (see appendix A2). This is notably explained by their relatively higher share of labor cost in total cost compared to other works (see the positive correlation between the share of DiY works and the weight of labor cost in total cost in Figure 11). The tax credit scheme was reformed to address this issue: in case of insulation measures, labor costs have become eligible to the subsidy in addition with the material cost from 2009 onwards.

In order to assess the effect of the CIDD tax credit on the probability to hire a declared professional, we can use the 2009 reform to implement a difference in difference estimation. Indeed, this reform provides a quasi-natural experiment in which insulation measures can serve as treatment group.¹³⁰ We use heating systems installation/replacement¹³¹ and window insulation as a control group. All retrofits observations potentially belonging to the control group are excluded if they are combined with any opaque insulation measures in order to avoid the decision on the opaque insulation measure contaminating the decision on other works.

The double differences estimator compares the evolution of the endogenous variable, namely the arbitrage between declared and undeclared works, in the treatment group with its evolution in the control group. Such estimator is correctly identified if:

¹³⁰ Ceiling insulation is excluded since it has been subsidized by the CIDD only from 2008.

¹³¹ We exclude observations for regulation heating systems and wood heating systems due to their low number of observations.

- both treatment and control groups are stable across periods (constant group fixed effects),
- both treatment and control groups are commonly affected by temporal shocks (common trend).

Consequently, such estimation requires that the affectation of each individual, i.e. each retrofitting observation, inside one of the two groups be exogenous, i.e. uncorrelated with unobserved variables. We assume that hypothesis is valid in our case, i.e. that it is not because the CIDD subsidizes labor cost for insulation measures that households would invest in opaque insulation rather than in heating systems or windows. The constant group fixed effects assumption would recommend building groups as much homogenous as possible. To build treatment and control groups with sufficient sample size, we need to gather different retrofitting types inside each group. We include retrofitting type fixed effects in case of variation in the retrofitting mix in each group over the period. The common trend assumption requires that without the treatment, both groups would have evolved in the same way. The arbitrage in favor of the undeclared works depends on both households' and investments' characteristics. As regards households' characteristics, it would depend of their opportunity cost of time, their manual skills, their risk aversion, their opinion as regards taxation, etc. These factors can be, at least partly, captured by the introduction of socio-demographic variables in the econometric model. As regards retrofitting investments' characteristics, it would depend on their level of technical complexity and risks, their labor cost in absolute value and in relative compared to total cost (see the positive correlation between the share of DiY works and the weight of labor cost in total costs in Figure 11). As regards the investment characteristics, it is impossible to include information from the EM survey since the cost variables are endogenous to the arbitrage between declared and undeclared works. However, the evolution of the IPEA indexes, which capture both the technical change and the price evolution (see Figure 8 in appendix A1), suggests that window replacement and climatic engineering have had the same trend over the period. We assume that has been the same for opaque insulation measure, even though the IPEA index does not include these works.

The econometric models in which is implemented the double differences estimator *DD* over 2005/2011 can be either a dichotomous logit model (model 1) or a linear probability model with robust standard error to control for the heteroscedasticity (model 2):

$$P(DiY_i = 1 | T_1, TG_i, X_i) = \frac{e^{\alpha + \alpha_T T_1 + \alpha_{TG} TG_i + \delta T_1 * TG_i + \beta X_i'}}{1 + e^{\alpha + \alpha_T T_1 + \alpha_{TG} TG_i + \delta T_1 * TG_i + \beta X_i'}} \quad (\text{model 1})$$

$$DiY_i = \alpha + \alpha_T T_1 + \alpha_{TG} TG_i + \delta T_1 * TG_i + \beta X_i' + u_i \quad (\text{model 2})$$

With DiY_i the endogeneous binary variable equal to one in case of DiY retrofitting, T_1 the dummy equal to one for the treatment period 2009/2011 which captures the common trend, TG_i the dummy equal to one for the retrofitting observations in the treatment group which captures the time constant differences between the two groups, X_i the control variable and u_i the residuals. X_i are the same as in section 3.2 except for the energy price variable in order to avoid dropping to many observations. Contrary to the analysis on the extensive margin, we do not use the data in panel since there are very few households present more than one period in the retrofitting observations. In the linear model 2, *DD* is directly identified by δ whereas in model 1, we have to compute the average of all the individual marginal effects of δ to get *DD*.

Results

Table 18 shows the results of the mean comparison test on the average share of DiY before and after the 2009 reform for all the retrofitting observations included in the treatment or the control group. Except for floor insulation the share of DiY works has decreased after the 2009 reform but the decrease is only significant for retrofitting type with sample size larger than 300 observations in each group (i.e. indoor wall insulation and roof insulation). As regards retrofitting type in the control group, the null hypothesis of mean equality is always accepted. Table 19 shows results for both econometric models. The two model give similar results. As regards the covariates, the Environmental concerns, the level of income, the socio-professional category, the family size, the location category, the tenure in the dwelling, the building type and the age of the building have significant coefficient in both models. As regards the time dummy

T_1 , the coefficient is slightly positive but significant only in the logit model with covariates (and at 10%). As regards the treatment group dummy TG_i , the coefficient are positive and strongly significant. As expected, the share of DiY is really larger in the opaque insulation measures than in works on heating systems. As regards δ , the effect of the reform itself, we find a significant negative effect of 6 percentage points at 5% (resp. at 1%) in the linear probability model (resp. in the logit model), when including control variables.¹³² Given a weighted average share of DiY retrofitting equal to 58%, it corresponds to a decrease by 10% in the probability of choosing the “DiY retrofitting”. In case of transfers from retrofitting carried out by households towards retrofitting carried out by registered professionals, this has positive impacts on the employment rate of the sector and on the quality of works, the latter conditioning the truly energy performance of the retrofitting, especially with the rising technical sophistication of the products. In case of transfers from unregistered to registered professionals, this has positive impacts on the official employment rate of the sector and on public finance.

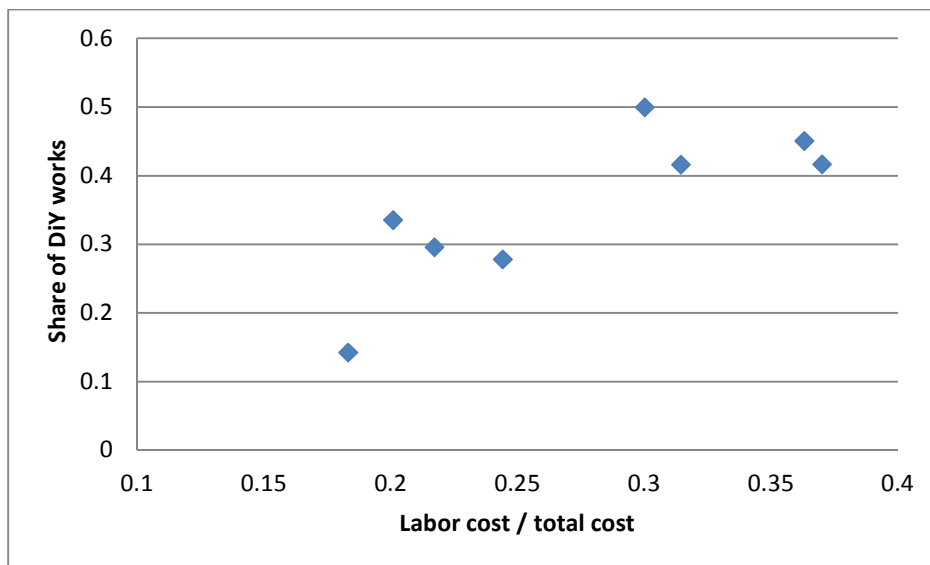


Figure 11. Share of DiY works in function of the weight of labor cost for insulation measures and heating systems.

¹³² The estimated effect is higher with no control variables.

Table 18. Mean comparison test for the average share of DiY works before and after the 2009 reform.

	Indoor wall insulation		Outdoor wall insulation		Roof insulation		Floor insulation	
	2005/2008	2009/2011	2005/2008	2009/2011	2005/2008	2009/2011	2005/2008	2009/2011
N	313	305	64	79	430	514	83	80
Mean	0.81	0.74	0.31	0.25	0.55	0.51	0.78	0.78
Std. Err.	0.02	0.03	0.06	0.05	0.02	0.02	0.05	0.05
t stat	2.11		0.78		1.32		0.12	
p value (Mean_T0≠MeanT1)	0.04		0.44		0.19		0.90	
p value (Mean_T0>MeanT1)	0.02		0.22		0.09		0.45	
	Window insulation		Boiler (with fuel switch)		Boiler (no fuel switch)		Heat-pump	
	2005/2008	2009/2011	2005/2008	2009/2011	2005/2008	2009/2011	2005/2008	2009/2011
N	818	793	80	46	268	246	127	90
Mean	0.08	0.09	0.05	0.02	0.09	0.11	0.01	0.01
Std. Err.	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01
t stat	-0.91		0.78		-0.77		-0.24	
p value (Mean_T0≠MeanT1)	0.36		0.44		0.44		0.81	
p value (Mean_T0>MeanT1)	0.82		0.22		0.78		0.60	

Table 19. OLS estimates and Logit model's marginal effects.

Variables	Linear probability model		Logit model	
	Coeff.	Coeff.	M.E.	M.E.
T1	0.011	0.012	0.026	0.027*
Treatment group	0.797***	0.78***	0.845***	0.868***
T1 * Treatment group	-0.062***	-0.059**	-0.06***	-0.056***
Retrofits fixed effect (<i>ref : indoor wall insulation & heat-pump</i>)				
<i>Outdoor wall insulation</i>	-0.494***	-0.458***		
<i>Roof insulation</i>	-0.249***	-0.208***		
<i>Floor insulation</i>	0.002	0.027		
<i>Window insulation</i>	0.073***	0.124***		
<i>Boiler (with fuel switch)</i>	0.031*	0.071***		
<i>Boiler (no fuel switch)</i>	0.085***	0.144***		
Environmental concerns		-0.022*		-0.034***
Economic concerns		0.01		0.014
HDD		-0.007		-0.001
Dwelling size		-0.004**		-0.003**
Building completion date (<i>ref : < 1974</i>)				
<i>1975/1988</i>		0.01		0.013
<i>1989/last year</i>		0.055***		0.043**
Multi-family housing (<i>ref: single-family home</i>)		-0.047***		-0.068***
Annual income of the dwelling (<i>ref : <18500 euros</i>)				
<i>18500 /36 300 euros</i>		-0.036**		-0.049***
<i>>36 300 euros</i>		-0.073***		-0.092***
Move in date (<i>ref : < 3 years</i>)				
<i>3 / 10 years</i>		0.013		0.015
<i>> 10 years</i>		-0.052***		-0.046***
Category of city (<i>ref : Parisian agglomeration</i>)				
<i>> 20.000 inhabitants</i>		-0.004		0.004
<i><20.000 inhabitants / rural</i>		0.059***		0.067***
Socio-professional category (<i>ref : Entrepreneur</i>)				
<i>Managers</i>		0.078*		0.082***
<i>Employees</i>		0.132***		0.134***
<i>Inactive</i>		0.016		0.008
Family size (<i>ref : 1 person</i>)				
<i>1 couple</i>		0.082***		0.096***
<i>>2 persons</i>		0.103***		0.104***
Constant	0.005	-0.064		
Adj R-squared	0.3803	0.4231		
Log likelihood			-2683.4871	-2286.3292
Nb of observations	4336	4037	4336	4037

*(resp. ** and ***) significant at 10% level (resp. 5% and 1%).

Note : the linear probability model is estimated with robust standard errors, the logit model is estimated by weighted maximum likelihood. The retrofitting fixed effects are included in the logit model but their marginal effects are not estimable.

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Chapter 3 Barriers to energy savings in the French residential sector: an inter- and intra-policy assessment.

Preliminary remark:

This chapter presents a new energy-economy simulation model: Menfis (Modèle ENergie et FIScalité) designed to assess the impact of French policies aiming at reducing the residential heating energy consumption. This model has been built for the French Agency for Environment and Energy Management (ADEME). Former Menfis versions have provided insights for policy makers. The contribution of this thesis to the development of Menfis is presented in appendix A7.

1. Introduction

The French climate plan aims at dividing by four the amount of greenhouse gas (GHG) emissions by 2050 relatively to their 1990 level. Recognizing the importance of retrofitting the existing residential building stock given its weight in the French households' energy consumption, the policy package called "Grenelle de l'environnement" (voted in 2009) aims at cutting residential final energy¹³³ consumption by at least 38% by 2020, relatively to its 2008 level. The new law project for 2015 targets an annual retrofitting level of 500000 dwellings from 2017 in order to entirely turn the existing stock into low energy consumption dwellings (Bâtiment Basse Consommation) by 2050.

Well studied in the "Energy Efficiency Gap" literature (Jaffe & Stavins 1994), different kinds of barriers¹³⁴ prevent stakeholders from investing and provide justification for public intervention (Jakob 2007, Michelsen & Madlener 2012, Allcott & Mullainathan 2010, Gillingham & Palmer 2013). Since the 2000s, French public policies promoting investments in energy efficiency have progressively emerged. In the residential sector, the main ones are: subsidies for energy efficiency retrofit such as a reduced value-added tax (VAT) since 1999, an income tax credit called *Crédit d'Impôt Développement Durable* (CIDD) since 2005 and a lump-sum premium in 2014; a zero rate loan called *Eco Prêt à Taux Zéro* (EcoPTZ) for energy efficiency investments since 2009; an Energy Performance Diagnosis (EPD) compulsory for property transfer since 2006 and for rental since 2007; a more ambitious thermal regulation for new constructions since 2012. However, over the period 2008/2012, the energy consumption of the existing residential stock of main dwellings (built before 1999) has decreased by 10% overall and

¹³³ *Final energy* consumption is the energy quantity supplied to the final consumer (here the households) whereas *primary energy* is the energy found in nature that has not been subjected to any conversion or transformation process. The gap between the two results from the energy use required in the transformation and the transportation processes. In Menfis, we assume the ratio between primary and final energy equal to one for fuel, gas and wood, equal to 2.58 for electricity, as recommended by ADEME.

¹³⁴ The main ones are the split incentives between tenants and landlords, the exhausting decision process in collective dwellings, liquidity or financing constraints for lower income households and the opportunity to retrofit in case of occupancy or propriety switch.

by respectively 13% and 8% for heating and water heating (CEREN data, Table 25),¹³⁵ which is far from the legal target of 38%.

In the new law project for 2015,¹³⁶ we find the extension of the CIDD income tax credit (see chapter 2 for more details on the CIDD). Whereas the CIDD scheme was evolving towards a more progressive subsidy proportional to energy efficiency (ADEME 2014),¹³⁷ the new CIDD design (called CITE “Crédit d’Impôt Transition Énergétique”) sets a uniform tax credit rate of 30%. The new law project also promotes information provision tools (carnet de santé du bâtiment, smart-meter) and the diminution of financing constraints thanks to a strengthened zero rate loan (EcoPTZ) and the development of “Third-party financing”.¹³⁸ However, it pays less attention to regulation tools¹³⁹ or Pigouvian tax-like instruments.¹⁴⁰

As shown in previous empirical works (Giraudet et al. 2011), such policy strategy is very unlikely to reach the legal target of -38% by 2020. In particular, ex-post empirical literature focusing on subsidies generally finds that subsidies are unable to overcome structural constraints such as the split incentive between tenants and landlords, leading to high free-riding, high public expenses and anti-redistributive effects (see chapter 2). To improve the cost-efficiency of such subsidies, Quirion (2004), Boomhower & Davis (2014) and Hunt et al. (2015) recommend to target beneficiaries more specifically, in function of the households’ propensity

¹³⁵ 7% for the total residential stock of main dwellings. No data on vacancy/secondary dwellings. Data are adjusted for climatic variations. CEREN is the French statistical office on the energy sector. It provides public statistics on the energy consumption of the residential, tertiary and industry sectors (<http://www.ceren.fr/stats/stat1.aspx>). More detailed data are also available for its financing companies (ADEME and historical national energy suppliers).

¹³⁶ Projet de loi relatif à la transition énergétique pour la croissance verte, <http://www.assemblee.nationale.fr/14/projets/pl2188.asp> puis <http://www.senat.fr/leg/pjl14-016.html>.

¹³⁷ From 2012, tax credit rate have been increased in case of multiple retrofit measures.

¹³⁸ The “Tiers Financement” in French is a financial service enabling companies to offer loans specific to residential energy efficiency retrofit with reimbursement scheduled accordingly to future energy savings.

¹³⁹ The new law project for 2015 has enforced the obligation to invest in outdoor wall insulation in case of façade restoration, roof insulation in case of roof repair and indoor wall insulation in case of new rooms furnishing. However, more significant measures are not considered, such as the obligation of retrofitting in case of occupancy switch as recommended by Salomon et al. (2005)

¹⁴⁰ The Finance Act 2014 implemented an implicit carbon tax introducing a carbon component in the existing energy taxes on fossil fuels. Corresponding tax levels are however far from the social valuation recommended in the Quinet report (2008) (7 euros per ton of CO₂ instead of 57 in 2014, 22 instead of 63 in 2016, in nominal). Other projects, such as the progressive energy taxation in the project law Brottes (2013), have been rejected. See Combet (2013) for an historical retrospective of the French carbon tax.

to “free-ride” or of the investment barriers they are subject to. Quirion (2004) also suggests to link subsidization and energy performance. Therefore, given the heterogeneity of both technical and socioeconomic barriers, the suitability of a uniform rate as implemented in 2015 can be questioned.

The economic literature has started to conduct ex-ante public policy assessment for energy efficiency in the residential sector through simulation models. Based on a bottom-up perspective, energy-economy models combine an explicit or implicit representation of technologies with a microeconomic investment decision component. To our knowledge, three models have been developed in the French context:¹⁴¹ Res-IRF (Giraudet et al. 2012), Charlier and Risch’ one (2012) and BEUS (Allibe 2012). As described in section 2, these models differ from each other in their technological and socioeconomic representation as well as in their way of endogenizing energy use drivers and investment barriers.

In this paper, we use another energy-economy model called Menfis (Modèle ENergie et FIScalité) to assess the expected policy over 2015/2025. Will the policy package designed in the new law project for 2015 reach the legal target of -38% by 2020? Which alternative policy strategy could reach it? By means of different policy scenarios, we first focus on “inter-policy” comparison and deal with three instruments: the subsidy “CIDD/CITE”, the zero rate loan “EcoPTZ” and the Carbon tax. Beyond the energy consumption target, we assess the policies in function of a cost benefit analysis through the computation of a social net present value of the undertaken investments. Second, we draw “intra-policy” scenarios in order to pay a particular attention to the subsidy design. Would a uniform subsidy underperform compared to a more refined subsidy scheme? We compare the CITE subsidy with a subsidy proportional to energy savings, in the spirit of the German KfW subsidies or the French ANAH subsidies.¹⁴²

¹⁴¹ This paper focuses on the French context but other energy-economy models exist in other countries such as CIMS in Canada (Jaccard & Dennis 2006), Markal in the UK, Yücel (2013) in The Netherlands, ENTRANZE for Europe (<http://www.entranze.eu/>), etc.

¹⁴² KfW is the German public investment bank. The KfW subsidization program for residential building retrofitting offers a 10% price cut if the retrofitted building reaches 115% of the standard energy needs for new constructions, and a 25% price cut if it meets the Passivhaus standard (Rüdinger 2013). ANAH (Agence National de l’Amelioration de l’Habitat) is a French public agency dealing with residential energy performance and fuel poverty.

As the other models and as shown in section 3, Menfis strives to model a realistic decision making and to explicit the main technological and socioeconomic investment barriers. However, its detailed level of representation allows us to assess more refined policy design nowadays debated, such as technologically differentiated policies, which has not been done yet. Besides, its explicit representation of the technical and socioeconomic investment barriers allows us to quantify the energy savings potential unexploited because of these barriers as well as their respective weight. Finally, an important originality of the model is that its calibration relies on past data coming from multiple statistical sources. As the model starts in 2008, outputs can be compared to the statistics over the period 2008/2012.

Results show that the policy package combining the EcoPTZ zero rate loan without access limitation and the Carbon Tax as recommended in the Quinet report (2008) is the best option regarding both energy consumption reduction and public budget. The implementation of subsidies in addition to these two instruments has no impact, except in terms of public cost. Moreover, we find that investment barriers lock a non-negligible part of cost-efficient energy savings potential and that some of these barriers could be overcome by subsidization proportional to investment barriers' magnitude. Finally, we show that a subsidy design in which the subsidy rate is proportional to energy savings performs better than a uniform subsidy.

The remainder of this paper is as follows. Section 2 provides an overview of the other energy-economy models of the French residential sector. Section 3 provides an overview of Menfis. Section 4 describes statistical sources and the calibration process. Section 5 presents the different policy scenarios studied in this paper. Section 6 presents the results, first comparing MENFIS outputs with statistical sources over the calibration period 2008/2012 and then dealing with the policy scenarios. Section 7 concludes.

The ANAH subsidization program "Habiter mieux" offers to middle and low-income households a price cut between 35 and 50% when the retrofitting reaches 25% of energy savings (<http://www.anah.fr>).

2. Other energy-economy models of the French residential sector

In the French context, to our knowledge, three other models have been developed: ResIRF (Giraudet et al. 2012), Charlier and Risch' one (2012) and BEUS (Allibe 2012). The first two analyze how the overall public policy package efficiency depends on the interactions between different instruments. The ResIRF model has been designed to handle technological and behavioral specificities in the household sector. It models retrofitting investment barriers, such as the landlord-tenant dilemma, myopic anticipation regarding future energy prices, energy consumption adjustment after retrofitting (rebound effect) and learning-by-doing. Designed to be integrated in IMACLIM, a macroeconomic model, ResIRF only describes the energy performance of a dwelling by its energy performance diagnosis (EPD) class and its heating energy source. Socio-economic investment barriers are also only implicitly represented by heterogeneous discount rates. Therefore, policies specifically targeted on certain technologies or households' category cannot be assessed. Charlier and Risch (2012) use another model comprising 12 explicit types of dwelling and 5 retrofitting measures. This model features explicit technologies but due to the absence of an endogenous thermal model, the retrofitting measures considered result from preliminary arbitrary choices. Besides, it does not model the rebound effect since it does not distinguish between the theoretical energy use, i.e. the level of consumption predicted by the thermal model, and the real one. The BEUS model has been developed by Allibe (2012). Technologically explicit, this model differs from the others by its specific retrofitting dynamics, which is only partly endogenous. The investment decision (extensive margin) is triggered by the end of the systems' life time, based on statistics on actual retrofitting rates, while only the level of energy efficiency (intensive margin) is determined by an endogenous cost-benefit analysis. Such modelling has strong implications in terms of policy response: an economic incentive raising the economic profitability of an investment cannot increase the investment at the extensive margin and thus cannot accelerate the dynamics of retrofitting. The assumption is that the obsolescence of the equipment is the main determinant regarding the extensive margin of the investment. As we have seen in chapter 1, this can be a

reasonable assumption for conventional heating systems to be replaced but not for insulation measures.

3. Overview of the Menfis model

Menfis forecasts the evolution of the energy performance of the French residential building stock at an annual step from 2008 to 2025.¹⁴³ Dynamics in the energy performance of the entire building stock is mainly achieved through retrofitting, decay, demolitions and new constructions. The retrofitting process is the major part of Menfis. Through technico-economic calculations, Menfis yearly determines which part of each building type will be retrofitted and at which energy performance level. Through a modelling of the rebound effect, it also forecasts the evolution of energy consumption and CO₂ emissions. Menfis architecture is represented in Figure 12 and its modules are described in the following sections. Decay, demolitions and new constructions are only partly endogenous (see appendix A3) but are ignored in this paper.

¹⁴³ The model is designed to advice policy makers in the short-run. The model can simulate longer scenario (until 2050) but as we assume constant retrofitting costs and energy savings per retrofitting technology (no learning-by-doing effects) and as we do not represent the obsolescence of the retrofits implemented after 2008, we would understate the increase in energy efficiency in long-run simulations.

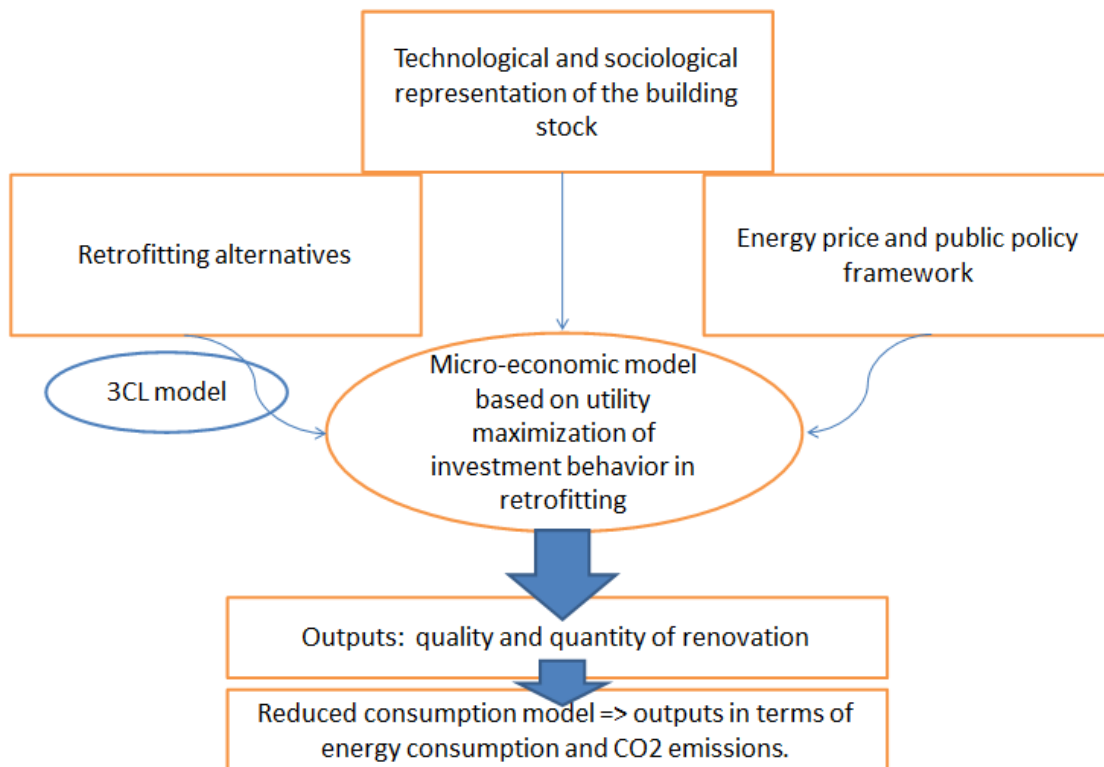


Figure 12. Memphis architecture.

Note: the rectangular shapes correspond to exogenous inputs or to outputs while the oval shapes correspond to the modelling of endogenous processes.

3.1. Technological and sociological representation of the building stock.

Memfis strives to give a precise representation of the French building stock and the retrofitting measures. The building stock is described, by four “building variables”: the type of building (single or multi-family housing), the main heating energy source (gas, fuel, electricity and wood), the building completion date (before 1948, 1949/1974, 1975/1980, 1981/1989, 1990/2001, after 2002) and the climatic zone.¹⁴⁴ Households are represented by their status of occupation and propriety: owner-occupier, private landlord and social housing. Note that the investment decision maker is assumed to be the owner in case of split incentives between

¹⁴⁴ The climatic zones split the French metropolitan territory in three <http://www.developpement-durable.gouv.fr/La-repartition-des-departements.html>

tenants and landlords. The decision makers are also represented by their income level (5 quintiles) and their family size (4 categories: 1 ; 1.3-1.5 ; 1.6-2 or > 2 consumption units¹⁴⁵). For each combination of family size and income quintile, we use the mean and the standard deviation to compute a specific normal distribution for income, which can allow us to smooth the impact of policy differentiated by income level. Menfis also models barriers due to collective decision process. This distinction between multi- and single-family dwellings (MFD and SFD) is done in the “building type” variable.

Each combination of these six “building and households variables” is called a “segment”. The model has 8640 segments, which is, to our knowledge, the most detailed representation of the French existing dwelling stock in hybrid energy-economy models.¹⁴⁶

3.2. Retrofitting alternatives

Each building is decomposed into 8 components: three for the building envelope (windows, roof and walls), one for the main heating system which is specific to each main energy source, two in case of supplementary systems (wood stove or heat-pump), one in case of separated hot water system and one for the potential presence of photovoltaic panels. Each component has two possible states of energy performance. Level 0 describes the state without any retrofitting or with a retrofit but without any significant energy efficiency improvement. Level 1 takes place in case of retrofitting with significant energy efficiency improvement. In most cases, level 1 energy performance corresponds to the criteria to benefit from the public policies over 2008/2012.¹⁴⁷ See Table 27 in Appendix A1 for technical details on high energy efficiency levels. The retrofitting alternative regarding the main heating system is itself divided in multiple options in order to integrate fuel switch. Each dwelling theoretically has the possibility to install a new heating system using an energy source different from the former one. Though, we put

¹⁴⁵ defined by INSEE : <http://www.insee.fr/en/methodes/default.asp?page=definitions/unite-consommation.htm>

¹⁴⁶ Other purely technological models may be more disaggregated, e.g. the ANAH/ADEME Perfologie model.

¹⁴⁷ Except for radiant panel systems which are not eligible to subsidies. For gas and fuel boilers, or for heat-pumps, as some systems became excluded from the CIDD after 2008 (air/air heat-pump or low-temperature boiler), we average the CIDD rate accordingly. In case of evolution in the eligibility requirement, we consider the average.

technical constraints on the fuel switch so that it mainly goes through fuel/gas switching and the installation of wood stoves or heat-pumps in combination with former systems.

For each segment, all combinations of one or two technically feasible retrofitting measures among the building components are considered.¹⁴⁸ In addition to fuel switch alternatives, it makes 50 potential alternatives per segment.¹⁴⁹ Retrofitting a building component is possible until it reaches the energy performance of level 1 at 100% on the segment. The calibration of the initial retrofitting states is explained section 4.1. Note that only energy efficiency investments reaching the energy performance of level 1 are explicitly modelled in Menfis. This means that energy efficiency investments below level 1 are not considered. However, wear and tear as well as repair/replacement works can be implicitly taken into account in the model (see appendix A3).

The theoretical/conventional energy performance of the building results from the combination of the four “building variables” (building type, main heating energy source, building completion date and climatic zone) and from the energy performance state of each building component. Calculations are derived from the official thermal calculations method 3CL which takes into account energy use for heating, cooling and hot water.¹⁵⁰ We get the Energy Performance Class (EPC) of each segment from conventional energy consumption in kWh per m2. The EPC ranges from G class (>450 kWh/m2/year in primary energy) to the most efficient A class (<50 kWh/m2/year in primary energy).

3.3. Energy price and public policy framework

This module provides all economic inputs (energy prices, interest rate, policy instruments, etc.) at each annual step in the model.

¹⁴⁸ The model could include more than two combinations but statistics from the EM survey show that the majority of the investments (95%) involved in the Menfis perimeter only include one or two retrofitting options.

¹⁴⁹ In this version, the investment of photovoltaic panels is considered independently from the other retrofitting options.

¹⁵⁰ http://travail-emploi.gouv.fr/publications/picts/bo/30122006/TRE_20060012_0110_0001.pdf. The algorithm has been simplified to fit the model perimeter.

Menfis first represents the main French national policies for the private building stock (alternative policies will be presented in section 5):¹⁵¹

- The French tax credit scheme CIDD (since 2005, see chapter 2 for more information): the purchase of energy efficient equipment and materials for main dwellings¹⁵² is eligible for income tax credits. All households, regardless of their level of income, can apply for the CIDD tax credit.¹⁵³ The tax credit subsidy is capped at 8,000€ for a one-person dwelling, 16,000€ for a two-person dwelling (with an additional allowance of 400€ per child) for a period of five consecutive years. Over 2008/2014, all high energy efficient retrofitting options in Menfis have been subsidized by the CIDD.¹⁵⁴ The tax credit rates range from 15 to 50% of investment cost and have evolved over 2008/2014. Notably, since 2009, the labor costs have also been subsidized for roof and wall insulation and, since 2014, CIDD rate have been majored in case of retrofitting combination of at least two options (with caps based on households income since 2014). In 2014, the CIDD has been complemented by a premium of 1350 euros following more or less the same energy efficiency criteria.
- The Zero Rate Loan “EcoPTZ” (since 2009): the EcoPTZ has been eligible for a loan of 20000 euros over 10 years for the retrofitting investment on dwellings built before 1990

¹⁵¹ The policies dedicated to the social housing have not been represented yet. As regard the private sector, Menfis ignores the subsidies offered by ANAH (existing since 2013), due to their small scope (31235 dwellings in 2013), and the regional subsidies, due to their huge heterogeneity and the national scale of the model.

¹⁵² The Tax Credit had only subsidized owner-occupiers and tenants but in 2009 it was extended to landlords renting their dwellings.

¹⁵³ For households who pay income tax, the CIDD takes the form of an income tax reduction. For households who do not pay income tax, the CIDD tax credit is converted into a direct payment proportional to the amount of income tax one would save for a similar measure.

¹⁵⁴ Note that glazed surface insulation (windows) have been excluded from the subsidization over 2012/2014 if realized in single-family dwellings without any other retrofitting type. Electric heating systems other than heat-pumps are always excluded from the CIDD subsidization.

in case of retrofitting combination of at least two options. It could have been cumulated (except in 2011) with CIDD under income conditions. Since 2014, EcoPTZ could have also been eligible for single retrofitting in case of collective dwelling for a loan of 30000 euros over 15 years. Note that Menfis integrates the EcoPTZ in setting the interest rate to zero.

- Feed-in tariffs for photovoltaic panels.

In order to fit to observed data, we exogenously take into account the fact that a share of the retrofitting is done through “undeclared works” (carried out by unregistered professionals) or “Do it Yourself (DiY) works” (carried out by households). Moreover, as the EcoPTZ has faced major barriers since 2009, mainly due to the reluctance of the banking sector to propose such loans (Pelletier 2011), we introduce exogenous barriers to reduce its impacts on the retrofitting investment (in average, only 20% of eligible investments benefit from the EcoPTZ in the current version). Note that since income is normally distributed specifically for each income quintile and dwelling size, in case of policy eligibility conditioned on income level or family size (e.g. for the CIDD), only a share of each segment can benefit from such policy depending on its income quintile and its number of consumption units.

3.4. Micro-economic model based on utility maximization of investment behavior in retrofitting

3.4.1. A choice based on economic trade-off embedded with technical and socioeconomic factors.

In Menfis, we assume that the observed part of the utility for the representative individual i (one representative individual for each segment, here segment and individual being synonymous) for a retrofitting alternative r , noted $U_{i,r}$, can be identified by the “subjective” perception of investment’s profitability. This perception is derived from a pure financial calculation of the net present value $NPV_{i,r}$ of the investment in which we incorporate parameters reflecting barriers and drivers specific to each socioeconomic situation or specific to each technical option: $U_{i,r} = NPV_{i,r}(\beta_i, \omega_r)$, with $\beta = (\beta_{CollectiveD}, \beta_{Income}, \beta_{Rening})$ parameters

specific to each building type, income quintile and occupation status and with ω_r parameters specific to each retrofitting option.

The perceived net present value is written as:

$$U_{ir} = -(1 + \beta_{CollectiveD})(1 + \omega_r) * InvestmentCost_{ir} + \sum_{t=1}^{l_r} \beta_{renting} CF_{t,ir} (1 + d_{ir}(\beta_{income}))^{-t}$$

with $InvestmentCost_{ir}$ the initial cost of the investment, $CF_{t,ir}$ the cash flows all along the investment theoretical lifetime l_r ¹⁵⁵ and d_{ir} the discount rate. $InvestmentCost_{ir}$ is majored by $\beta_{CollectiveD} > 0$ in case of multi-family dwellings representing barriers specific to the collective decision process. $InvestmentCost_{ir}$ can also be over or under stated by ω_r reflecting attributes called “intangible/hidden” costs or benefits specific to each retrofitting option. For example, as regards benefits, the desire of acoustic comfort can favor windows. By contrast, the risk aversion for new technologies can penalize new retrofitting measures such as solar water heater. The loss of surface area induced by opaque surface insulation can also penalize these measures. Since the owners imperfectly benefit from future savings through rent increase or through the capitalization of the green value, we assume that they only take into account some part of the future energy savings. $\beta_{renting} < 1$ minors the consideration of future economic gains in case of split incentives between owner and tenant.

The initial cost of the investment is the sum of the costs of each retrofitting options r:

$$InvestmentCost_{ir} = Cost_{TotalInvestment,ir} - Subsidies_{ir}$$

with the $Cost_{TotalInvestment,ir}$, the entire retrofitting cost (material + labor), and $Subsidies_{ir}$ the total amount of subsidies. The potential residual value of the former investment is assumed to be part of the unobserved residuals (see below).

¹⁵⁵ Average of the lifetimes of all the combined measures weighted by their costs.

The cash flows $CF_{t,ir}$ are:

$$CF_{t,ir} = P_{ener,t} * EnerSavings_{t,ir} + t_{CarbonTax,t} * CO2emissionsSavings_{t,ir} + P_{pv,t} * PVproduction_{t,ir}, \text{ with}$$

$P_{ener,t}$ the heating energy price corresponding to the energy mix of each dwelling (multiple prices can be considered in case of fuel switch),

$EnerSavings_{t,ir}$, the amount of theoretical energy savings got from the retrofiting,

$t_{CarbonTax}$ the potential carbon tax on CO₂ emissions due to heating,

$CO2emissionsSavings_{t,ir}$, the avoided CO₂ emissions thanks to the retrofiting,

$P_{pv,t}$ the price (feed-in tariffs) offered for photovoltaic panels' electricity production,

$PVproduction_{t,ir}$ the amount of electricity production in case of photovoltaic panels installation.

Regarding $P_{ener,t}$, we assume that households have myopic anticipations as regards energy prices: we consider that they ignore the possibility of rising prices and that they take into account an average of energy prices observed in the past few years to compute their cash flows.¹⁵⁶ Myopic anticipation represents market barriers linked to uncertainty (on future energy prices and on future policy), imperfect information and behavioral failures. Individuals take into account constant theoretical annual energy savings all along the lifetime of the investment. Therefore, they do not endogenize potential rebound effect, i.e. the fact that they can adjust their real future energy consumption compared to theoretical savings resulting from thermal module calculations. However, this compensates the fact that we do not take into account the welfare gains in terms of thermal comfort in case of rebound effect.

The discount rate d_{ir} of the individual i for the retrofiting option r is based on the weighted average cost of capital (WACC): $d_{ir} = \left(\frac{r_{Li} * L_r + r_{Ki} * K_r}{L_r + K_r} \right)$, with L_r, K_r respectively the

¹⁵⁶ An average of 5 years is chosen in the calibration process, see section 4.

loan and the own capital part of the investment and r_{li}, r_{Ki} respectively the loan and capital return rates specific to each income quintile. $r_{ki} = \beta_{Income} r_k, k = L, K$ with r_L, r_K the average loan and capital return rates respectively proposed by the bank sector. $\beta_{Income} \geq 1$ decreases with the level of income (Hausman 1979). It represents the heterogeneity between the different quintiles of income as regard the liquidity constraints and the preference for the present. Note that when CIDD and EcoPTZ cannot be cumulated, a pre-financial calculation is made comparing the cumulated and discounted borrowing cost under each configuration to select the more profitable.

3.4.2. Investment modelling

The decision sequence is decomposed into two steps (Figure 13).¹⁵⁷ At each step, the individual representative of the segment i faces R alternatives and chooses the alternative r if $r = \arg \max_{r \in R} (U_{ir}^*)$. We assume that the utility that the decision maker i obtains from alternative r is decomposed into a part labeled U that is known by the modeler and a part \mathcal{E} unknown by the modeler and treated as random: $U_{ir}^* = U_{ir} + \mathcal{E}_{ir} \forall r$.

¹⁵⁷ The decision making modeling is inspired by the models CIMS and Res-IRF but our originality compared to these two models is that we explicit more the microeconomic decision model behind the logistic curves.

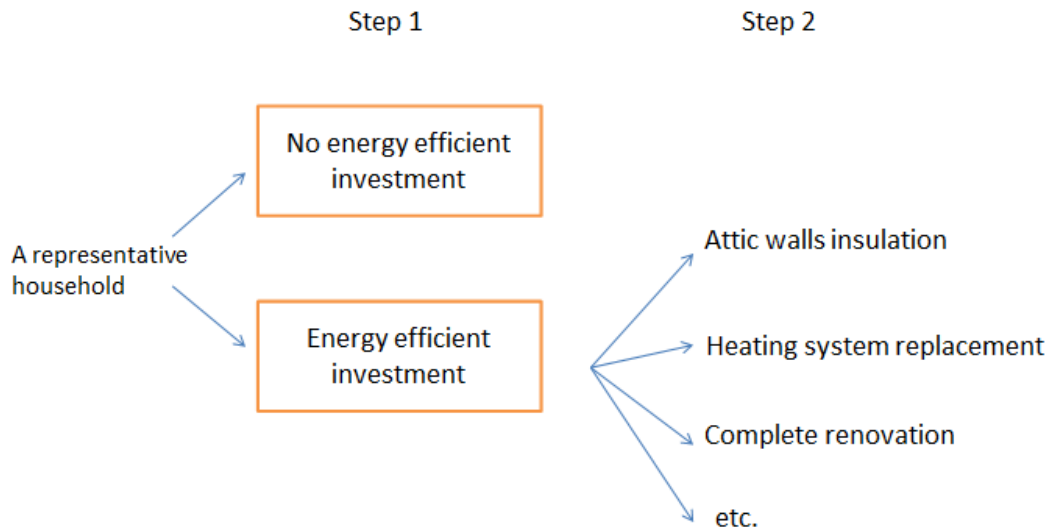


Figure 13. A decision process in two steps.

Be $P_{ir} = P(U_{ir}^* > U_{ir'}^*), \forall r' \neq r$ the probability for the individual i to choose the alternative r . If we assume that \mathcal{E} is independently, identically distributed extreme value,¹⁵⁸ the probabilities follow a logistic function¹⁵⁹ which exhibits several the desirable properties of a probability (Train 2003):¹⁶⁰

¹⁵⁸ The distribution is also called Gumbel and type I extreme value (and sometimes, mistakenly, Weibull). The density for each unobserved component of utility is: $f(\mathcal{E}_{nj}) = e^{-\mathcal{E}_{nj}} e^{-e^{-\mathcal{E}_{nj}}}$ and the cumulative distribution is $F(\mathcal{E}_{nj}) = e^{-e^{-\mathcal{E}_{nj}}}$. Using the extreme value distribution for the errors is nearly the same as assuming that the errors are independently normal. The extreme value distribution gives slightly fatter tails than a normal, which means that it allows for slightly more aberrant behavior than the normal. The choice of such distribution is standard in the choice modelling literature since it is this particular distribution which allows the Random Utility Maximization models having good properties for probabilities (Afsa Essafi 2003).

¹⁵⁹ the difference between two extreme value variables is distributed logistic:

$$\mathcal{E}_{nji}^* = \mathcal{E}_{nj} - \mathcal{E}_{ni} \text{ and } F(\mathcal{E}_{nji}^*) = \frac{\mathcal{E}_{nji}^*}{1 + \mathcal{E}_{nji}^*}$$

¹⁶⁰ P_{ir} is necessarily between zero and one and the sum of all the probabilities of the choice set is equal to 1. The logit probability for an alternative is never exactly zero. If an alternative has actually no chance of being chosen by a decision maker, that alternative can be excluded from the choice set. A probability of exactly 1 is obtained only if the choice set consists of a single alternative. We also implicitly normalize the scale of utility assuming the variance equal to $\pi^2 / 6$ (Train 2003).

$$P_{ir} = \prod_{r' \neq r} e^{-e^{-(\epsilon_{ir} + V_{ir} - V_{ir'})}} f(\epsilon_{ir}) d\epsilon_{ir} \Rightarrow P_{ir} = \frac{e^{U_{ir}}}{\sum_R e^{U_{ir'}}$$

With this specification, P_{ir} is a function of all $U_{ir}, \forall r \in R$. But holding constant the utility of all the alternatives except the alternative r , P_{ir} approaches one when U_{ir} rises (reflecting an improvement in the observed attributes of the alternative) and P_{ir} approaches zero when U_{ir} decreases. It gives the following logistic function of $P_{ir}(U_{ir})$ as illustrated in Figure 14:

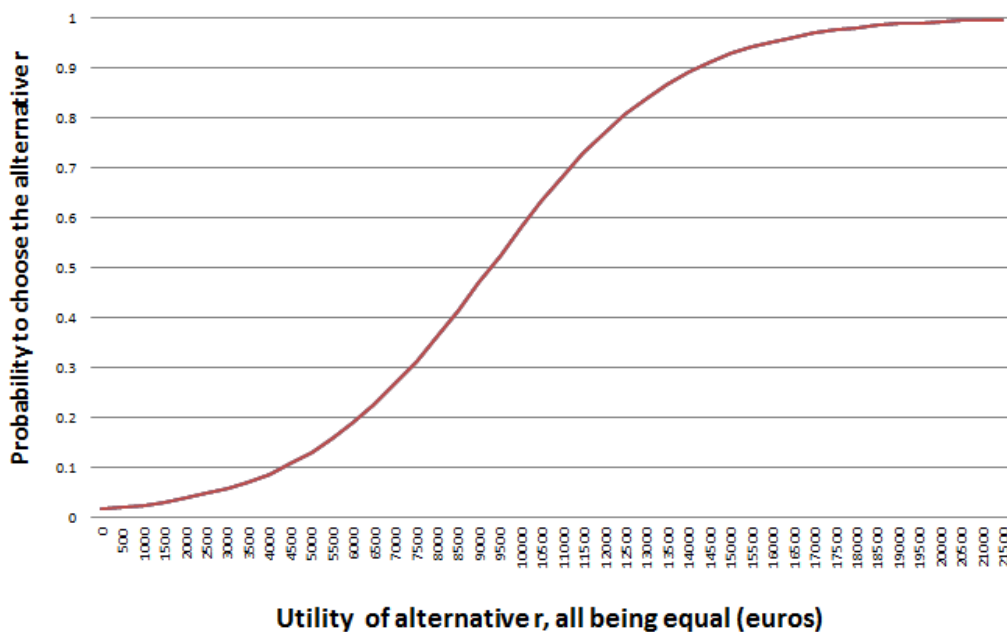


Figure 14. Graph of the logistic function in the decision process.

The decision making process is modeled in two steps and is resolved backward. In the second step of the decision sequence (resolved first), each U_{ir} is equal to NPV_{ir} described in section 3.4.1 and denotes a single retrofitting alternative. P_{ir} , the probability that the alternative r is chosen among all the technically feasible alternatives R is:

$$P_{ir} = MS_{ir} = \frac{e^{\frac{U_{ir} - \bar{U}_i}{\sigma_{U_i}}}}{\sum_R e^{\frac{U_{ir} - \bar{U}_i}{\sigma_{U_i}}}},$$

Utilities are centred reduced by \bar{U}_i and σ_{U_i} , respectively the mean and the standard deviation of $(U_{i,r})_{r \in R}$ within each building segment. These P_{ir} give the market shares MS_{ir} of all the retrofitting alternatives inside each segment.

Note that in order to make vary the level of unobserved heterogeneity between retrofitting alternatives, similar models (CIMS, Res-IRF) include an heterogeneity parameter. Here, it would be equivalent to multiply σ_{U_i} by an heterogeneity parameter η . When η increases, the unobservable heterogeneity is assumed larger and the market shares MS_{ir} are more equally distributed. The value of such heterogeneity parameter is very difficult to calibrate and generally more or less arbitrarily chosen (Jaccard & Dennis 2006, Giraudet 2011). Since the sensitivity analysis performed on the Res-IRF model (Branger et al. 2015) does not assign an important weight to such heterogeneity parameter and since Menfis represents more heterogeneity including technology-specific intangible costs/benefits calibrated on observed market shares (see below), we chose to ignore this heterogeneity parameter in this paper.

From this first step, we get \bar{U}_i^{MS} the average utility of each segment i weighted by the market shares MS_{ir} of each retrofitting alternative. The first sequence of the choice (resolved in second) is then modelled by another logistic function and gives the probability of retrofitting PR_i for each segment i :

$$PR(\bar{U}_i^{MS}) = \frac{1}{1 + e^{-\left(\frac{\bar{U}_i^{MS} - \alpha_{mean} U_{mean}}{\alpha_{std} U_{std}}\right)}},$$

With $\alpha = (\alpha_{mean}, \alpha_{std})$ parameters endogenously chosen in the calibration process (see section 4.3). \overline{U}_i^{MS} is centred reduced by U_{mean} and U_{std} respectively the mean and the standard deviation of all the \overline{U}_i^{MS} of the building stock.

3.5. Representation of the energy consumption drivers and the direct rebound effect.

Energy efficiency improvements are usually followed by energy sufficiency relaxation, i.e. increased utilization of energy consuming capital (Alcott 2008). “Consumers may choose to heat their homes for longer periods and/or to a higher temperature following the installation of loft insulation, because the operating cost per square meter has fallen” (Sorrell et al. 2009). The resulting discrepancy between effective energy savings and the savings theoretically achievable under a constant utilization assumption is referred to as the direct rebound effect.

The integration of the rebound effect in Menfis is largely inspired by the Res-IRF model (Giraudet 2011), which uses a statistical relationship between conventional energy consumption, energy use costs and real energy consumption established by Allibe (2012).

Let be $\frac{E_{fin}}{E_{conv}}$, with E_{fin} the real level of energy consumption and E_{conv} the conventional/

theoretical energy consumption computed with a thermal module (both in kWh/y/m² of final energy), representing a dimensionless “service factor” or utilization rate of the heating infrastructure. Allibe (2012) finds a statistical relationship linking the service factor E_{fin} / E_{conv} to the annual theoretical fuel bill at current energy prices, using data coming from a survey of customers of the French electricity company EDF. It states that the higher (lower) the energy expenditure is, the more (less) is restrictive the utilization, i.e. sufficiency strengthening (relaxation). Energy efficiency improvements due to retrofitting may therefore be partly compensated by sufficiency relaxation. The relationship used in Menfis is presented in Figure 15. Note that the constant elasticity specification is used in Menfis in order to inverse the function to find theoretical consumption from real one in the calibration process (see section 3.1).

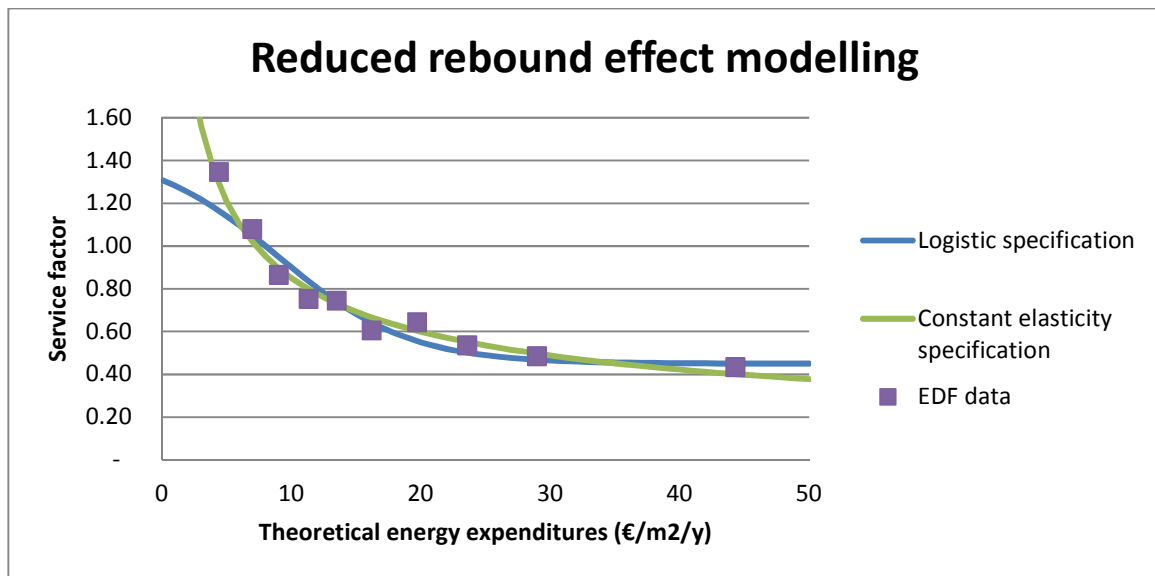


Figure 15. Rebound effect modelling (Allibe 2012, Giraudet 2011).

4. Calibration

Menfis is calibrated using multiple French statistical sources following the evolution of the markets linked to residential energy conservation and residential energy consumption.

4.1. Data on the technological and sociological representation of the building stock.

For each segment, data on the number of dwellings, the surface area in m² and the real energy consumption in kWh/m² are provided by a CEREN database built for ADEME and based on the national survey ENL made by INSEE in 2006.¹⁶¹ It only covers the main residences (26 millions of dwellings in 2006).

Data are distinguished between: single- and multi-family dwellings; owners and renters; income quintiles; consumption units; main heating energy sources; building completion periods;

¹⁶¹ For Enquête National Logement (Housing National Survey). The CEREN, the French statistical office on the energy sector historically supervised by ADEME and national energy suppliers, provides statistical adjustments to households' declaration on their energy bills to provide energy consumption in physical units.

and winter climatic zones. As this CEREN database does not distinguish between social and private landlords, we allocate landlords into these two categories assuming 56.5% of the rental stock belongs to the private sector and 43.5% to the social one (« L'état du logement en 2010 » 2012 p9). Moreover, since we model the owner of the dwelling as the decision maker of potential retrofitting and since this survey give the financial situation of the occupiers, we have to change the distribution of income for the private landlords. We use statistics on their specific income distribution to allocate them accordingly.¹⁶² As regards social landlords, we suppose no liquidity constraints and put all of them in the highest quintile of income.

As regards the technical representation, in the absence of data on the 2008 state of energy performance of the building stock at our level of disaggregation, we calibrate it. From data on real energy consumption in physical units, we use the inverse relationship between the utilization rate of the heating infrastructure ($\frac{E_{fin}}{E_{conv}}$) and the theoretical energy costs (see section 3.5) to get conventional energy consumption and the Energy Performance Class (EPC) of each segment from real energy consumption data (using 2006 energy prices). Then, we randomly draw an average renovation state corresponding to each segment's building characteristics and EPC.¹⁶³

Aggregated EPC distribution of the French building stock based on the ENL/CEREN data in 2006 and the Menfis methodology is shown in Figure 16 in comparison with other models or studies: Perfologie, a technical model used by ANAH¹⁶⁴ and ADEME, EXIM (2011), a study based on property transfer (notarial data), Phebus (SOeS, CGDD 2014), a survey dedicated to residential energy performance, and two other studies (Energies Demain 2011 and Marchal 2008). Compared to other data sources, the method used in Menfis provides similar EPC distribution, except for the share of EPC A buildings which is overstated. This may be due to the limitations of the statistical relationship found by Allibe when inverted and applied to disaggregated building segments. In appendix A2, EPC distribution, as well as resulting average

¹⁶² Dossier compte du logement 2008 et premiers résultats 2009

¹⁶³ We subdivide the segments into 10 sub-segments to perform the random draws and average them at the segment level afterwards.

¹⁶⁴ Agence Nationale de l'Amélioration de l'Habitat

initial retrofitting states, are refined per building construction period and building type are presented. We notably observe a potential upward bias in the calibration of multi-family dwellings' energy performance.

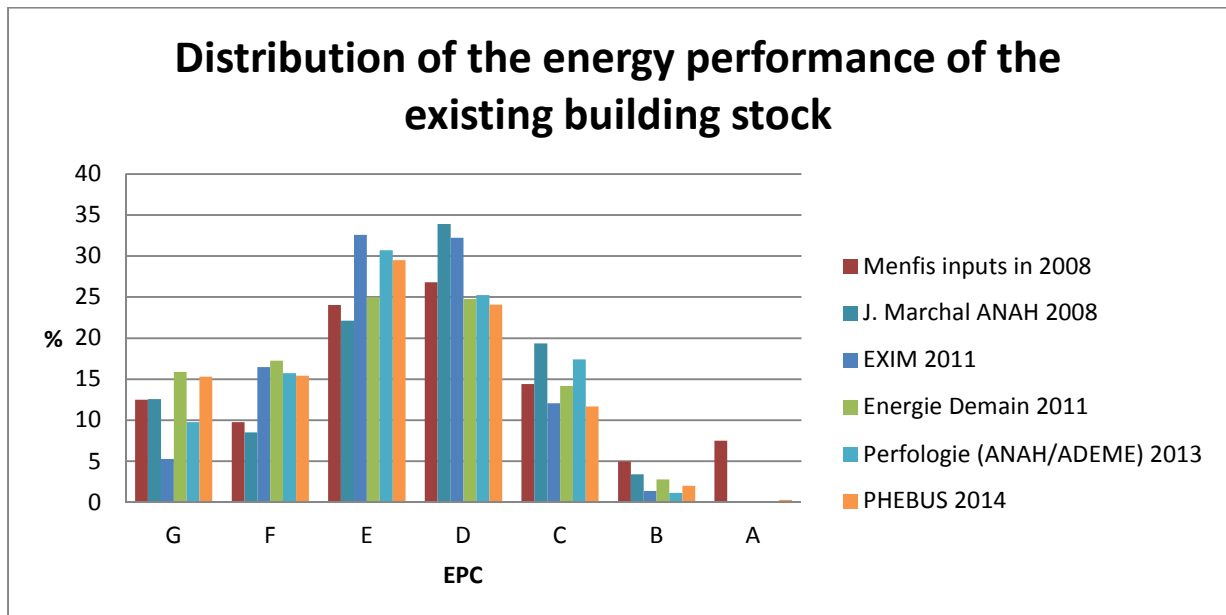


Figure 16. Energy Performance Certificate distribution of the existing dwelling stock from several data sources.

4.2. Data on economic inputs.

As regards energy prices, past data (over 2008/2013) are taken from the Pegase database supervised by the French Ministry of Ecology, to which we add the Value Added Tax (VAT).¹⁶⁵ The annual future growth rate of the tax-excluded real prices (in euros constant 2008)¹⁶⁶ are projected thanks to the main 2013 WEO forecasts for gas and fuel (OECD / IEA 2013). Given WEO projection at 2035 in their reference scenario (9% and 16% price increase over 2011/2035 for respectively gas and oil), we compute an average annual growth rate of

¹⁶⁵These prices include energy taxes (TIC and TLE in French) but not the VAT <http://www.statistiques.developpement-durable.gouv.fr/energieclimat>.

¹⁶⁶All input prices in the model are expressed in real terms but output can be expressed in real or nominal terms given an exogenous annual inflation rate.

0.34% and 0.63% for respectively gas and fuel.¹⁶⁷ We assume an average annual growth rate of 0.5% for electricity prices and no increase in wood price (see Figure 24 in appendix A1). The new carbon component in the energy taxes introduced in 2014 by the Finance Act is also included in Menfis, keeping its 2016 level for the subsequent years in the absence of any other carbon tax.¹⁶⁸

Regarding the discount rate, the proportion of the loan L_r increases with the investment cost (26% for investments below 7500 € up to 45% for investment above, based on OPEN 2009) and is higher for EcoPTZ loans.¹⁶⁹ Interest rate and capital return rate are fixed at respectively 4%¹⁷⁰ (0% in case of EcoPTZ) and 2.5%. Therefore, given income barriers β_{Income} as calibrated in the reference scenario (see below), discount rates decrease with income from 6% (1st income quintile) to 3% (5th income quintile). The choice of such discount rate levels is explained and discussed in appendix A5. In the literature, discount rate estimates implicitly integrate all investment barriers which cannot be properly identified or observable. In Menfis, we adopt discount rates values based on a financial mathematics approach because the investment barriers are identified separately and extracted from the discount rate in the cost/benefit analysis. However, sensitivity analysis will be done using higher discount rates.

Data on retrofitting measures come from the OPEN survey and the “Energy Management” (EM) survey (TNS Sofres & ADEME 2012). The EM survey annually provides detailed information about retrofitting investment: the retrofit options, the households’ and dwellings’ characteristics, the subsidization, etc.¹⁷¹ The OPEN survey is similar to the EM survey although more detailed on the retrofitting measures (OPEN 2009) but not annually realized. The EM survey does not provide the precise energy performance of each retrofitting type contrary to OPEN. However, it gives precious information in terms of retrofitting dynamics (annual time

¹⁶⁷ In former Menfis version, linear regressions were estimated on past data to forecast future energy price increase used in Menfis.

¹⁶⁸ All together (except the VAT), the energy taxes correspond to respectively 2%, 6% and 2% of the tax-excluded price for gas, fuel and electricity in 2013 and 6%, 11% and 2% in 2016.

¹⁶⁹ In case of EcoPTZ, loans reach the legal cap of 20000€ (30000€ for collective dwellings from 2014).

¹⁷⁰ 4% is in the lower range of values given the statistical study made by D. Berthon and L.G. Giraudet at CIRED (mémoire de recherche 2014) ranging average interest rates of 5 French banks between 3.6 and 5.9% (between 6 and 9% for the 3 surveyed credit institutions).

¹⁷¹ For more information, see Appendix A4 and also Appendix A2 in chapter 1.

series) and comparative investment rates between different household categories. Table 26 in Appendix provides the main input data used in Menfis. Note that at that stage, retrofitting costs are constant over time.

4.3. Calibration of the logistic functions and Menfis parameters.

We calibrate the logistic function modelling the first sequence of the decision making choosing both $\beta = (\beta_{CollectiveD}, \beta_{Income}, \beta_{Renting})$ and $\alpha = (\alpha_{mean}, \alpha_{std})$ in order to minimize the sum of squared difference between observed retrofitting rate in the EM survey and simulated ones in 2008 on 11 larger household/dwelling categories. These categories are all the combinations of the three occupation status (occupying homeowners, private landlords and social housing) and the two dwelling types (multi-family and single-family housing), which makes 6 categories, in addition to 5 other categories corresponding to the five income quintiles among occupying homeowners of single-family housing.¹⁷² Note that we only use the EM statistics to provide relative retrofitting rates between household categories. In particular, final retrofitting rates are lower in MENFIS outputs than in EM statistics because the EM survey covers more retrofitting types than MENFIS does. Besides, note that the EM survey statistics possibly understate retrofitting rate for private landlords and social housing (see the appendix on the EM survey in chapter 1).

The slope of this calibration curve determines households' response in terms of additional investment to any increase in the utility. Such increase can be notably due to an economic stimulus, i.e. a policy implementation or an increase in energy price. Therefore, this calibration process strongly influences the additionality brought about by the policies. We check the policy response of the calibration in section 6.1.2.

Table 20 shows the socio-economic parameters as calibrated in 2008. The parameter related to the collective decision making is mute, i.e. set at zero. This may be because of correlations between the different socio-economic characteristics (more renters and low-income households in multi-family dwellings) and of the fact that multi-family dwellings have

¹⁷² Retrofitting statistics for more disaggregated categories would not be reliable given available data.

smaller area than single-family dwellings (75m² instead of 110m² in average). The initial calibration also assigns higher initial performance to multi-family dwellings (see appendix A2). Since the renting parameter multiplies the total annual energy savings per dwelling, the difference of surface area between single- and multi-family dwellings also explains why the renting parameter is lower for single-family dwellings.

Intangible costs/ benefits specific to each building component ω_i are calibrated in order to fit observed realization rate per retrofitting type in 2008 (OPEN 2009). Calibrated parameters are shown in Table 21. Regarding hidden benefits, investment cost are decreased by 30% for heat-pumps (hidden benefits such as cooling or green value) and 30% for windows (esthetic, acoustic insulation). Regarding hidden costs, investment cost are increased by 120% for solar water heating (possibly due to understated costs in Menfis, risk aversion towards innovative technology or technical constraint for installation) and by 50% for wall insulation (hidden costs such as discomfort generated by the works, surface loss in case of indoor insulation or architectural constraints in case of outdoor insulation).¹⁷³ When intangible costs are calibrated at zero, it means that there is no need to modify the economic investment cost to get the targeted market shares.

Finally, it is important to note that due to the presence of non-linearities in the model and of numerous interactions between all the variables, it would have been difficult to endogenize an optimization process to perform these two steps of calibration. At that stage, these two steps are calibrated successively, with manual iterations. This means that some discrepancies are tolerated between the model outputs and the targeted values, the aim being to keep the good orders of magnitude.

¹⁷³ In his calibration of technology-specific intangible costs, B. Allibe (2012) also finds high intangible cost for (outdoor) wall insulation, especially as opposed to windows.

Table 20 Socio-economic parameters calibration in the reference scenario.

Socio-economic parameters					
Beta collective decision making	0				
	MFD	SFD			
Beta renting	0.85	0.6			
	quintile 1	quintile 2	quintile 3	quintile 4	quintile 5
Beta income	2	2	1.6	1.3	1

MFD = multi-family dwelling; SFD = single-family dwelling

Table 21. Hidden cost/benefit calibration in the reference scenario.

	gas & fuel	heat-pumps	wood	solar water	windows	wall	roof	photovoltaic
Hidden costs/benefits**	0%	-30%	0%	120%	-30%	50%	0%	0%

** in % of retrofitting cost (hidden cost if positive, hidden benefit if negative)

5. Scenarios

In the following results, for simplicity, we only model the retrofitting process. The dwelling stock does not integrate any new construction and no destruction rate is applied on the existing dwelling stock. Differences would be marginal in the short run. Therefore, absolute numbers of retrofits are equivalent to retrofitting rates and energy aggregate consumption equivalent to unitary consumption.

We build three sets of scenarios corresponding to three research questions. An inter-policy set assesses the efficiency of three instruments: the CIDD/CITE subsidy, the EcoPTZ zero rate loan and the carbon tax. A second set explores the energy savings potential unexploited because of all the investment barriers. A third set finally focuses on the subsidy design.

Even if the final energy consumption reduction is an important output to consider, especially given the French legal commitment of -38%, the cost-benefit of the different scenarios is assessed according to what we call the Social Net Present Value (Social NPV). The Social NPV consists in computing all the investment costs minus all the energy savings socially valued over the entire period of comparison 2008/2025. Contrary to households' NPV, energy savings are monetized with the "real" forecasted tax-excluded energy prices (no more myopic

anticipation). Saved CO₂ emissions are valued according to the Quinet report (2008).¹⁷⁴ All the Social NPV are cumulated and discounted over the period with a discount rate of 2.5% (the zero-risk rate recommended in the Quinet report (Quinet & Baumstark 2013)). Moreover, in order to check the policy response of the model induced by the calibrated logistic curve, we also look at the multiplier effect of a policy. This multiplier effect is called the BFTB multiplier (for “Bang For The Buck” by Ientile & Mairesse 2009) and computes the additional amount of private investment generated by one euros of public spending. The BFTB multiplier is a rather complete metric since it integrates the effects on both the extensive and intensive margins of the investment. However, when comparing different policy instruments, we ignore the problematic of the opportunity costs of public funds (OCPF), which has to be apprehended in a macroeconomic framework.

5.1. 1st set Inter policy scenario

Reference scenario: Following past policies over 2008/2014 (CIDD over 2008/2014, EcoPTZ with accessibility constraint over 2009/2014, the premium of 1350 euros in 2014), this scenario implements after 2014 a simplified CIDD subsidy rate of 30%. It keeps the same restricted EcoPTZ as over 2009/2014 but removes the premium. Note that the eligibility criteria or the expenditures ceilings depending on family size or households’ income are represented, as well as the differences in the tax credit rate depending on retrofitting types over 2008/2014.

BAU 2008 scenario: No policy since 2008.

EcoPTZ+ scenario: Same policies as in the Reference scenario over 2008/2014. After 2014, the EcoPTZ is the single policy and is no more restricted (all eligible investments benefit from it).

Carbon tax (CT) scenario: Same policies as in the Reference scenario over 2008/2014. After 2014, the carbon tax is the single policy. Following Quinet report (Quinet et al. 2008), the tax starts at 44 euros (in euros 2008) per ton of CO₂ in 2015 to reach 56 euros in 2020 and 100 euros in 2030. Contrary to future energy prices, the households have perfect anticipations as

¹⁷⁴ The tax starts at 44 euros (in euros 2008) per ton of CO₂ in 2015 to reach 56 euros in 2020 and 100 euros in 2030.

regards carbon tax once this tax is implemented (i.e. after 2015). Note that the carbon component introduced in the energy taxes from 2014 is included in all scenarios (see section 4.2.), except in this one from 2015. All energy sources are taxed accordingly to their CO₂ concentration.¹⁷⁵

Then policy package scenarios combine two or three of the three studied instruments (CIDD, EcoPTZ, Carbon tax): the **Reference & EcoPTZ+ scenario**, the **Reference & CT scenario**, the **CT & EcoPTZ+ scenario**, the **Reference & EcoPTZ+ & CT scenario**.

5.2. 2nd set Unexploited potential due to investment barriers

Zero barrier scenario: The BAU 2008 scenario without any socio-economic barrier or intangible costs (hidden benefits are still represented).

No income barrier scenario: The BAU 2008 scenario without any income barrier ($\beta_{Income} = 1$ for all income quintile).

No renting barrier scenario: The BAU 2008 scenario without any renting barrier ($\beta_{renting} = 1$ for all occupation status).

No Intangible Costs (CI) scenario: The BAU 2008 scenario without any intangible costs (hidden benefits are still represented). Note that such elimination of the intangible costs can be discussed. Indeed, referring to the classical distinction made in the Energy Efficiency Gap literature between market imperfections requiring public intervention and other investment barriers (cf the general introduction of the thesis), the intangible costs include both types of investment barriers. For example, the intangible costs specific to wall insulation (discomfort, loss of surface area) may not justify public intervention. However, intangible costs due to risk aversion, more specific to innovative systems such as solar water heating for example, may justify public intervention to foster learning-by-doing.

¹⁷⁵ CO₂ concentrations (in grams of CO₂ per kWh in final energy) for respectively gas, fuel, electricity and wood are 206, 268, 180 and 0.

5.3. 3rd set : intra-policy scenario and focus on subsidy design

In this set, we investigate how a uniform subsidy as implemented in the new subsidy scheme (now called CITE) could underperform compared to more refined subsidy design. In the **CITE** scenario, we model an ad valorem subsidy with a rate of 30% on all the retrofitting types. This is a simplified version of the CITE subsidy implemented for 2015 as all households are eligible with any subsidy cap. In the alternative scenario, called **SPEE** for Subsidy Proportional to Energy Efficiency, we model an ad valorem subsidy with a rate proportional to theoretical energy savings per m² (in final energy) resulting from the retrofitting in the spirit of the KfW or ANAH subsidization programs.¹⁷⁶ Rates are chosen to be between 0 and 60%. In order to make the two scenarios comparable, the multiplicative factor is fixed in order to get the same amount of public cost each year.

This third set of scenarios makes simplifying assumptions in order to facilitate the analysis of the results. In order to benefit from a longer observation period, we start the comparison between the policies right from 2008. To capture only the policy effects, we fix energy prices constant at their 2008 level over the entire period. In order to limit both the intra- and the inter-individual “costs/savings ratio” heterogeneity and keep it tractable, we assume no “Do it Yourself” works, no fuel switch and we assume the same initial renovation state in all segments. We also apply the subsidies on both labor and material costs and uniformly on all households’ categories. All differences left between the retrofitting options are the investment cost, the resulting energy savings, the specific intangible costs and the subsidies. For further simplifications, we exclude retrofitting combinations and the installation of photovoltaic panels. Finally, in this set, the calibration keeps the same values of parameters as shown in section 4.3 but the logistic curve is endogeneously recalibrated to approximate the good relative market shares.

¹⁷⁶ KfW is the German public investment bank. The KfW subsidization program for residential building retrofitting offers a 10% price cut if the retrofitted building reaches 115% of the standard energy needs for new constructions, and a 25% price cut if it meets the Passivhaus standard (Rüdinger 2013). ANAH (Agence National de l’Amelioration de l’Habitat) is a French public agency dealing with residential energy performance and fuel poverty. The ANAH subsidization program “Habiter mieux” offers to middle and low-income households a price cut between 35 and 50% when the retrofitting reaches 25% of energy savings (<http://www.anah.fr>).

6. Results

Section 6.1 presents in detail the Reference scenario, focusing on the comparison with observed data over 2008/2012 and with other models. Section 6.2, 6.3 and 6.4 respectively present the results of the 1st, 2nd and 3rd scenarios set.

Located at the end of section 6.3, Table 23 presents the results for sections 6.1, 6.2 and 6.3. It shows economic aggregates (Social NPV, public cost and benefit, etc.) and the reduction rate of physical units (average theoretical and real energy consumptions per m² in final energy, average theoretical CO₂ emission per m²) over different sub-periods between 2008 and 2025.

6.1. Comparative results

6.1.1. Retrofitting rate

Figure 17 shows annual retrofit per technology over 2008/2025. 2008 is also compared with the 2008 OPEN data used as a reference to calibrate the parameters related to hidden costs and benefits. The fit is good, except an understatement of roof insulation measures.¹⁷⁷ More importantly, Figure 17 shows the progressive exhaustion of the profit-making retrofitting potential. Retrofitting rates start to decrease after 2016. This suggests the importance of path dependency in policy assessment. Recall that the model does not explicitly represent replacement works without significant energy efficiency and does not represent the wear and tear of retrofitting done after 2008, which understates the retrofitting level in the long-run. The discontinuities in the annual retrofitting rates is due to the combination of policy modifications (increase in the CIDD rate in 2015 in particular), the evolution of dwelling segments' renovation state and to some extent the evolutions in energy prices.

¹⁷⁷ We chose not to include hidden benefits due to the lack of theoretical justification for hidden benefits in case of roof insulation. Moreover, we are not sure that OPEN data only include complete roof insulation.

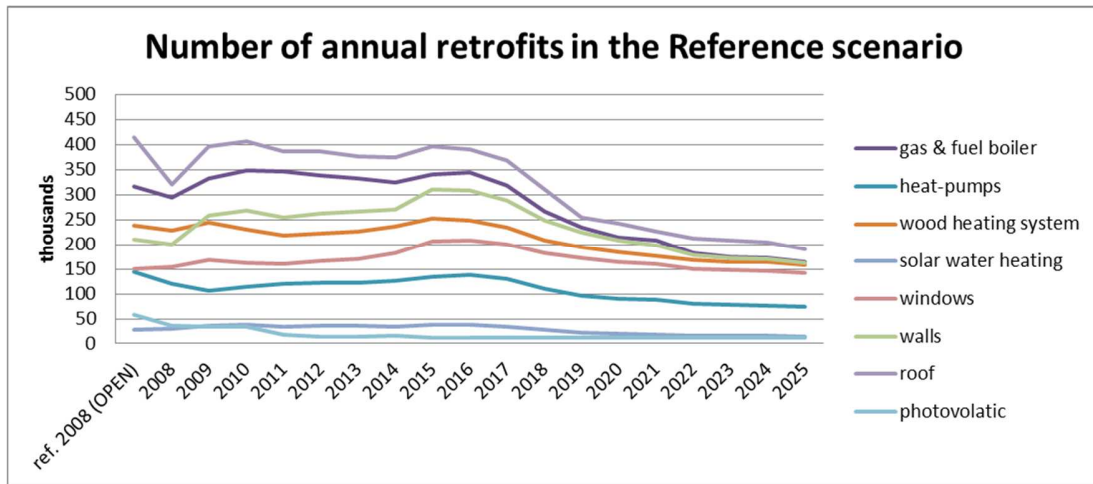


Figure 17. Number of retrofit per retrofitting type in the reference scenario

Figure 18 and Figure 19 respectively give the retrofitting distribution between household category distinguished by occupation status and building type and between income quintile among the homeowners of single-family dwellings. Compared to EM statistics, Menfis outputs provide similar distribution for single-family dwellings (SFD) and for income quintile among homeowners in single-family dwellings. For multi-family dwellings (MFD), we find some switching in the retrofitting investment between homeowners and landlords (too many landlords and too few homeowners). This may be due to structural differences between their respective dwellings in terms of energy savings potential as well as the retrofitting cost-efficiency. In appendix, Figure 25 shows the average ratio between investment cost and energy savings (called “costs/savings ratio”) among households’ categories. Essentially due to smaller surface area for MFD than for SFD, we find higher “costs/savings ratio” for MFD than for SFD when considering total annual savings. Moreover, Figure 26 shows the average NPV in 2008 for the scenario without any subsidy. These NPV measures merge the cost/savings ratio heterogeneity with the socioeconomic barriers heterogeneity. We see an important gap between MFD and SFD. Interestingly, there is little difference between occupation status among MFD compared to the situation among SFD. These features, namely a lower cost-efficiency and a lower differentiation between occupation status for MFD than for SFD, result from differences in investment costs, surface area, thermal calculations and initial renovation state calibration between MFD and SFD.

Figure 20 finally shows annual retrofitting rate per household category. It confirms that retrofitting is mainly done by the occupying homeowners of single-family dwellings but also shows how this category is more rapidly affected by the exhaustion of the energy savings potential. Since the cost-efficiency of the retrofitting decreases with this exhaustion, it suggests the unexploited gains in cost-efficiency when keeping strong investment barriers on other household categories.

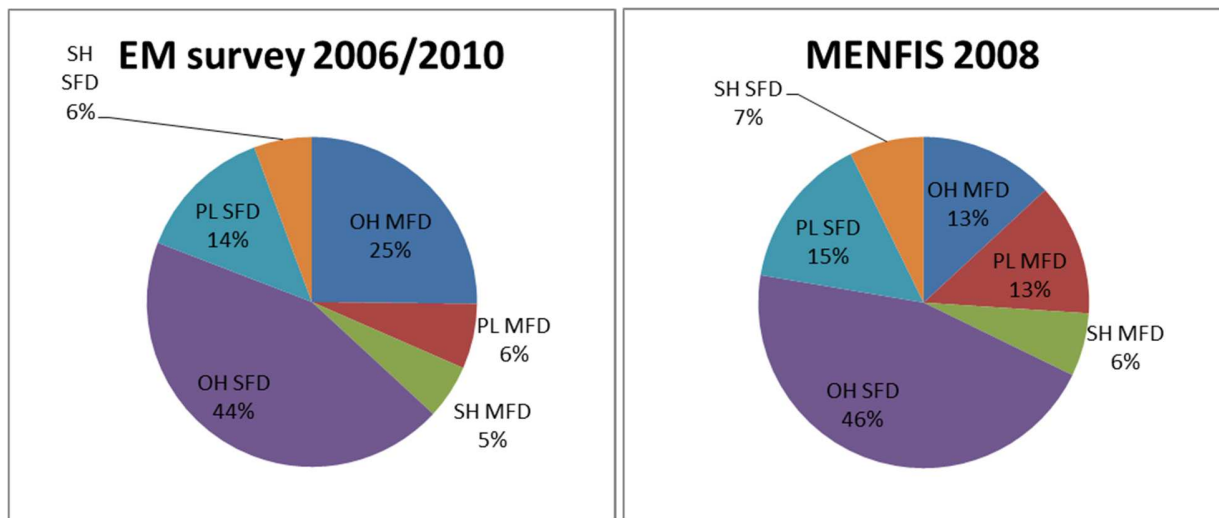


Figure 18. Retrofitting rate distribution among household category.

Note: OH=Occupying-homeowners; PL=Private landlords; SH=Social Housing; MFD=Multi-Family Dwelling; SFD=Single-Family Dwelling

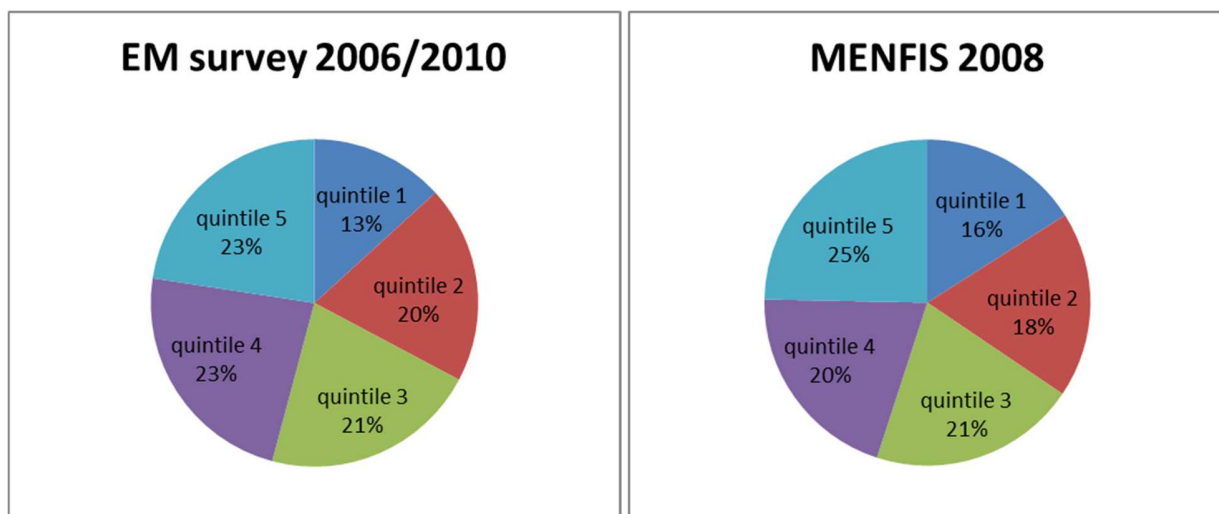


Figure 19 Retrofitting rate distribution among income quintile of homeowners of single-family houses.

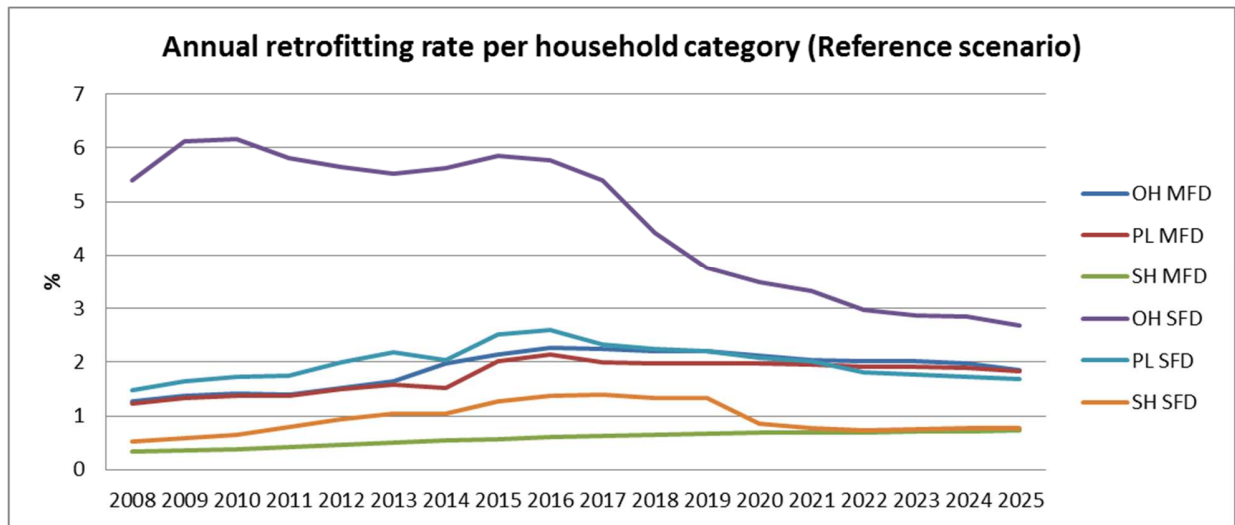


Figure 20. Retrofitting rate in the Reference scenario per household category.

6.1.2. Public expenses and additionality

As shown in Table 22, we check if Menfis provides realistic outputs in terms of economic aggregates related to the turnover of the retrofitting sectors and to public expenditures. Sector revenues are slightly understated compared to OPEN’s estimation, possibly due to divergences in the way of integrating “Do it Yourself” works. Aggregates related to EcoPTZ and CIDD are close to statistics, though slightly lower, but seem to decrease more slowly.¹⁷⁸ Recall that the benefit from EcoPTZ is constrained: only 20% of eligible investments are really subsidized.

We also check the policy additionality computing the “Bang For The Buck (BFTB)” multiplier (Ientile & Mairesse 2009). To do so, we compare in 2008 the aggregated private investment in the Reference scenario (the only effective policy being the CIDD) and in the BAU 2008. We find a BFTB multiplier equal to 2.1 when excluding replacement windows without energy efficiency improvement.¹⁷⁹ This means that 48% of the aggregated value of the

¹⁷⁸ This lower decrease may also be due to the fact that Menfis does not represent the fact that the same household cannot benefit from the CIDD or the EcoPTZ several times.

¹⁷⁹ Given that the eligibility criteria were very low for windows replacement, we consider that all the windows replacements observed in 2008 which have not led to significant energy efficiency improvement (i.e.

retrofitting investment would have been undertaken anyway. This BFTB seems in the low range of the values found in chapter 2, in which BFTB estimates over 2008/2011 are found between 3.4 and 2.2 € privately invested per € of public spending. In their study, Mauroux and Daussin (2014) find a BFTB multiplier of 1.5 but only in case of a 15% increase of the tax credit rate over 2007/2008. When extrapolating to the entire CIDD scheme, they find a BFTB multiplier of 2.2 (see appendix A4 in chapter 2).¹⁸⁰

Table 22. Economic aggregates over 2008/2012: statistics and Menfis outputs.

	2008	2009	2010	2011	2012
Turnover of the renovation sector					
Estimated (OPEN)*	16				
Menfis output	13.9	15.0	15.3	14.8	14.7
CIDD costs (billions of euros)					
Observed (Fiscal data)	2.6	2.5	1.9	1.1	
Menfis output	2.2	2.3	1.8	1.4	1.1
EcoPTZ loans delivered (thousands of dwellings)					
Observed (SGFgas**)		71	78	40	39
Menfis output		62	64	22	48
Total amount of EcoPTZ loans (billions of euros)					
Observed (SGFgas**)		1.1	1.3	0.7	0.6
Menfis output		0.9	0.9	0.4	0.7

Note: data sources are in parenthesis

* Author's own calculations for the corresponding perimeter from the OPEN report 2008.

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6.1.3. Energy consumption: comparison with historical data

Theoretical and real consumption start at respectively 478TWh and 303TWh. The latter is close to CEREN data: 268TWh for heating and 49TWh for water heating in 2008 for the whole building stock (including new constructions). As shown in Table 23, in the **Reference** scenario, theoretical and real consumption respectively decrease by 14% and 12% over 2008/2012; by 32% and 28% over 2008/2025. Note that setting retrofitting rate to nearly zero, the real energy consumption reduction over 2008/2012 is still 6% only due to energy price increase. We

similar level to the average level present in the market before the CIDD implementation) but which have benefited from the CIDD subsidy would have been made anyway. In other words, we assume an complete free-riding in these cases. If we include these subsidized investments, the BFTB multiplier is 1.2.

¹⁸⁰ As a benchmark, the empirical estimates of the BFTB multiplier for the R&D tax credit reviewed by Ientile et Mairesse (2009) range between 0.26 and 2.96 (mean:1.1, std:0.7, over 33 studies published between 1983 and 2009).

compare 2008/2012 Menfis outputs to CEREN data (Table 25 in appendix A1): real energy consumption for heating (i.e. the main source of energy savings in Menfis) decreases by 11% when considering the whole building stock and 13% when considering the existing building stock built before 1999, which is close to Menfis outputs (12%).

6.1.4. Energy consumption: comparison with other models.

We also compare Menfis outputs with other models. Menfis forecasts higher energy consumption reduction than BEUS (Allibe 2012) and maybe than Res-IRF (Giraudet 2011):¹⁸¹

- in BEUS, a very optimistic scenario (highest energy efficiency option chosen at each retrofitting opportunity) only leads to 20% of reduction in theoretical energy consumption over 2010/2020 (author's own calculations from Allibe (2012) p257). By comparison, Menfis BAU 2008 scenario leads to a theoretical energy consumption reduction of 24.6% over 2008/2020. Differences are possibly due to divergence in the way of modelling retrofitting investment at the extensive margin (exogenously fixed and constant over time in BEUS). Note that assumed future energy prices are higher in BEUS scenario (over 2010/2030: 28% and 35% for respectively gas and fuel based on the World Energy Outlook 2011 and 29% for electricity according to UFE scenario « 50% nucléaire en 2030 » Allibe, 2012 p254). Same assumptions on energy prices would increase the difference between both models.
- in ResIRF, the "Reference scenario" without any policy has to be compared to our BAU 2008. Real unitary energy consumption reduction (in kWh/m²/year in final energy, including the rebound effect) for the whole building stock is 15.6% over 2008/2020 (Giraudet 2011, table 6 p100). In Menfis, it is 23% and only for the existing building

¹⁸¹ I do not compare with Charlier and Risch's model as there is no distinction between real and conventional energy consumption.

stock. However, assumed future energy prices are lower in ResIRF regarding gas and electricity (similar regarding oil, Giraudet 2011 table 20 p94). Same assumptions on energy prices would decrease the difference between both models.¹⁸²

6.2. 1st set of scenarios: inter-policy assessment

We now turn to the comparison between inter-policy scenarios. First looking at the Social NPV (Figure 21 and Table 23), we see that the scenario implementing both the carbon tax and the EcoPTZ zero rate loan without access limitation (**CT & EcoPTZ+**) dominates the others. The addition of the CIDD subsidy in this scenario (the **Ref & CT & EcoPTZ+** scenario) does not provide further improvement. Regarding the instruments implemented separately, the zero rate loan without access limitation (the **EcoPTZ+** scenario) performs better than the others. Recall that the zero rate loan is represented in Menfis in setting the interest rate to zero. This makes decrease households' discount rate (see section 3.4.1). In Res-IRF on the contrary, both the CIDD and the EcoPTZ are modelled as subsidies, i.e. making decrease investment cost. This explains why Res-IRF's results lead to similar energy consumption reduction for both EcoPTZ and CIDD (Giraudet 2011, Table 6 p100). Therefore, the superiority of the EcoPTZ over the CIDD found in Menfis comes from this differentiated representation of these two instruments in the microeconomic decision. It shows the importance of the way of endogenizing instruments but also the impact of the discount rate level on the retrofitting investment. As shown in the sensitivity analysis in appendix A6, higher discount rates would increase even more the efficiency of the EcoPTZ relatively to the other instruments.

In terms of theoretical final energy consumption reduction over 2008/2025, the **EcoPTZ+** scenario performs better (40%) than the **Reference** (i.e. the CIDD, 33%) or the **CT** scenarios (35%). Regarding the real final energy consumption reduction over 2008/2025 however, the Carbon tax performs slightly better than the EcoPTZ zero rate loan (34% and 32% for respectively the **CT** scenario and the **EcoPTZ+** one) which shows the stronger rebound effect

¹⁸² The real energy consumption reduction is only 9% over 200/2020 in the BAU 2008 of Menfis when we assume no rising energy price, which shows the strong influence of energy prices when considering real energy consumption.

limitation of the Carbon tax. As already shown in (Giraudet 2011), the subsidization is the worst instrument due to the rebound effect (28% for the **Reference** and the **CIDD only** scenarios).

Note that, in the Reference scenario, as well as in any scenario with constant policies over time, additional reduction in energy consumption decreases over time: from 27% over 2008/2012 to 15% over 2008/2025 in terms of theoretical energy consumption reduction (Table 23). This shows the importance of path dependency, i.e. the progressive exhaustion of the energy savings potential when the most profitable energy efficiency investments (with a given policy) have already been done. Also note that the additional energy consumption reduction compared to the BAU 2008 scenario is lower in real than in theoretical consumption (in final energy) because of the common effect of rising energy prices on real energy consumption in both the Reference and the BAU 2008 scenario.

None of these scenarios can reach the official target of -38% with the current energy price scenario, the best scenarios (**Reference & CT & EcoPTZ** or **CT & EcoPTZ**) only reaching -34.6% in 2020 (not reported in the table) and -39% in 2025. Comparing the BAU 2008 scenario with the BAU 2008 & price 2008 scenario in which we set all future energy prices at their 2008 level, we see the strong influence of the energy price increase in energy savings investment as well as in consumption adjustment (reduction by respectively 29% and 19% over 2008/2025 for theoretical consumption and by 26% and 10% for real consumption).

Results in terms of CO₂ emissions provide similar policy ranking, still favoring the **CT & EcoPTZ+** scenario. Note that theoretical CO₂ emissions reductions over 2008/2025 are 13/15% higher than theoretical energy consumption reductions over 2008/2025 for all the inter-policy scenarios. This is due to changes between heating energy sources, which essentially goes through the switch from fuel to gas and, to lower extent, the switch from fuel to wood or electricity (with heat-pumps).¹⁸³ Due to different CO₂ concentration among energy sources,

¹⁸³ In 2008, 52% of dwellings previously heated by fuel installs gas boiler for only 10% of dwellings previously heated by gas switching to fuel boiler. Additional wood systems (137 000 retrofits in 2008) are mainly installed in dwellings mainly heated by fuel (41%) and electricity (41%). Heat-pumps (104 000 retrofits in 2008) are mainly installed in dwellings mainly heated by fuel (44%) or electricity (49%). Note that the initial average distribution among energy carriers is 41% for gas, 17% for fuel, 36% for electricity and 6% for wood, some energy mix being assumed in dwellings mainly heated by woods or using heat-pumps.

supplementary results show that the share of electricity is relatively higher with the carbon tax than with the other instruments: while the share of electricity decreases by respectively 3% and 2.3% over 2008/2025 in the **EcoPTZ+** and in the **CIDD only** scenarios, its share only decreases by 0.5% in the **CT** scenario. Symmetrically, the share of fuel decreases slightly more importantly in the **CT** scenario (by 28.9% over 2008/2025) than in the **EcoPTZ+** and **CIDD only** scenarios (by respectively 28% and 25.7% over 2008/2025). Note that the gap between the **CT** and the **EcoPTZ+** scenarios is reduced by the higher retrofitting level in the **EcoPTZ+** scenario.

Finally, the combination of Carbon tax and EcoPTZ+ is all the more efficient when we adopt a budgetary perspective. In addition to foster retrofitting investment (mainly through the EcoPTZ) while limiting the rebound effect (mainly through the Carbon Tax), the **CT & EcoPTZ+** scenario succeeds in balancing public budget. Over 2008/2025, the total cost is 22 billions of euros for a total benefit of 20 billions of euros. Besides, the EcoPTZ cost corresponds to a tax credit compensating the bank sector. Such cost is got multiplying the aggregated amount of loan by a constant “compensation rate” of 17,7%.¹⁸⁴ However, this public cost could decrease if the policy device used to reduce loan interest rate turns to “Third-party financing” devices or specific loans guaranteed by the State (like for the real estate loans, as recommended by the Caisse des Dépôts et Consignations, 2013).

6.3. 2nd set: barriers investment potential

The removal of all the barriers to retrofitting yields higher energy savings potential than the implementation of expected policies (**Reference** scenario) since the theoretical energy consumption reduction over 2008/2025 is 41% in the **Zero Barrier** scenario instead of 33% in the **Reference** scenario. The **Zero Barrier** scenario nearly leads to the same Social NPV as the best inter-policy scenario (**CT & EcoPTZ+**, Figure 21).

Additional energy consumption reduction compared to the BAU 2008 is 43% in the **Zero Barrier** scenario, 11% for income barriers, 13% for renting barriers and 19% for intangible costs,

¹⁸⁴ Average of all the quarterly compensation rates for the 10-year EcoPTZ loans, the most common duration (SGFgas).

which seems to be additive. Investment barriers related to intangible costs seem to be the most important.

Let assume that all these barriers are market imperfections requiring public intervention and that subsidization may overcome them. We can compute implicit subsidy rates necessary to yield the same retrofitting rates as the **Zero Barrier** scenario. Such implicit subsidy rates are decreasing with income (from 59% for the 1st quintile to 25% for the 5th quintile among occupying home-owners of single-family dwellings) and are higher for renters than occupying homeowners (respectively around 80% and 40% in case of single-family dwellings).¹⁸⁵ This suggests the implementation of subsidy rates proportional to investment barriers. However, recall that even if the socioeconomic barriers (renting and income barriers) require public intervention, subsidization may not be the most cost-efficient policy. Besides, all the barriers embedded in the intangible costs do not require public intervention.

¹⁸⁵ Regarding multi-family dwellings, implicit subsidy rates vary much less with the occupation status (between 40 and 53%) and are quite close to the ones faced by occupying home-owners of single-family dwellings. This is linked to the observations made in section 6.1.1 regarding multi-family dwellings.

Table 23. 1st and 2nd sets scenarios results

	BAU & price 2008	BAU 2008	Reference	CIDD only	EcoPTZ+	CT	Ref. & EcoPTZ+	Ref & CT	CT & EcoPTZ+	Ref & CT & EcoPTZ+	Zero Barrier	No Intangible cost	No Income Barrier	No Renting barrier
Total over 2008/2025 discounted from 2008														
Social NPV (billions euros)	87	155	171	168	198	181	194	191	214	210	207	181	171	167
CO2 emissions savings (billions euros)	26	43	50	49	61	53	61	59	70	69	61	52	48	47
Energy savings (billions euros)	130	221	263	259	318	275	317	303	360	358	345	274	256	252
Total over 2008/2025 without discount:														
Subsidy cost (billions euros)	-	-	21	21	8	8	27	26	8	32	-	-	-	-
EcoPTZ cost (billions euros)	-	-	2	1	17	1	13	2	22	16	-	-	-	-
Tax carbon benefit (billions euros)	-	-	-	-	-	24	-	23	20	20	-	-	-	-
Sector turnover (billions euros)	167	208	235	232	276	243	276	266	311	310	294	243	229	229
Theoretical average energy consumption per m2 (final energy)														
Reduction rate														
2012 vs 2008	8%	11%	14%	14%	14%	14%	14%	14%	14%	14%	20%	14%	14%	13%
2025 vs 2008	19%	29%	33%	33%	40%	35%	40%	39%	45%	45%	41%	34%	32%	33%
Additional reduction \ BAU 2008														
2012 vs 2008			27%	27%	27%	27%	27%	27%	27%	27%	84%	31%	27%	19%
2025 vs 2008			15%	13%	38%	21%	39%	34%	56%	57%	43%	19%	11%	13%
Real average energy consumption per m2 (final energy)														
Reduction rate														
2012 vs 2008	4%	10%	12%	12%	12%	12%	12%	12%	12%	12%	15%	12%	12%	12%
2025 vs 2008	10%	26%	28%	28%	32%	34%	32%	36%	39%	39%	33%	29%	28%	28%
Additional reduction \ BAU 2008														
2012 vs 2008			15%	15%	15%	15%	15%	15%	15%	15%	47%	18%	15%	10%
2025 vs 2008			8%	7%	23%	28%	24%	36%	49%	50%	27%	11%	6%	8%
Theoretical average CO2 emission per m2														
Reduction rate														
2012 vs 2008	9%	13%	16%	16%	16%	16%	16%	16%	16%	16%	23%	17%	17%	16%
2025 vs 2008	22%	33%	38%	37%	45%	40%	46%	44%	51%	51%	46%	39%	37%	37%
Additional reduction \ BAU 2008														
2012 vs 2008			24%	24%	24%	24%	24%	24%	24%	24%	74%	27%	25%	18%
2025 vs 2008			14%	12%	36%	21%	37%	33%	53%	54%	39%	16%	10%	11%

Note: the CO2 emissions savings are valued according to the Quinet report (2008), the energy savings are valued with current tax-excluded energy prices.

Note2 : the sector turnover takes into account "Do it Yourself" retrofits and windows replacement without significant energy efficiency improvement. To be compared to other public costs/benefits, the subsidy cost does not take into account the subsidy cost for windows replacement without significant energy efficiency improvement for which we assume complete free-riding (see section 6.1.2.)

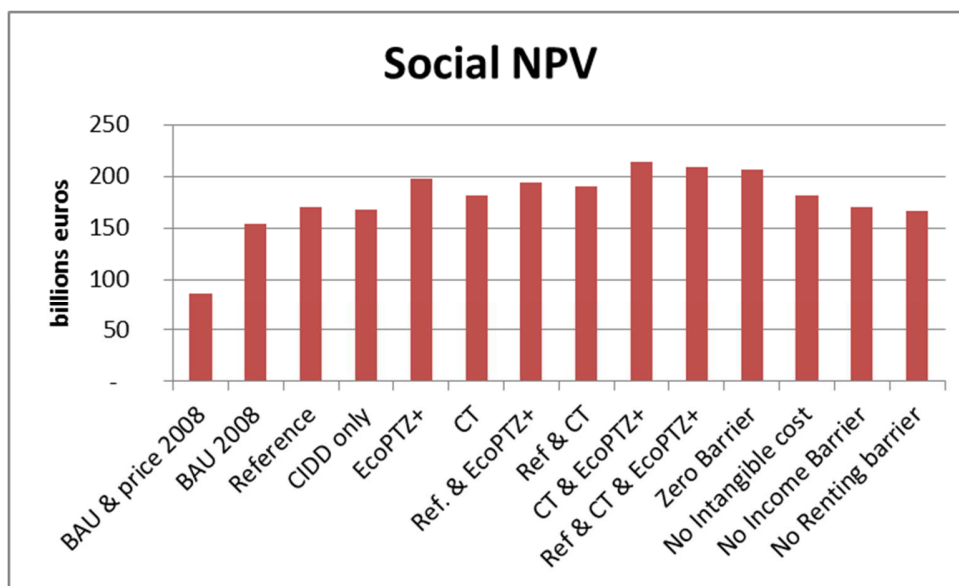


Figure 21. Social NPV for the 1st and 2nd sets of scenarios.

6.4. 3rd set : subsidy design scenario

Figure 22 shows the “cost/savings ratio” averaged among all building segments, i.e. the investment cost per annual energy savings per m². We see that in average the installation of gas and fuel condensing boilers as well as energy efficient wood heating systems (not in case of additional system) are more cost-efficient than the installation of heat-pump or other electric heating systems (radiant panel systems, see Table 27). Opaque surface (roof, walls) insulation is more cost-efficient than glazed surface (windows) insulation. As shown in Figure 23, the SPEE scenario subsidizes relatively more gas and fuel heating systems and opaque surface insulation while the CITE subsidy is the same whatever the retrofitting option. The correspondence between subsidy rates and cost-savings ratio in the SPEE scenario is not perfect due to heterogeneous investment costs and energy savings among building segments (e.g. heat-pumps have different energy savings depending on the initial heating energy source).

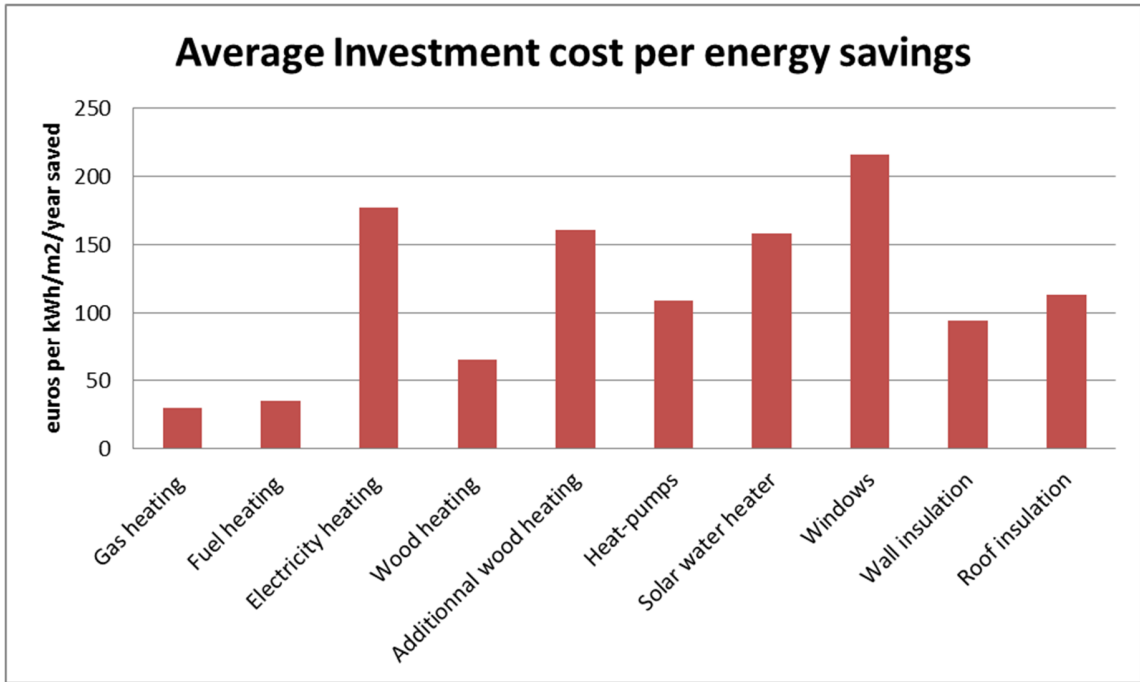


Figure 22. Average cost/savings ratio per retrofitting option

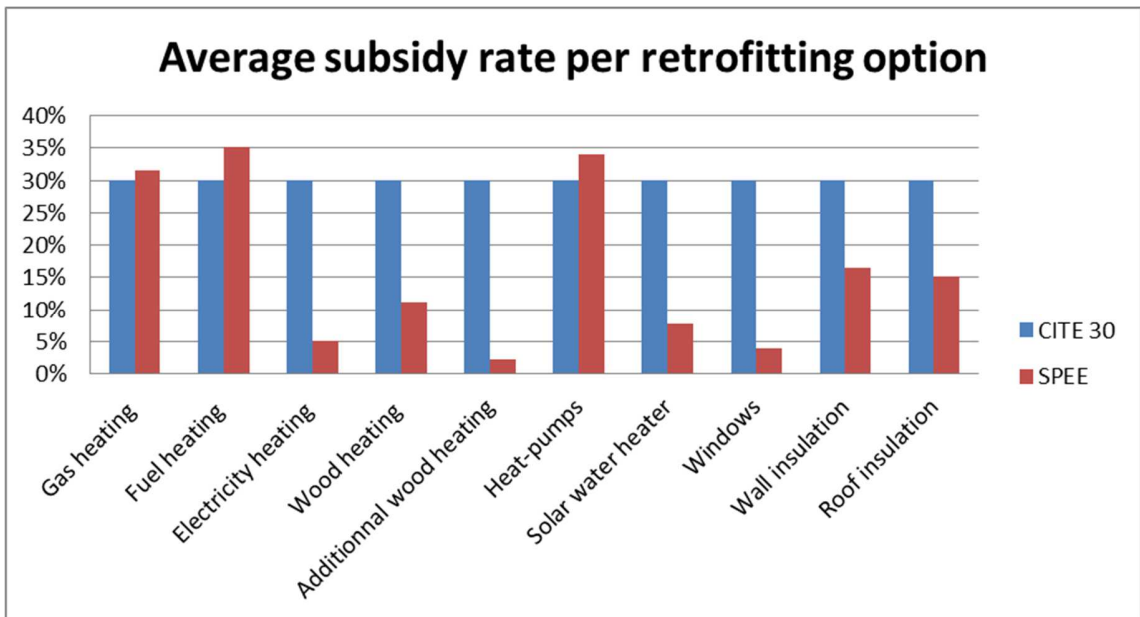


Figure 23 Average subsidy rate in the CITE and SPEE scenarios

Table 24 shows the results comparing the SPEE and the CITE scenarios while fixing annual public costs. Given both the Social NPV and the energy consumption reduction (theoretical or real), the SPEE scenario performs better than the CITE one. However, the total sector turnovers over 2008/2025 are the same in both scenarios (even slightly higher in the CITE scenario). This means that the SPEE subsidy leads to slightly less retrofitting investment but to more cost-effective investment types. This is corroborated by the average “costs/savings ratio” over 2008/2025, which is lower in the SPEE scenario than (49.8 in euros/kWh/m2/year) than in the CITE scenario (56.2) and even compared to the BAU scenario (52.1).

Table 24 CITE and SPEE scenarios results

	BAU 2008	CITE	SPEE
Total over 2008/2025 discounted from 2008:			
Social NPV (billions euros)	94	130	143
CO2 emissions savings (billions euros)	26	37	39
Energy savings (billions euros)	120	176	182
Total over 2008/2025 without discount:			
Subsidy cost (billions euros)	0	30	30
Sector turnover (billions euros)	168	198	197
Average over 2008/2025:			
Cost/savings ratio (euros/kWh/m2/year)	52.1	56.2	49.8
Theoretical average energy consumption per m2 (final energy)			
Reduction rate			
2012 vs 2008	6.0%	9.8%	10.4%
2025 vs 2008	20.3%	28.5%	29.3%
Additional reduction \ BAU 2008			
2012 vs 2008		62.6%	72.8%
2025 vs 2008		40.4%	44.1%
Real average energy consumption per m2 (final energy)			
Reduction rate			
2012 vs 2008	3.2%	5.4%	6.0%
2025 vs 2008	11.4%	16.7%	17.8%
Additional reduction \ BAU 2008			
2012 vs 2008		66.9%	86.8%
2025 vs 2008		46.2%	55.5%

Note: the CO2 emissions savings are valued according to the Quinet report (2008), the energy savings are valued with current tax-excluded energy prices.

Note2 : the sector turnover takes into account "Do it Yourself" retrofits and windows replacement without significant energy efficiency improvement. To be compared to other public costs/benefits, the subsidy cost does not take into account the subsidy cost for windows replacement without significant energy efficiency improvement.

7. Discussion and conclusion

7.1. Results

Regarding inter-policy scenario, the EcoPTZ zero rate loan is the most efficient instrument to foster retrofitting investment while the Carbon tax is the best one to limit the rebound effect. The EcoPTZ loan & Carbon tax combination performs better than other policy packages both in terms of real energy consumption reduction (-39% over 2008/2025) and public budget. The introduction of a subsidy in addition to these two instruments has no impact, except negatively in terms of public cost. Therefore, these results recommend orientating the policy strategy towards the Carbon tax and the EcoPTZ.

The Zero barrier scenario suggests an important energy savings potential locked because of technical (intangible costs) and socioeconomic barriers. Solving these investment barriers leads to higher socially profitable investments (higher Social NPV) as well as higher energy consumption reduction than the foreseen policy package (Reference scenario). It nearly reaches the Social NPV of the best policy package (EcoPTZ + Carbon Tax). These results suggest that investment barriers do matter in terms of energy savings achievements. This can be compared to the results of the sensitivity analysis performed on the Res-IRF model, in which Branger et al. (2015) find little influence of the investment barriers on energy consumption reduction by 2020, especially regarding the socioeconomic barriers embedded in differentiated discount rates. Further comparative works need to be done but a possible explanation could be that the endogeneous calibration process compensates changes in the investment barriers by modifying calibration parameters. In our case for example, the calibration of the logistic function results from the heterogeneity between households' categories both in terms of retrofitting rates and average NPVs. This notably means that assuming lower investment barriers would lead to a steeper slope of the calibrated logistic curve. Such steeper slope then leads to higher response in terms of households' investment to an exogenous increase of the NPV (e.g. due to a policy or to rising energy prices).

These no barriers scenarios provide insights in favor of designing subsidy rates proportional to investment barriers' magnitude, but only when these barriers require public intervention, which has to be discussed. The comparison between the CITE and the SPEE scenarios finally promotes an alternative subsidy design. It shows that a subsidy proportional to the amount of energy savings performs better than a uniform subsidy both in terms of Social NPV and energy consumption reduction. This result recommends to develop subsidy design closer to the ones offered by the French agency ANAH or by the KfW German public investment bank¹⁸⁶ rather than the actual CITE subsidy scheme. Moreover, progressive subsidy design may have other crowding in effects. For example, increasing the subsidy rate in case of global and ambitious retrofitting can encourage the retrofitting market to organize an appropriate offer. Crowding out effects may also be found in case of uniform subsidy scheme. As shown by Houde (2013) in case of labels, in case of constant subsidy rate, firms may not be encouraged to innovate and offer further energy efficiency beyond the subsidy eligibility criteria. However, the gains in terms of Social NPV got in optimizing the subsidy design seem lower than those got changing instruments. Indeed, regarding inter-policy comparison, the **CIDD only** scenario and the **EcoPTZ+** scenario lead to a Social NPV higher than the one in their corresponding **BAU 2008** scenario of respectively 9% and 28%. The social NPV surplus in the **EcoPTZ+** scenario is therefore 3 times higher than the one in the **CIDD only** scenario. Regarding intra-policy comparison, the **CITE** scenario and the **SPEE** scenario lead to a Social NPV higher than the one in their corresponding **BAU 2008** scenario of respectively 38% and 52%. The social NPV surplus in the **SPEE** scenario is therefore only 1.4 times higher than the one in the **CITE** scenario.¹⁸⁷

The retrospective period over 2008/2012 allows us to compare Menfis outputs with diverse statistics. This is one of the main advantages of the detailed level of Menfis' representation. Another advantage is that it allows refining public policy assessment, such as working on the policy design or making modelling distinctions between subsidies and zero rate

¹⁸⁶ Recall that the KfW subsidization program for residential building retrofitting offers a 10% price cut if the retrofitted building reaches 115% of the standard energy needs for new constructions, and a 25% price cut if it meets the Passivhaus standard (Rüdinger 2013). The ANAH subsidization program "Habiter mieux" offers to middle and low-income households a price cut between 35 and 50% when the retrofitting reaches 25% of energy savings (<http://www.anah.fr>).

¹⁸⁷ However, the differences in the assumptions underlying these two scenarios sets prevent a perfect comparison.

loans. Moreover, such detailed representation highlights the importance of correlations between technical and socioeconomic variables (e.g. the fact that households facing more investment barriers live in less energy efficient buildings) and allows us quantifying the energy savings potential unexploited because of the investment barriers. However, more detailed the representation is, more difficult is the understanding of the results, due to all the variables' interactions. This notably explains the need of simplifying assumptions in the 3rd set of scenarios. This drawback is common to all modelling works as soon as we want to address all potential policy issues with one single model, which is what the ADEME needs.

7.2. Limits and extensions

Dwelling stock representation and rebound effect modelling

The difficulties to reproduce the retrofitting distribution among multi-family dwellings call for further works regarding the suitability of the inputs and the calibration regarding these specific building segments. In particular, we have noticed in section 4.1 (and appendix A2) a potential upward bias regarding multi-family dwellings' initial energy performance. This could result from the calibration process using an aggregated statistical relationship between theoretical and real energy consumption (Allibe 2012) on disaggregated building segments. Given the importance of the progressive exhaustion of profitable investment in policy assessment, further works need to be done in the calibration of the initial retrofitting state based on newly available data sources (e.g. Phebus, SOeS, CGDD 2014) or on more refined technological modelling works such as the ANAH/ADEME's Perfologie model.

Endogenizing technologically-specific and long-term drivers

Given the results of chapter 1, drivers specific to the real estate market (e.g. the opportunity created by property transfer or occupancy switch, the perception of the green value) strongly impact the investment dynamics of certain retrofitting options (especially for insulation measures and global retrofitting). Next steps in the development of Menfis could be to integrate such drivers.

Besides, the Model currently focuses on the short-run. In order to forecast residential energy performance and energy consumption on the long-run, we would need to include long-

term determinants such as technological change and learning-by-doing effects in the market. This would notably require introducing new technologies over time and/or make evolve equipment's energy performance as well as retrofitting costs. On the long-run, Menfis would also have to endogenize the entire life cycle (including wear and tear) of the retrofits done after 2008.

8. Appendix

A.1. Supplementary data

A.1.1. External data and inputs

Table 25. CEREN statistics on residential final energy consumption (normal climate, filtered of temperature variations). Note : annual energy consumption is adjusted for climatic variations.

	Energy consumption reduction							
	Heating				Water heating			
	All stock		Existing stock*		All stock		Existing stock*	
	2008/2012	1999/2012	2008/2012	1999/2012	2008/2012	1999/2012	2008/2012	1999/2012
All energy	11%	13%	13%	23%	3%	2%	8%	19%
Electricity	-2%	-22%	4%	4%	-4%	-14%	4%	12%
Gas	11%	0%	13%	11%	7%	-22%	10%	-4%
Fuel	20%	37%	20%	40%	16%	47%	17%	53%
GPL	25%	50%	27%	56%	17%	51%	19%	60%
Coal	6%	64%	6%	64%	6%	69%	6%	70%
Other (wood)	-1%	21%	3%	27%	-4%	1%	0%	9%

(*) built before 1999

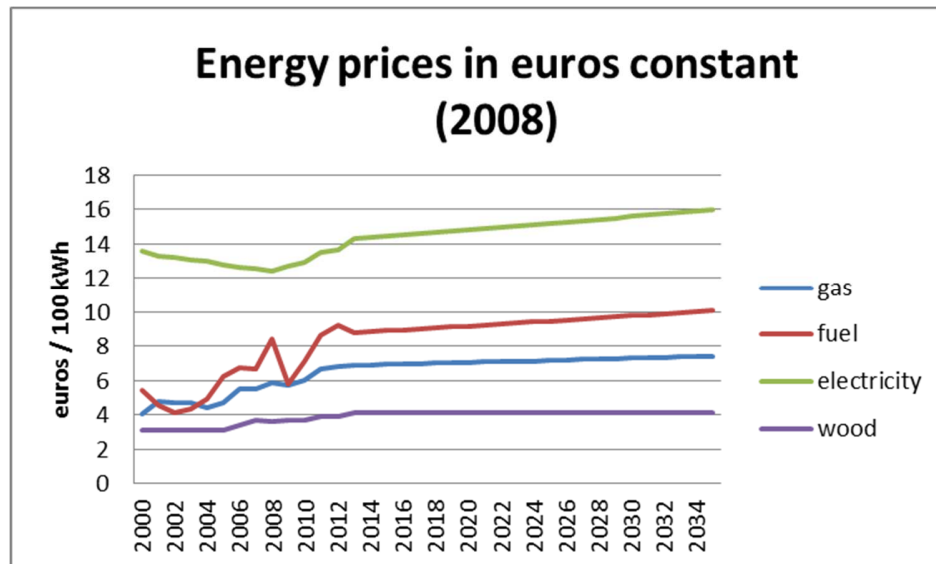


Figure 24. Energy prices

Table 26. Retrofitting input data.

Retrofitting type	main gas heating boiler*	main fuel heating*	panel radiant	heat pump	main wood heating**	additionnal wood stove	solar heater water	windows insulation	roofs insulation	walls insulation	Photovoltaic pannels
Input for energy efficiency renovation:											
Costs for single-family housing	7500	7500	8000	13000	5500	5000	7000	5000	8000	8000	10000
Costs for multi-family housing (in % of single-family housing cost)	0.5	0.5	0.5	1	0.5	Imp.	1	0.9	0.75	0.75	1
Share of labor cost in % of total cost	25%	25%	25%	25%	25%	25%	18%	20%	50%	50%	20%
Theoretical life duration***	15	15	15	15	15	15	15	15	35	35	30
Share of undeclared or DiY works in % of total works.	10%	10%	10%	10%	10%	10%	15%	35%	55%	55%	1%

* weighted mean between low-temperature and condensing boilers, ** weighted mean between wood stove and boilers, *** from Energy Performance certificates worksheets

Table 27. Retrofitting technologies.

Technology for each high-energy performance level per retrofitting option	
Retrofitting type	
Systems	
main gas heating	condensation & low-temperature boiler*
main fuel heating	condensation & low-temperature boiler
main electricity heating	radiant panel system
main wood heating	wood stove & wood boiler energy efficiency >70%**
installation of heat-pump	COP 2.5***
installation of additionnal heating	wood stove****
heat water	solar
renewable energy production	photovoltaic pannels
Building envelope	
windows	U = 1.2
roofs	R = 4.5
walls	R = 3.7

* Averaged by the market shares in 2008

** Averaged by the market shares in 2008. In case of main wood heating, we assume a mix with wood and electricity, with a share of electricity energy consumption of 50% before renovation and 30% after.

*** Heat-pumps air/air (resp. air/water) for dwelling heated by electricity (resp. gas or fioul)) The split between electricity and gaz (or fioul) energy consumption is respectively 80 and 20%.

**** The share of wood energy consumption is 25%, 70% in case of dwelling heated by electricity.

A.1.2. Other results

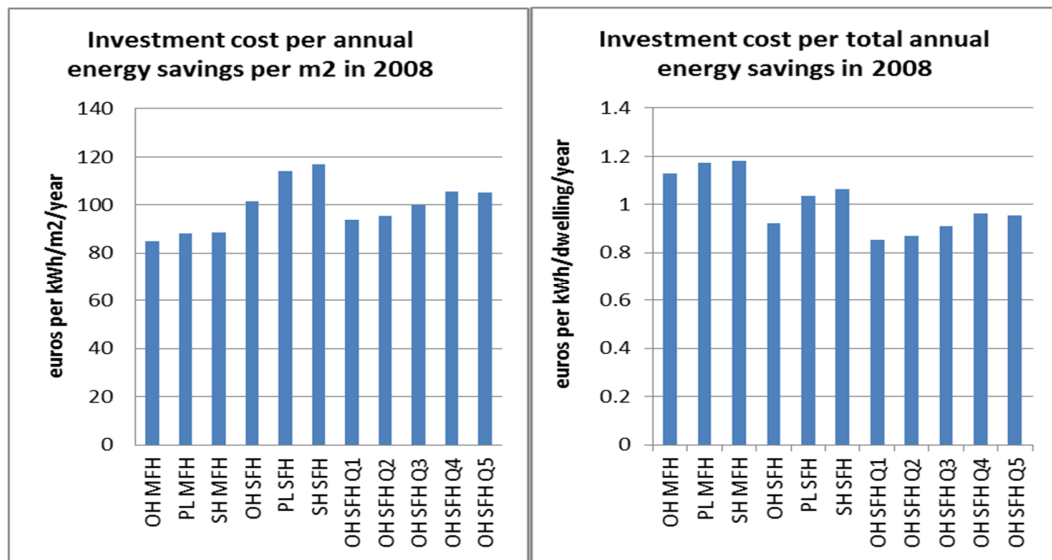


Figure 25. Average “costs/savings ratio” among households’ categories

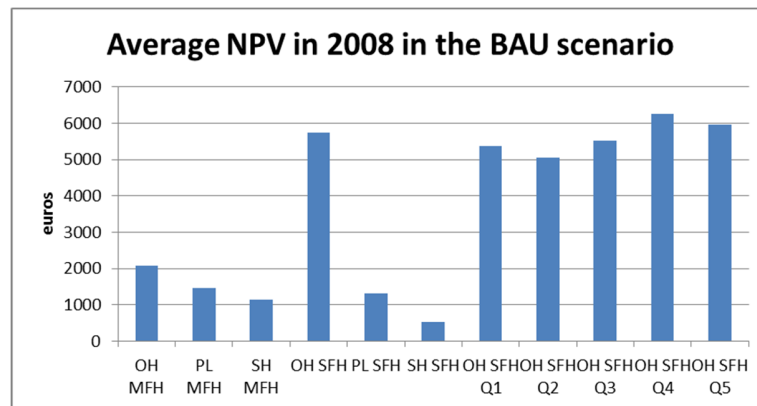


Figure 26. Average NPV among households’ categories

A.2. Initial energy performance calibration

As shown in Figure 27, the calibration method used in Menfis provides an energy performance higher in multi-family housing (MFH) than single-family housing (SFH). The share of EPC A buildings range from 10% to 28% for MFH built after 1949. Even if we can expect that energy performance is structurally higher in MFH, due to the compactness and the proximity of the dwellings for instance, such shares of EPC A is very likely to be overestimated. This may be because the uniform statistical relationship between theoretical energy expenditures and energy use intensity is appropriate in average but not on disaggregated building segment especially when these segments structurally have heterogeneous consumption level. Therefore, we know that Menfis may have an upward bias on MFH's energy performance and that further works need to be done to check this potential bias.

Figure 28 and Figure 29 show the initial retrofitting state per building performance resulting from the calibration process distinguished by respectively building type and energy carriers. It confirms that initial renovation state may be overstated for MFH. However, this does not seem to be highly problematic on the short-run, on which focuses the analysis.

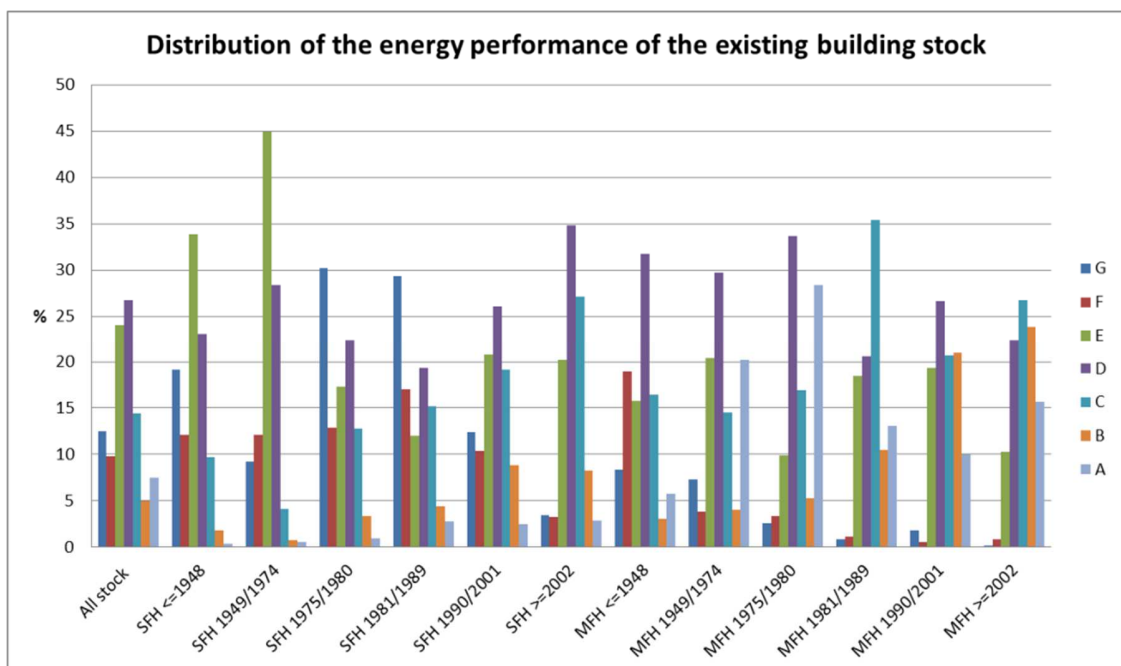


Figure 27. Energy Performance Class distribution of the existing dwelling stock by building type and completion date

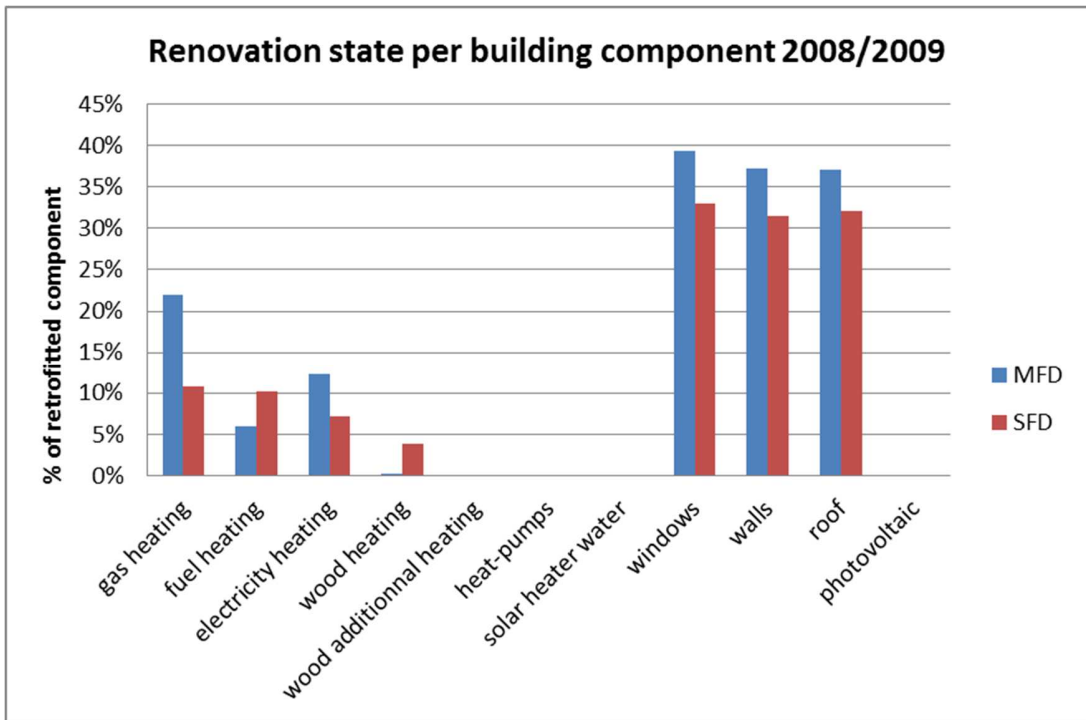


Figure 28. Initial retrofitting state of the existing dwelling stock per dwelling type.

Note: SFH = Single-Family Housing; MFH = Multi-family housing

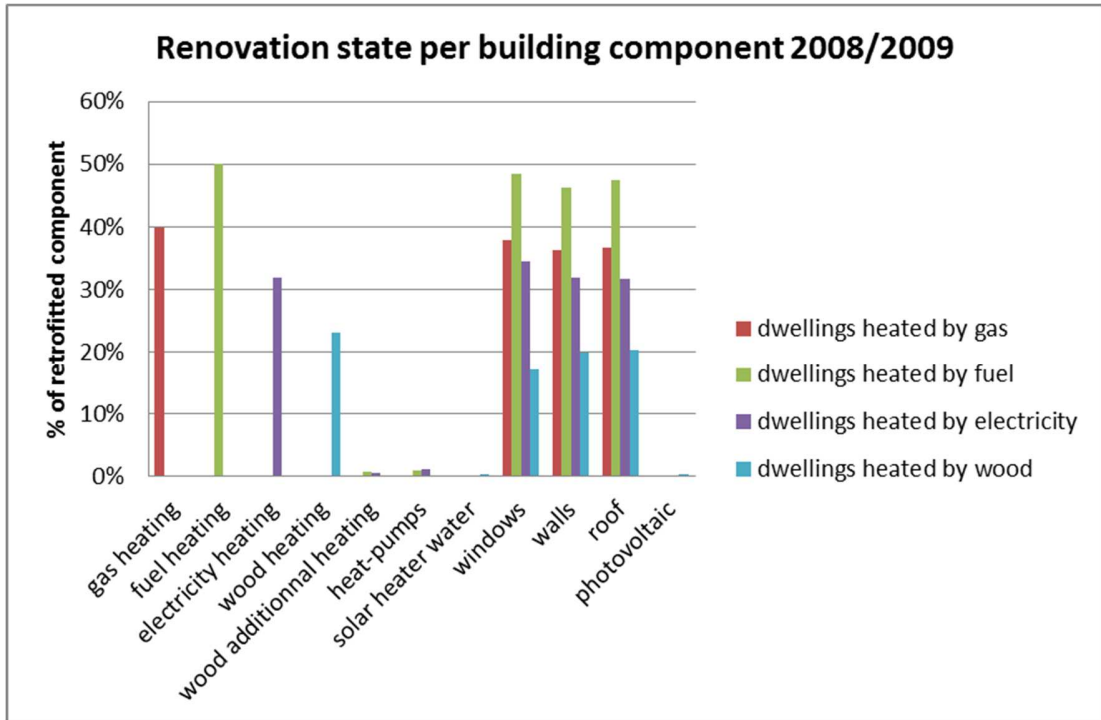


Figure 29. Initial retrofitting state of the existing dwelling stock per energy carriers

A.3. Decay, demolitions and new constructions

NB: Although decay, demolitions and new construction are exogenously represented in Menfis as explained below, we ignore them in this chapter which focuses on the retrofitting process.

Decay

For heating systems and windows, since their retrofitting are mainly driven by the wear and tear of existing equipment (see Chapter 1),¹⁸⁸ we exogenously assume that a share of each segment, which is equal to the inverse of the statistical life duration of the system,¹⁸⁹ replace

¹⁸⁸ We assume that such approach is not valid for building envelope insulation measures as wear and tear does not seem a major determinant and as we do not have proper statistics to observe it.

¹⁸⁹ We make a distinction between the “theoretical life duration”, which is the life duration taken into account in economic and engineering calculations (in the French energy performance certificate worksheets¹⁸⁹ for example) and the “statistical life duration”, which come from statistics on the actual replacement rate for each building component. Theoretical and observed life durations for each component are respectively taken from the French

their systems and windows each year. The difference between these exogenous replacement rates and the endogenous energy efficiency investment rate gives the implicit annual retrofitting rate for maintenance/repair works, i.e. retrofitting without significant improvement in energy efficiency. This implicit representation of non-energy efficiency retrofitting does not change anything in terms of energy consumption outputs.

Demolitions and new constructions

Demolition rates are exogenous percentage specific to each Energy Performance certificate (EPC).¹⁹⁰ New constructions take into account increasing demand for building stock. Each year, demand for building stock depends on the existing building stock (the one of last year minus the destructions), the population growth and the decreasing trend in the number of persons per dwelling, modeled as in Res-IRF (Giraudet 2011). Demographic forecast comes from INSEE¹⁹¹. Successive thermal regulations¹⁹² give us the EPC of new constructions. Ruled so far by Building Code 2005, new constructions have to conform to EPC C between 2008 and 2012 and to Low Energy level in 2013 (50 kWh/m²/y of primary energy for heating, cooling, hot water and ventilation). In addition, the “Grenelle de l'Environnement” aims at reaching a Zero Energy level for new building in 2020.

A.4. EM survey¹⁹³

Every year, around 10 000 households are asked about their residential energy consumption and the investments they have or not made, in order to improve the energy efficiency of their dwelling. A first questionnaire provides socio-economic variables, housing information (type of building, heating energy source, building date, etc.), and information about dweller's situation (occupation status, move-in date).

energy performance certificate worksheets (<http://www.developpement-durable.gouv.fr/1-le-secteur-du-batiment.html>) and from Allibe's study (Allibe 2012 p226).

¹⁹⁰ 0.1% each year for EPC E, 0.2% the EPC F and 0.34% for ECP G.

¹⁹¹ <http://www.insee.fr/fr/ffc/ipweb/ip1320/ip1320.pdf>

¹⁹² Building code regulations have been applied to new residential buildings in France since 1975 (Martin et al. 1998).

¹⁹³ See Appendix in Chapter 1 for more information on the survey.

Those who have invested in retrofitting during the last year (around 10% each year) answer a second questionnaire to provide information on retrofitting types, investment costs, some payment modalities, the economic or non-economic incentives investors have benefited from (including tax credit), as well as other qualitative information such as their motivation, personal context, satisfaction, etc. In this second questionnaire, each investment is described by 1 to 4 items taken from a retrofitting options list. Retrofitting options include insulation (external insulation of wall, internal insulation of wall, roof, attic, ceiling, windows, shutters), heating system improvement (thermostatic valves, heat cost allocators, ambient thermostat, programming equipment), new heating system (radiator, boiler, wood stove, heat-pump, solar heater) or heating system replacement (with information on fuel switching).

A.5. Discussion on discount rate estimation

As well explained in (Cohen et al. 2014), “following the work of Hausman (1979) on room air conditioners, many researchers have found implicit discount rates that are substantially larger than real financial discount rates. In the case of electric appliances, rates reported for refrigerators range from 39% to 300% (Revelt and Train, 1998; Hwang et al., 1994; McRae, 1985; Meier and Whittier, 1983; Gately, 1980; Cole and Fuller, 1980); for air conditioners between 19% to 77% (Matsumoto, 2012; Train and Atherton, 1995; Hausman, 1979; Kooreman, 1995); and for water heaters between 67% and 84% (Hwang et al., 1994; Goett and McFadden, 1982).”

Cohen et al. explain how econometric and data problems can bias upwards discount rate estimates. Using product-level panel data from 2002 to 2007 on the UK refrigerator market over, they find a lower discount rate of 10.5%.

Moreover and especially in the case of retrofitting investment, implicit discount rate estimation integrates all investment determinants influencing the weighting of upfront costs relatively to the streams of future benefits which are not included (observable) in the econometric model. Such determinants include time preferences (as always in discount rates) but also myopic anticipation and all investment barriers such as the collective decision making process, split incentives between tenants and landlords, etc. This is why that in ResIRF for example, discount rates integrate investment barriers such specific to renters and collective dwellings. In the absence of such barriers, i.e. for occupying homeowners of individual dwellings, private discount rate are set equal to 7%, and others are fixed in order to get an average discount rate on the whole population of 21%, i.e. the main estimation reviewed by Train (1985): 12% for occupying homeowners of collective dwellings, 11% for private landlords in individual dwellings, 32% for private landlords in collective dwellings (Giraudet 2011).

In Menfis, these investment barriers are extracted from the discount rate and explicitly modelled in the utility. Therefore, our discount rates have only to reflect investment barriers related to income in addition to classical discount rate components (preference for the present, financial interest rate etc.) , and induced by lower energy consumption.

Jaccard & Dennis (2006) provide rather appropriate discount rate estimates for the Menfis model. They conduct a choice experiment survey only on occupying homeowner of a single family dwellings and find implicit discount rates of 20.8% for opaque surfaces insulation measures and 9% for heating systems installation. As insulation measures bear intangible costs which are also explicitly modelled in Menfis, we prefer to refer to the estimation on 9%, similar to Cohen et al. estimates.

Therefore, discount rate values in the reference case in Menfis are quite low compared to recent literature, whereas discount rate values in the sensitivity analysis are closer to the literature.

A.6. Sensitivity analysis

Table 28 shows the same results of the different policy scenarios as in Table 23 (energy consumption, CO₂ emissions reduction as well as economic aggregates) but with discount rate twice as high as in the main results presented in section 6. Results in Table 23 are based on a loan interest rate of 4%, a capital return interest rate of 2.5% and income parameters as in Table 20. In the “high discount rate” case of Table 28, we get an average discount rates of 10%, (13% for the 1st two quintiles, 10% for the 3rd one, 8% for the 4th one, 6% for the 5th one), corresponding to empirical estimates found in the recent literature (see appendix A5). Recall that the initial choice of the discount rate values is justified by the fact that we extract the main investment barriers from the discount rate (see section 4.2 and appendix A5). Note that the calibration is renewed accordingly to the new levels of discount rate.

Due to the recalibration, theoretical and real energy consumption reductions as well as Social NPV are similar in the **BAU 2008** and the **Reference** scenarios in both tables, i.e. whatever the discount rate level. However, regarding the Social NPV, the superiority of the scenarios including **EcoPTZ+** and of the **No Income Barrier** scenario increases in the “high discount rate” case compared to the “low discount rate” case. The EcoPTZ zero rate loan even performs better in terms of real energy consumption reduction (36% over 2008/2025) than the carbon tax (34%), which was not the case in the “low discount rate” case. This gain in efficiency for the EcoPTZ is directly due to the fact that the EcoPTZ sets to zero the loan interest rate, i.e. a component of the discount rate (section 3.4.1). Its effect is stronger for higher discount rate values. Regarding the **No Income Barrier** scenario, it also directly comes from the way investment barriers related to income are endogenized in the microeconomic decision (lower income households face higher discount rates).

Finally, note that additional energy consumption or CO₂ emissions reductions compared to the BAU 2008 scenario are higher in the increases in the “high discount rate” case than in the “low discount rate” case. It may be due to the fact that in the BAU 2008 scenario, the only driver of retrofitting investment and rebound effect limitation is the rise in energy prices. This “rising energy prices” driver is minimized when the discount rate increases.

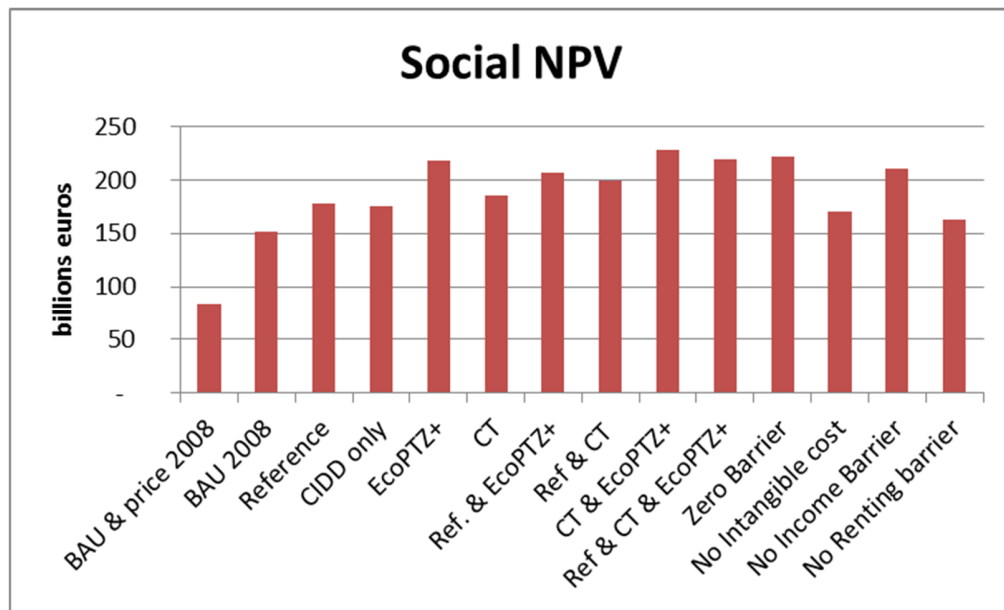


Figure 30. Social NPV in the high discount rate case.

Table 28. 1st and 2nd sets scenarios results (high discount rate case)

	BAU & price 2008	BAU 2008	Reference	CIDD only	EcoPTZ+	CT	Ref. & EcoPTZ+	Ref & CT	CT & EcoPTZ+	Ref & CT & EcoPTZ+	Zero Barrier	No Intangible cost	No Income Barrier	No Renting barrier
Total over 2008/2025 discounted from 2008														
Social NPV (billions euros)	83	152	178	175	218	185	207	200	228	220	222	170	211	163
CO2 emissions savings (billions euros)	23	40	50	49	69	52	65	59	77	73	69	47	60	44
Energy savings (billions euros)	117	208	264	259	364	269	345	306	401	383	411	249	341	231
Total over 2008/2025 without discount:														
Subsidy cost (billions euros)	-	-	20	19	8	8	30	25	8	35	-	-	-	-
EcoPTZ cost (billions euros)	-	-	2	1	23	1	17	2	28	20	-	-	-	-
Tax carbon benefit (billions euros)	-	-	-	-	-	24	-	23	19	20	-	-	-	-
Sector turnover (billions euros)	154	194	226	222	305	229	291	255	339	325	341	224	275	208
Theoretical average energy consumption per m2 (final energy)														
Reduction rate														
2012 vs 2008	7%	10%	14%	14%	14%	14%	14%	14%	14%	14%	26%	13%	20%	12%
2025 vs 2008	17%	28%	33%	33%	45%	34%	44%	39%	49%	48%	46%	32%	40%	31%
Additional reduction \ BAU 2008														
2012 vs 2008			36%	36%	36%	36%	36%	36%	36%	36%	155%	28%	100%	16%
2025 vs 2008			19%	17%	62%	23%	56%	41%	77%	72%	66%	16%	44%	11%
Real average energy consumption per m2 (final energy)														
Reduction rate														
2012 vs 2008	4%	10%	12%	12%	12%	12%	12%	12%	12%	12%	19%	12%	16%	11%
2025 vs 2008	10%	26%	29%	28%	36%	34%	35%	36%	42%	41%	36%	28%	33%	27%
Additional reduction \ BAU 2008														
2012 vs 2008			20%	20%	20%	20%	20%	20%	20%	20%	85%	15%	55%	8%
2025 vs 2008			11%	10%	38%	30%	34%	40%	62%	59%	39%	9%	27%	6%
Theoretical average CO2 emission per m2														
Reduction rate														
2012 vs 2008	8%	13%	17%	17%	17%	17%	17%	17%	17%	17%	29%	16%	24%	14%
2025 vs 2008	20%	32%	38%	37%	50%	39%	49%	45%	55%	54%	52%	37%	45%	35%
Additional reduction \ BAU 2008														
2012 vs 2008			32%	32%	32%	32%	32%	32%	32%	32%	134%	25%	87%	14%
2025 vs 2008			18%	16%	57%	23%	52%	40%	73%	68%	62%	15%	41%	9%

Note: the CO2 emissions savings are valued according to the Quinet report (2008), the energy savings are valued with current tax-excluded energy prices.

Note2 : the sector turnover takes into account "Do it Yourself" retrofits and windows replacement without significant energy efficiency improvement. To be compared to other public costs/benefits, the subsidy cost does not take into account the subsidy cost for windows replacement without significant energy efficiency improvement.

A.7. L'historique de Menfis

Version 0

La première version de Menfis date de 2012. Elle fut utilisée pour évaluer l'efficacité des politiques publiques telles que le Crédit d'Impôt Développement Durable et le prêt à taux zéro EcoPTZ ainsi que leur modalité de mise en œuvre comme par exemple l'efficacité d'un cumul ou non de ces deux instruments (réforme Pelletier). Cette version segmente le parc de logement en 63 éléments (appelé segment): 7 classes correspondant au DPE (A - ... -G), 3 vecteurs énergétiques (Elec - Gaz et chauffage urbain - Fioul/GPL/Charbon), 2 types d'habitation (maison individuelle - logement collectif). Les travaux de rénovation énergétique sont représentés par des travaux types (bouquet de travaux ou travaux unitaires) pour chaque saut de classe et chaque segment de logements. Les économies d'énergie étaient calculées pour chacun de ces travaux pour un logement type sur type de logement (chacune des 6 combinaisons vecteurs énergétiques * types d'habitation). Au sein de chaque segment du parc, tous les travaux pour lesquels la VAN est négative sont distribués par leur temps de retour sur investissement désiré selon une loi normale paramétrée de façon à reproduire les observations 2008 (montants de travaux, montants de CIDD, nombre de travaux). Des paramètres exogènes « ad hoc » représentent certaines barrières à l'investissement (ex : prise de décision collective). Cette version ne permet pas de changer de vecteur énergétique de chauffage et ne distinguaient pas entre consommation théorique et réelle. Enfin, Menfis V0 est sous excel.

Evolutions du modèle jusqu'à la version actuelle (développement dans le cadre de la thèse).

Le modèle est d'abord codé sous scilab afin de permettre plus facilement son développement. La représentation du parc de logements et des ménages est affinée à partir des données ENL 2006 / CEREN (cf section 3.1.). Les travaux ne sont plus préalablement définis mais l'ensemble des alternatives possibles de travaux comprenant une ou deux mesures de rénovations (cf 3.2.) est représentée. Un module thermique est introduit dans le modèle, à partir d'une simplification de la méthode 3CL, permettant le calcul des économies d'énergie pour chaque type de travaux sur chaque segment du parc et non plus sur les 6 logements types ci-dessus. Les critères du choix sont modifiés, afin notamment de microfonder la modélisation

de la décision d'investissement et d'endogénéiser les barrières à l'investissement. L'effet rebond est introduit. La calibration du modèle repose sur un ensemble plus grand de statistique, la courbe de calibrage étant elle-même optimisée sur des statistiques de rénovation prenant en compte l'hétérogénéité des barrières à l'investissement. Ce travail de développement s'est fait par étape, le working paper intitulé « MENFIS, an energy-economy model to assess energy savings policies in the French residential sector » et présenté à la conférence IAEE à Venise en septembre 2012 en présente notamment une version intermédiaire.

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Chapter 4 Energy efficiency policy with price-quality discrimination

Preliminary remark:

This chapter is derived from an article written with Louis-Gaëtan Giraudet¹⁹⁴ and Philippe Quirion¹⁹⁵ submitted for publication in a special issue of *Energy Economics*.

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Abstract

We compare a range of energy efficiency policies in a durable good market subject to both energy-use externalities and price-quality discrimination by a monopolist. We find that the social optimum can be achieved with differentiated subsidies. With ad valorem subsidies, the subsidization of the high-end good leads the monopolist to cut the quality of the low-end good. The rates should always be decreasing in energy efficiency. With per-quality subsidies, there is no such interference and the rates can be increasing if the externality is large enough relative to the market share of low-type consumers. Stand-alone instruments only achieve second-best outcomes. A minimum quality standard may be set at the high-end of the product line if consumers are not too dissimilar, otherwise it should only target the low-end good. An energy tax should be set above the marginal external cost. Likewise, a uniform ad valorem subsidy should be set above the subsidy that would be needed to specifically internalize energy-use externalities. Lastly, if, as is often observed in practice, only the high-end good is to be incentivized, a per-quality schedule should be preferred over an ad valorem one. An ad valorem tax on the high-end good may even be preferred over an ad valorem subsidy if the externality is small enough and low-end consumers dominate the market.

Keywords: energy efficiency, price-quality discrimination, imperfect discrimination, vertical differentiation, ad valorem subsidy, subsidy, standard

JEL codes: H23, Q48, Q54

1. Introduction

Energy efficiency has become a popular theme in the policy arena. The enthusiasm is sustained by engineering studies (for instance Mc Kinsey & Co.(2009), to name only the most impactful) claiming that energy efficiency is the most cost-effective way to save energy, hence internalize the multiple externalities associated with energy use. Such externalities include carbon dioxide emissions at the source of the climate change problem, local pollution, risks related to nuclear energy and national concerns about the security of energy supply. They motivate implementation of numerous energy efficiency standards, labels and subsidies across the world.¹⁹⁶

These policies are commonly devised in highly concentrated market environments. In the US, Fischer (2005) documents high concentration levels in appliance manufacturing, as measured by Herfindhal-Hirschman indexes (HHI) and the market shares of the top four firms, which systematically exceed 50%. In France, HHI indexes are also substantially higher in the appliance and energy retrofit industries than in other industries (Carbonnier 2008). The French Anti-trust authority has pointed to high levels of concentration in the heating, air conditioning and hot water industries, both at the manufacturing and retail levels, raising suspicion over collusive practices (Conseil de la Concurrence 2006).¹⁹⁷

Such an imperfect competition context is conducive to price-quality discrimination. The problem, first studied by Mussa and Rosen (1978), goes as follows. A dominant firm facing consumers with heterogeneous tastes for quality can find it optimal to restrict the provision of quality at the low-end of the product line while at the same time increasing the price charged for high-end products. As shown by Fischer (2005), this general economic problem can provide a

¹⁹⁶Just for the EU, 550 energy efficiency policies are referenced in the MURE database (<http://www.measures-odyssee-mure.eu/>)

¹⁹⁷The five largest firms have a 59% market share in the floor boilers sector, the three largest firms have a 80% market share in the mural boilers sector and the four largest firms have a 90% market share in the electric heating systems sector.

supply-side explanation as to why energy efficiency levels are too low in the economy, a phenomenon known as the energy efficiency gap (Jaffe & Stavins 1994).¹⁹⁸

Recent studies find empirical evidence that appliance industries actually do discriminate among consumers along the price and energy efficiency dimensions. Houde (2013) deals with the U.S. ENERGY STAR program implementing a voluntary certification for energy efficient products in addition to less stringent federal minimum energy efficiency standards. First using transaction data¹⁹⁹ from a large number of appliance retailers, he exploits revisions in the certification requirements between 2005 and 2011 to show that firms use the certification to extract part of the consumer surplus associated with the high willingness to pay for the Energy Star label²⁰⁰ by price discriminating. Firms offer products that bunch at the minimum standard and, for those just meeting the ENERGY STAR standard, they charge a price premium. Second estimating a structural econometric model of price quality discrimination with data on the US refrigerator market for the year 2008,²⁰¹ Houde simulates the market with and without the certification. Accounting for the changes in externality costs, consumer surplus, and profits, the welfare gains due to the certification is estimated at \$102 per refrigerator sold, the majority being firms' profit (\$98, corresponding to 7.4% of the average price with the certification). Changes in consumer surplus are insignificant. Regarding energy savings, the average electricity consumption of a purchased refrigerator increases by about 10% by removing the certification. He shows that the certification affects all prices. It is the heterogeneity in the consumers' valuation of the label that allows firms to screen consumers in the energy efficiency dimension and extract consumer surplus from all consumers, even the ones that do not value the certification. Without certification, firms still distort energy efficiency levels to extract rents from consumers albeit to a lesser extent. Focusing on clothes washers, Spurlock (2014) also

¹⁹⁸ This is one of the few supply-side explanations. The existing literature on the energy efficiency gap tends to focus more on demand-side explanations. For comprehensive reviews, see Sorrell (2004), Gillingham et al. (2009), Allcott & Greenstone (2012).

¹⁹⁹ Monthly national sales, monthly average prices, main appliance attributes for refrigerators, air conditioners, clothes washers, and dishwashers.

²⁰⁰ Specifically studied in another empirical paper (Houde 2014).

²⁰¹ Data include for each transaction the refrigerator model, the price and taxes paid, attribute information, the location of the store, demographic information in addition to external data for electricity prices and rebates.

studies the U.S. ENERGY STAR standards. Using changes in the program in 2004 and 2007, she shows how purchase price drops when standard stringency increases. The largest drop is for mid-low efficient products, which is a consistent pattern of price quality discrimination. In the UK, Cohen et al. (2014) finally study how producers in the refrigerator market respond to energy price increases. Due to imperfect competition, they decrease the purchase price to compensate higher cost of use. Due to product differentiation, firms react asymmetrically reducing relatively more the price of high energy-consuming products in order to limit demand shifts from energy consuming to energy efficient appliances.

Against this background, we are interested in the following question: How do various policy instruments compare in a market for energy efficiency subject to both energy-use externalities and price-quality discrimination? From a normative perspective, after the Tinbergen rule, the existence of two market failures calls for a combination of two policy instruments (Tinbergen 1952). Interestingly, the tools usually warranted to internalize energy-use externalities, namely energy taxes, energy efficiency subsidies and standards, can in some ways also be used to address market power. How market failure interference change the design and merit order of these instruments is an open question. From a positive perspective, it is also questionable how second-best policy can be designed when, due to political constraints, only one instrument can be implemented.

Partial answers to the question can be found in the literature. A first set of papers focuses on the instruments specifically needed to address price-quality discrimination, without consideration for energy-use externalities. Following Mussa and Rosen (1978), Besanko et al. (1988) show in a monopoly setting that the deadweight loss can be eliminated by ad valorem subsidies, the rate of which should be decreasing in the quality of the product. Fischer (2005) studies the same problem in a more specific energy efficiency context and pays specific attention to various forms of quality standards. In a subsequent paper, the author extends her analysis to a Bertrand price and quality competition framework (Fischer, 2011). Another set of papers, in line with Cremer and Thisse (1994), discuss instrument combinations in an oligopoly setting where price-quality discrimination coexists with energy-use externalities. Lombardini-Riipinen (2005) finds that the social optimum can be achieved by a combination of a uniform

ad valorem tax on the durable good coupled with either an emission tax or a subsidy proportional to the environmental quality of the good. Bansal (2008) studies second-best policy and finds that the second-best ad valorem incentive should be a subsidy if environmental damages are high, and a tax otherwise.²⁰²

In this paper, we compare a wide range of first-best and second-best energy efficiency policies. We integrate in a unified framework energy efficiency subsidies, minimum efficiency standards and energy taxes. We build on the model of Fischer (2005), which features a monopoly and two consumer types with fixed market shares.²⁰³

Our main contribution is to pay specific attention to a variety of subsidy designs. Indeed, little is known about the properties of energy efficiency subsidies in an imperfect competition context.²⁰⁴ This is at odds with the importance of the instrument in practice, perhaps the most widespread of all energy efficiency policies. For instance in France, a tax credit has been implemented in 2005 in the residential building sector. The program can be seen as a differentiated ad valorem subsidy. The subsidy rates, frequently updated, were initially increasing in energy efficiency. Until recently, the subsidy rate was 15% of the price for low-temperature boilers and 25% for more efficient condensing boilers, while the least-efficient boilers were not eligible (see chapter 2 or Nauleau 2014). Since 2014, only the best available technologies are eligible to a 30% subsidy rate. This can be seen as an ad valorem subsidy restricted to high-end goods. In parallel, since 2014, all building energy efficiency measures are eligible to a reduced VAT rate, irrespective of the energy efficiency level achieved. This program can be seen as a uniform ad valorem subsidy.

²⁰² Product differentiation has different causes in monopoly and oligopoly settings (Champsaur & Rochet 1986). In an oligopoly structure *à la* Cremer and Thisse, it results from quality-specific fixed costs which compel firms to specialize into one single quality. In Mussa and Rosen's monopoly model, there are no such fixed costs and product differentiation only results from a strategy consisting in creating variety to discriminate.

²⁰³ We do not analyse energy efficiency labels because they are usually warranted to address information asymmetries (not considered here) rather than energy-use externalities. For an analysis of energy efficiency labels in an imperfect competition context, see Houde (2013) and Spurlock (2013). The authors model labels by supposing that information provision change the preferences over energy efficiency for a fringe of consumers.

²⁰⁴ The existing literature on energy efficiency subsidies is mostly empirical and concerned with estimating the effectiveness of and windfall gains from subsidies (see chapter 2, or to quote a few of them : Hassett & Metcalf 1995, Grösche & Vance 2009, Boomhower & Davis 2014). The few existing theoretical works assume perfect competition (Giraudet & Quirion 2008).

We find that in an economy subject to both energy-use externalities and price-quality discrimination, the social optimum can be achieved with differentiated subsidies. With ad valorem subsidies, the subsidization of the high-end good leads the monopolist to cut the quality of the low-end good. The rates should always be decreasing in energy efficiency. With per-quality subsidies, there is no such interference and the rates can be increasing if the externality is large enough relative to the market share of low-type consumers. Stand-alone instruments only achieve second-best outcomes. A minimum quality standard may be set at the high-end of the product line if consumers are not too dissimilar, otherwise it should only target the low-end good. An energy tax should be set above the marginal external cost. Likewise, a uniform ad valorem subsidy should be set above the subsidy that would be needed to specifically internalize energy-use externalities. Lastly, if, as is often observed in practice, only the high-end good is to be incentivized, a per-quality schedule should be preferred over an ad valorem one. An ad valorem tax on the high-end good may even be preferred over an ad valorem subsidy if the externality is small enough and low-end consumers dominate the market.

The paper is organized as follows. Section 2 introduces the model and the different market environments. Section 3 discusses first-best policy interventions, focusing on ad valorem and per-quality subsidies with differentiated rates. Section 4 discusses second-best policy interventions, involving minimum quality standards, energy taxes and various single-instrument subsidies. Section 5 concludes.

2. Set-up

Model notations are outlined in Table 29, equilibrium notations are outlined in Table 30 and illustrative equilibrium outcomes are summarized in Figure 1.

2.1. Consumer demand for energy efficiency

We build on the model of Fischer (2005). Consumers purchase durable goods which, combined with energy, provide energy services such as light and heat. The durable goods considered here can be appliances, light bulbs, heating systems, improvements to building

envelopes (wall insulation, double glazing windows), vehicles, etc. The goods are characterized by their energy intensity $\phi_j > 0$, bounded from above by Φ , the energy intensity that would be chosen if energy were costless. Energy intensity is the energy use per unit of energy service, hence the inverse of energy efficiency. Energy efficiency is the only dimension of quality in the model (that is, quality is negatively correlated with energy intensity).²⁰⁵ We abstract from ancillary attributes of the goods, such as noise for appliances, aesthetics for light bulbs or safety for cars. There are two levels of energy efficiency, high (h) and low (l), with $0 < \phi_h < \phi_l < \Phi$.

For consumer i , the net surplus of purchasing and using good j is

$$CS_{ij} \equiv \beta_i(v - g \phi_j) - p_j \quad (1)$$

$v > 0$ is the annual gross utility of the energy service. It is produced with a combination of energy, purchased at a constant price $g > 0$, and the durable good j , purchased at price $p_j > 0$.

We assume heterogeneity across the population in the valuation of energy services. This is reflected by parameter β_i , the cumulative discount factor for the net utility flow over the lifetime of the durable good. Heterogeneity stems from either preferences or financial constraints. It materializes through differences across consumers in their willingness to invest in energy efficiency and their frequency of utilization of the goods after investment. For instance, a homeowner sensitive to the cold will be likely to upgrade her heating system and set her thermostat at a high temperature. Both margins are in fact identified into β_i .²⁰⁶ For simplicity, we assume that consumers are of two types, high (h) and low (l), with $\beta_h > \beta_l$.

²⁰⁵ Plourde and Bardis (1999) study the opposite model in which quality is positively correlated with energy intensity. This is supposed to mimic the fact that for safety reasons, consumers may have a higher preference for large, inefficient cars than for small, efficient cars. Unsurprisingly, they find opposite results to those of Fischer (2005).

²⁰⁶ As discussed by Fischer, the willingness to invest v_i and the discounted frequency of utilization u_i could be determined endogenously through the following net utility: $v_i(u_i) - u_i g \phi_j - p_j$. Yet thanks to the Envelope theorem, the impact of small changes of u_i on utility would be second-order compared to those of ϕ_j . As we are primarily interested here in how firms set ϕ_j , we follow Fischer and keep utilization exogenous through β_i . For a model with endogenous frequency of utilization, see Giraudet and Houde (2014).

The two types of consumers cover the market in fixed proportions n_h and n_l , with $n_h + n_l = 1$. Through this assumption, we confine our attention to the intensive margin of investment in durable goods. Therefore, our model is more relevant to capital maintenance investment (e.g. replacement of broken appliances or light bulbs) than to capital enhancement investment (e.g. improvements to the building envelope).

2.2. The firm

Energy efficiency is supplied at a convex increasing cost. In other words, the cost of energy intensity $c(\phi_j)$ is decreasing: $c' < 0$ and $c'' > 0$. We assume that $-c'(\Phi) < g\beta_l$, which guarantees separating equilibria with interior solutions.²⁰⁷

We assume that the firm supplying the durable good is a monopolist. This is admittedly an extreme case of imperfect competition. However, qualitative insights would be similar in a more general (though less tractable) oligopoly setting, as the two approaches of Fischer (2005, 2011) illustrate.

Table 29. Model notations

Variable	Definition	Illustrative unit
p_h, p_l	Price of durable good	€ per durable good
v	Gross utility of energy service	€ per unit of energy service
Φ, ϕ_h, ϕ_l	Energy intensity (inverse of energy efficiency)	kWh per unit of energy service
g	Energy price	€ per kWh
γ	External cost	€ per kWh
β_h, β_l	Flow of energy service, discounted over the lifetime of the durable good	Discounted years
n_h, n_l	Share of consumers of each type	Percentage
$(n_h + n_l = 1)$		

²⁰⁷ If $g\beta_l \leq -c'(\Phi) < g\beta_h$ then in the equilibria studied hereafter ϕ_h will be interior and ϕ_l will be a corner solution. If $-c'(\Phi) \geq g\beta_h$ there will be a pooling equilibrium with two corner solutions.

Table 30. Equilibrium notations

	Superscript	Associated equilibrium
	*	Social optimum
Market structures	M	Monopoly equilibrium
	E	Competitive equilibrium with energy-use externalities
	ME	Laissez-faire equilibrium (monopoly + energy-use externalities)
First-best policies	AA	Differentiated ad valorem subsidy
	PP	Differentiated per-quality subsidy
Second-best policies	S	Minimum quality standard
	T	Energy tax
	A	Uniform ad valorem subsidy
	P	Uniform per-quality subsidy
	H	Ad valorem subsidy restricted to good h
	Q	Per-quality subsidy restricted to good h

2.3. Social optimum

Let $\gamma \geq 0$ be the constant marginal external cost of energy use. This may include environmental pollution or energy security concerns. A benevolent social planner would maximize total surplus TS, defined as the difference between the gross consumer surplus and the three types of costs: the energy cost, the external cost and the production cost of the durable good.

$$\text{Maximize}_{\phi_h, \phi_l} \text{TS} = n_h(\beta_h(v - (g + \gamma)\phi_h) - c(\phi_h)) + n_l(\beta_l(v - (g + \gamma)\phi_l) - c(\phi_l))$$

The first-order conditions for total surplus maximization are (equilibrium outcomes are denoted with superscript *):

$$\forall i \quad \frac{\partial \text{TS}}{\partial \phi_i} = 0 \Leftrightarrow -c'(\phi_i^*) = \beta_i(g + \gamma) \Leftrightarrow \phi_i^* = -c'^{-1}(\beta_i(g + \gamma)) \quad (2)$$

The social planner would separate the two markets and allocate good i to consumer i . Optimal energy efficiency levels would be set so that marginal production costs equate the discounted social value of energy savings to the targeted consumer.

If energy-use are not internalized, energy efficiency levels are set at lower values (denoted with superscript E): $\forall i \quad \phi_i^E = -c'^{-1}(\beta_i g) > \phi_i^*$.

2.4. Monopoly

To isolate the discrimination problem from energy-use externalities, we first suppose that the latter are internalized. Consumers thus face social energy cost $g + \gamma$ and enjoy surplus $CS_{ij}^* \equiv \beta_i(v - (g + \gamma)\phi_j) - p_j$. In Section 2.5, we will study how the two market failures interfere.

2.4.1. Perfectly discriminating monopolist

A perfectly discriminating monopolist would maximize the following profit function:

$$\text{Maximize}_{\phi_h, \phi_l, p_h, p_l} \pi = n_h(p_h - c(\phi_h)) + n_l(p_l - c(\phi_h))$$

subject to individual rationality constraints (IR^M): $CS_{ij}^* \geq 0$. The resulting energy efficiency levels would be similar to those set by the social planner. Moreover, the prices of the durable goods would be set so as to extract all consumer surplus: $p_j = \beta_j(v - (g + \gamma)\phi_j)$.

2.4.2. The screening problem

More realistically, the monopolist knows the distribution of consumer types but cannot prevent consumers h from buying the goods targeting consumers l , or cannot prevent arbitrage. A screening problem arises: if the monopolist set price and energy efficiency levels as above, then consumers h will purchase good l . By doing so, consumers h will enjoy a positive surplus $CS_{hl}^* = (\beta_h - \beta_l)(v - (g + \gamma)\phi_l^*)$, instead of zero surplus by consuming good h .

2.4.3. Imperfectly discriminating monopolist

As demonstrated first by Mussa and Rosen (1978), to prevent consumers h from purchasing good l , the imperfectly discriminating monopolist cuts the quality of good l . This diminishes the surplus from buying good l to consumers h , hence allows the monopolist to raise the price of good h to make consumers indifferent between buying either good. The monopolist cannot deteriorate good l too much, though, otherwise the profit loss from producing a low-end good is no longer compensated by the surplus extracted from consumers h .

Formally, such an equilibrium requires the monopolist to endogenize Incentive Compatibility constraints (IC) in addition to IR to ensure that consumers self-select into the good they are targeted for. The monopolist maximizes profit subject to (superscript M denotes monopoly outcomes):

$$IR_l^M: \beta_l(v - (g + \gamma)\phi_l) \geq p_l$$

$$IR_h^M: \beta_h(v - (g + \gamma)\phi_h) \geq p_h$$

$$IC_l^M: \beta_l(v - (g + \gamma)\phi_l) - p_l \geq \beta_l(v - (g + \gamma)\phi_h) - p_h$$

$$IC_h^M: \beta_h(v - (g + \gamma)\phi_h) - p_h \geq \beta_h(v - (g + \gamma)\phi_l) - p_l$$

It can be shown that only IR_l and IC_h will bind. That is, consumer l is left with no surplus and consumer h is indifferent between purchasing either good (see appendix A1 or Spurlock (2013) for a formal demonstration).

In equilibrium, the quality of good h will still be defined by Equation (2), so that

$$\phi_h^* = \phi_h^M.$$

In contrast, the quality of good l will be determined by the following first-order condition:

$$-c'(\phi_l^M) = (g + \gamma) \left(\beta_l - \frac{n_h}{n_l} (\beta_h - \beta_l) \right) \quad (3)$$

For ϕ_l^M to be interior, the right-hand side must be positive, hence:

$$\frac{\beta_l}{\beta_h} > \frac{n_h}{n_h + n_l} = n_h \quad (4)$$

Inequality $-c'(\phi_l^M) \leq -c'(\phi_l^*)$ leads to

$$\phi_l^M > \phi_l^*.$$

In words, imperfect discrimination generates a suboptimal level of energy efficiency, even if energy-use externalities are fully internalized. This can be a rational explanation for the energy efficiency gap, that is, the apparently low levels of energy efficiency in the economy (Jaffe and Stavins, 1994).

The price of good l leaves no surplus to the low-end consumer:

$$p_l^M = \beta_l (v - (g + \gamma) \phi_l^M)$$

In contrast, some surplus is left to the consumer h :

$$p_h^M = v\beta_l - (g + \gamma)\beta_h\phi_h^M + (g + \gamma)(\beta_h - \beta_l)\phi_l^M$$

The distortions on the price of good h and the quality of good l interfere. The lower the quality offered to the low-end consumer, the smaller the surplus left to the high-end consumer:

$$d p_h^M / d \phi_l^M = (g + \gamma)(\beta_h - \beta_l) > 0$$

2.5. Monopoly with energy-use externalities

If, in addition to monopoly distortions, energy-use externalities are not internalized, a new equilibrium is reached. Equilibrium outcomes (denoted with superscript ME) can easily be visualized by setting $\gamma=0$ in Equations (2) and (3). Energy efficiency is undersupplied at the high-end of the product line:

$$\phi_h^{ME} = \phi_h^E > \phi_h^* = \phi_h^M$$

The same effect occurs at the low-end of the product line, where the two market failures reinforce each other:

$$\phi_l^{ME} > \phi_l^E > \phi_l^* \text{ and } \phi_l^{ME} > \phi_l^M > \phi_l^*$$

Which stand-alone market failure has the largest effect on the degradation of good l is ambiguous. Discrimination has a smaller impact if and only if:

$$\phi_l^M > \phi_l^E \Leftrightarrow \frac{\beta_l}{\beta_h} > n_h \left(1 + \frac{g n_l}{\gamma + g n_h} \right) \quad (5)$$

Since the discrimination problem has no impact on the level of good h , this condition is also a sufficient one for the discrimination problem to generate a smaller deadweight loss than the externality problem. Note that the right-hand side is greater than n_h . That is, Condition (5) is more restrictive than Condition (4) in that it requires less heterogeneity across consumers.

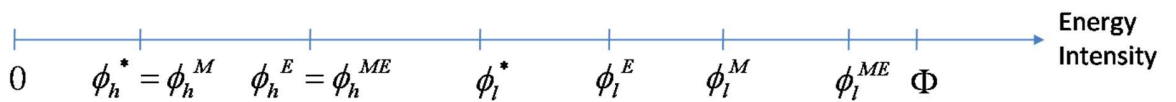


Figure 1: Illustrative quality levels under different market structures. Energy intensity increases rightward and energy efficiency increases leftward. Note that ϕ_l^E needs not be more energy-efficient than ϕ_l^M ; this depends on Condition (5). Likewise, ϕ_h^{ME} needs not be more energy-efficient than ϕ_l^* ; this depends on Condition (19).

3. First-best policies with two instruments

We now consider an institution in charge of regulating the imperfectly discriminating monopolist, subject to energy-use externalities. The monopolist and the regulator are assumed to share the same level of information. The regulator seeks to decentralize the energy efficiency pair from its laissez-faire level $(\phi_h^{ME}, \phi_l^{ME})$ to its socially optimal one (ϕ_h^*, ϕ_l^*) .

After the Tinbergen rule, the regulator should employ two policy instruments to address the two market failures. This can be done in many different ways. The regulator can combine what we shall call “pure instruments,” that is, policies with only one instrument variable. Such instruments include quality standards (e.g. minimum or average), energy taxes, or uniform energy efficiency subsidies. Perhaps the most intuitive intervention is to combine a minimum quality standard equal to ϕ_l^* (meant to address the discrimination problem) and an energy tax equal to γ (meant to address the externality problem).

Alternatively, the regulator can use “differentiated instruments,” that is, policies that accommodate several instrument variables. In the context of the model, where energy efficiency is undersupplied, this can be achieved through differentiated subsidies.²⁰⁸

In this section, we focus on two main types of subsidy design: per-quality and ad valorem. Throughout, we consider a partial equilibrium setting in which subsidies are funded by lump-sum taxes. We assume that the subsidies are received by the consumers, but the results would be the same if they were received by the firm.

3.1. Per-quality subsidies

The regulator can offer subsidy payments that depend on the energy efficiency level of the durable good purchased by the consumer.²⁰⁹ Such an incentive can be modeled as a two-

²⁰⁸ Note that there could be other justifications for subsidy implementation than the two market failures considered here. Subsidies may for instance be warranted if the adoption of energy efficient technologies generates positive externalities.

²⁰⁹ The closest practical experience we can think of is the feebate system currently implemented in the automobile sector in various countries (e.g. France, Canada, the Netherlands and Norway). The feebate system

stage game played by a principal, the regulator, and an agent, the monopolist. In the second stage of the game, the monopolist takes policy parameters as given and sets price and energy efficiency levels so as to maximize profit under the consumers' individual rationality and incentive compatibility constraints. Using backward induction, resolution of the second stage gives equilibrium outcomes as functions of the policy parameters. In the first stage of the game, the regulator sets policy parameters so as to maximize total surplus.

3.1.1. Second stage: monopolist's response to the policy

Consumers are offered a payment $(z_i - \phi_i)\sigma_i$ for purchasing good i , with σ_i the per-quality subsidy rate. $z_i > \phi_i$ is an energy-intensity reference level, higher than the market equilibria, below which consumers receive the payment. It disappears in the first-order conditions so it does not change the product prices and efficiencies. The monopolist maximizes profit subject to (equilibrium outcomes are denoted with superscript PP):

$$IR_l^{PP} : \beta_l(v - g\phi_l) + (\phi_l - z_l)\sigma_l \geq p_l$$

$$IR_h^{PP} : \beta_h(v - g\phi_h) + (\phi_h - z_h)\sigma_h \geq p_h$$

$$IC_l^{PP} : \beta_l(v - g\phi_l) + (\phi_l - z_l)\sigma_l - p_l \geq \beta_l(v - g\phi_h) + (\phi_h - z_h)\sigma_h - p_h$$

$$IC_h^{PP} : \beta_h(v - g\phi_h) + (\phi_h - z_h)\sigma_h - p_h \geq \beta_h(v - g\phi_l) + (\phi_l - z_l)\sigma_l - p_l$$

With binding IR_l^{PP} and IC_h^{PP} constraints, equilibrium efficiency levels are determined by the following first-order conditions:

$$-c'(\phi_h^{PP}) = \sigma_h + g\beta_h \quad (6)$$

$$-c'(\phi_l^{PP}) = g\left(\beta_l - \frac{n_h}{n_l}(\beta_h - \beta_l)\right) + \sigma_l \quad (7)$$

Per-quality subsidies raise both the energy efficiency ($d\phi_i^{PP}/d\sigma_i = -1/c'' < 0$) and price ($dp_i^{PP}/d\sigma_i = g\beta_i > 0$) levels of the good they specifically target. While a subsidy on good

combines taxes and subsidies, the amount of which depends on the energy efficiency level of the car purchased, regardless of its price (D'Haultfoeuille et al. 2013).

h does not change the price of good l ($dp_l^{PP}/d\sigma_h = 0$), a subsidy on good l reduces the price of good h :

$$\frac{dp_h^{PP}}{d\sigma_l} = -g(\beta_h - \beta_l) < 0$$

This is because with σ_l , the more efficient good l would provide consumer h with a higher surplus, would this consumer buy that good. The monopolist thus responds by lowering the price of l to keep consumer h indifferent between buying either good. In contrast, the provision of good l is not affected by σ_l , so the monopolist does not need to change the price of good l .

3.1.2. First stage: Regulator's intervention.

The regulator seeks the subsidy rates that maximize total surplus, taking into account energy-use externalities. This leads to the same first-order conditions for both goods:

$$\forall i \quad n_i [-(g + \gamma)\beta_i - c'(\phi_i^{PP})] \frac{d\phi_i^{PP}}{d\sigma_i} = 0 \quad (8)$$

Since $d\phi_i^{PP}/d\sigma_i < 0$, both subsidies will implement the socially optimal energy efficiency levels:

$$\forall i \quad -c'(\phi_i^{PP}) = (g + \gamma)\beta_i \quad (9)$$

By matching the right-hand side of Equation (9) with that of Equation (6), we derive the optimal subsidy rate on good h to correct the two market failures:

$$\sigma_h^{PP} = \beta_h \gamma$$

By matching the right-hand side of Equation (9) with that of Equation (7), we obtain the optimal subsidy rate on good l :

$$\sigma_l^{PP} = \beta_l \gamma + g \frac{n_h}{n_l} (\beta_h - \beta_l)$$

3.1.3. Comments

Subsidy rates σ_h^{PP} and σ_l^{PP} can be decomposed into two additive components. The $\beta_i \gamma$ terms are the components needed to internalize the energy-use externality. The second term in each subsidy formula (zero for σ_h^{PP} and $g(\beta_h - \beta_l) n_h/n_l$ in σ_l^{PP}) is the one needed to address the discrimination problem.

Which subsidy rate should be higher is not straightforward. It depends on:

$$\sigma_h^{PP} > \sigma_l^{PP} \Leftrightarrow \frac{\gamma}{g} > \frac{n_h}{n_l}$$

The externality must be large and/or the market share of the high-end consumers must be small for the subsidy rates to be increasing in energy efficiency. To put this condition in perspective, current estimates of the implicit carbon price in OECD countries typically range in the 10% of domestic energy price, hence $\gamma/g \approx 0.1$. In such a market environment, the market share of the high-end consumers should be no larger than 11% for the optimal subsidy schedule to be increasing in energy efficiency. In practice, the subsidy schedules tend to be increasing in energy efficiency (e.g. the French tax credit program until 2013).

3.2. Ad valorem subsidies

An alternative to relating subsidy rates to the quality of the durable goods is to link them to the price of the goods. Such a subsidization schedule prevails in many countries (e.g. the French tax credit program introduced above). For instance in Germany, the KfW subsidization program for residential building retrofitting offers a 10% price cut if the retrofitted building reaches 115% of the standard energy needs for new constructions, and a 25% price cut if it meets the Passivhaus standard (Rüdinger 2013). Again, such an instrument is modeled here within a principal-agent framework.

3.2.1. Second stage: monopolist's response to the policy

We consider ad valorem subsidies of rate ϵ_i to good i . p_i denotes producer prices while $p_i(1 - \epsilon_i)$ denotes consumer prices. The monopolist maximizes profit subject to

$$IR_i^{AA} : \beta_l(v - g\phi_l) \geq p_l(1 - \epsilon_l)$$

$$IR_h^{AA}: \beta_h(v - g\phi_h) \geq p_h(1 - \epsilon_h)$$

$$IC_l^{AA}: \beta_l(v - g\phi_l) - p_l(1 - \epsilon_l) \geq \beta_l(v - g\phi_h) - p_h(1 - \epsilon_h)$$

$$IC_h^{AA}: \beta_h(v - g\phi_h) - p_h(1 - \epsilon_h) \geq \beta_h(v - g\phi_l) - p_l(1 - \epsilon_l)$$

Under binding IR_l^{AA} and IC_h^{AA} constraints, profit maximization leads to the following energy efficiency levels:

$$-c'(\phi_h^{AA}) = g \frac{\beta_h}{1 - \epsilon_h} \quad (10)$$

$$-c'(\phi_l^{AA}) = g \frac{\beta_l}{1 - \epsilon_l} - \frac{n_h}{n_l} \frac{\beta_h - \beta_l}{1 - \epsilon_h} \quad (11)$$

Like per-quality subsidies, ad valorem subsidies increase the energy efficiency of the good they specifically target:

$$\forall i \quad \frac{d\phi_i^{AA}}{d\epsilon_i} = \frac{-g\beta_i}{(1 - \epsilon_i)^2 c''[\phi_i^{AA}]} < 0 \quad (12)$$

Yet unlike per-quality subsidies, ad valorem subsidies entail some interference. The subsidy on good h indeed deteriorates the quality of good l :

$$\frac{d\phi_l^{AA}}{d\epsilon_h} = \frac{n_h}{n_l} \frac{g(\beta_h - \beta_l)}{c''[\phi_l^{AA}](1 - \epsilon_h)^2} > 0 \quad (13)$$

This is because of the two channels that can be used by the monopolist to maximize profit, namely cut ϕ_l or increase p_h , an ad valorem subsidy makes the latter costlier for him. The monopolist therefore harnesses the former.

The effect of ad valorem subsidies on the prices of the durable goods is more subtle than that of per-quality subsidies. This is detailed in Appendix A2.

3.2.2. First stage: Regulator's intervention.

The regulator seeks the subsidy levels that maximize total surplus, taking into account energy-use externalities. The first-order conditions for maximization are:

$$n_h [-(g + \gamma)\beta_h - c'(\phi_h^{AA})] \frac{d\phi_h^{AA}}{d\epsilon_h} + n_l [-(g + \gamma)\beta_l - c'(\phi_l^{AA})] \frac{d\phi_l^{AA}}{d\epsilon_h} = 0 \quad (14)$$

$$n_l [-(g + \gamma)\beta_l - c'(\phi_l^{AA})] \frac{d\phi_l^{AA}}{d\epsilon_l} = 0 \quad (15)$$

Since $d\phi_l^{AA}/d\epsilon_l > 0$, Equation (15) simplifies to:

$$-c'(\phi_l^{AA}) = (g + \gamma)\beta_l \quad (16)$$

This implies that the efficiency of good l will be set at its optimal level. This result, introduced in equation (14) and combined with the fact that $d\phi_h^{AA}/d\epsilon_h < 0$ implies that good h will also be set at its optimal level:

$$-c'(\phi_h^{AA}) = (g + \gamma)\beta_h \quad (17)$$

By matching the right-hand side of Equation (17) with that of Equation (10), we derive the optimal subsidy rate on good h to correct the two market failures:

$$\epsilon_h^{AA} = \frac{\gamma}{g + \gamma}$$

Using this and matching the right-hand side of Equation (16) with that of Equation (11), we derive the optimal subsidy rate on good l :

$$\epsilon_l^{AA} = \frac{n_h(\beta_h - \beta_l) + \frac{\gamma}{g + \gamma} n_l \beta_l}{n_h(\beta_h - \beta_l) + n_l \beta_l}$$

3.2.3. Comments

Ad valorem subsidies differ from per-quality subsidies in two ways. First, they cannot systematically be decomposed into two additive components meant to specifically address one market failure. If discrimination were the only market failure to address ($\gamma = 0$), the subsidy rate would be nil on good h ($\epsilon_h^M = 0$) and equal to $\epsilon_l^M = n_h(\beta_h - \beta_l)/[n_h(\beta_h - \beta_l) + n_l \beta_l]$ on good l . Reciprocally, if energy-use externalities were the only market failure to internalize, energy efficiency levels would be set so that equilibrium levels with the subsidy (defined by $-c' = g\beta_i/(1 - \epsilon_i)$) match the socially optimal ones (defined by $-c' = (g + \gamma)\beta_i$). Hence, both

goods would need to be subsidized at the same uniform rate $\epsilon = \gamma/[\gamma + g]$. With these definitions, $\epsilon_h^{AA} = \epsilon^E + \epsilon_h^M$ and:

$$\epsilon_l^{AA} = \epsilon^E + \epsilon_l^M - \epsilon_l^M \epsilon^E = \epsilon^E + \epsilon_l^M (1 - \epsilon_h^{AA})$$

In other words, if the two market failures are to be jointly corrected, the subsidy rates specifically needed for each market failure are additive on good h but sub-additive on good l . Indeed, since the subsidy on good h deteriorates the efficiency of good l , the subsidy on good l needs to be higher.

A second difference between ad valorem subsidies and per-quality ones is that with the former, subsidy rates should always be larger on good h than on good l : $\epsilon_h^{AA} < \epsilon_l^{AA}$. An intuition for this result is that efficiency of good h must increase only to internalize the externality, while the efficiency of good l must increase to also correct the distortion due to imperfect discrimination. Yet the fact that subsidy rates should always be larger on good l does not mean that good l necessarily receives a larger amount of subsidies per unit sold, since it is cheaper than good h and subsidies are ad valorem. In other words, $p_h^{AA} \epsilon_h^{AA}$ may be higher or lower than $p_l^{AA} \epsilon_l^{AA}$.

4. Second-best policies with one instrument

In practice, the Tinbergen rule is rarely applied. For a variety of informational, institutional or political reasons, there are seldom as many policy instruments as there are market failures to correct.²¹⁰ In the context we are interested in, for instance, implementing differentiated subsidy rates would open room for lobbying from industrial firms.

In this section, we therefore take a more positive view and examine how single instruments perform in the context of two market failures. In addition to classical minimum

²¹⁰ To quote Tinbergen himself, "Economists or economic politicians holding the opinion that there is such a one-by-one correspondence between targets and instruments evidently assume a very special structure." (Tinbergen, 1952, note 1, p. 31).

quality standards and energy tax, we examine several forms of single-instrument energy efficiency subsidies.

4.1. Minimum quality standard

This instrument is widely applied worldwide. Most European countries and some US states have implemented minimum quality standards for new buildings after the oil shocks of the 1970s, and have strengthened them since then. The main appliances, as well as electric motors and lighting equipment are also covered by energy efficiency standards in most of the developed and transition countries.

Let us consider the effect of a standard (denoted S) on each good i , independently of the other good. The deadweight loss of a standard ϕ^S on good i is:

$$DWL_i = n_i[(g + \gamma)\beta_i(\phi^S - \phi_i^*) + c(\phi^S) - c(\phi_i^*)]$$

It varies with ϕ^S in an ambiguous manner:

$$\frac{dDWL_i}{d\phi^S} = n_i[(g + \gamma)\beta_i + c'(\phi^S)] \begin{cases} < 0 \text{ if } \phi_i^* < \phi^S \leq \Phi \\ = 0 \text{ if } \phi^S = \phi_i^* \\ > 0 \text{ if } 0 \leq \phi^S < \phi_i^* \end{cases} \quad (18)$$

That is, tightening the standard is welfare-improving, up to the point that the socially optimal value of the good is reached. Beyond that point, further tightening the standard is socially detrimental. The question of interest now is: should the standard constrain the efficiency of both goods (pooling standard) or that of good l only (separating standard)?

4.1.1. A necessary and sufficient condition for a pooling standard

An optimal pooling standard would minimize the sum of the deadweight losses on each of the two goods. This leads to the following first-order condition:

$$-c'(\phi^S) = (n_h\beta_h + n_l\beta_l)(g + \gamma)$$

The pooling standard would be optimal to a consumer of average type $n_h\beta_h + n_l\beta_l$. To be effective, such a standard should be more stringent than the monopolist's supply of good h : $\phi^S \leq \phi_h^{ME}$. This is true if and only if $c'^{-1}(-(g + \gamma)(n_h\beta_h + n_l\beta_l)) \leq c'^{-1}(-g\beta_h)$, that is:

$$\frac{\beta_h}{n_h\beta_h+n_l\beta_l} \leq 1 + \frac{\gamma}{g} \quad (19)$$

4.1.2. A sufficient condition for a pooling standard

If the externality is so large that $\phi_h^{ME} \geq \phi_l^*$ then the standard, at least equal to ϕ_l^* , is necessarily more stringent than $\phi_h^{ME} \geq \phi_l^*$. This occurs when $c'^{-1}(-(g + \gamma)\beta_l) \leq c'^{-1}(-g\beta_h)$, which leads to the sufficient condition for a pooling standard:

$$\frac{\beta_h}{\beta_l} \leq 1 + \frac{\gamma}{g}$$

Obviously, this condition implies Condition (19).

4.1.3. Separating standard

If Condition (19) is not satisfied, $\phi^S > \phi_h^{ME}$. It is not optimal for the monopolist to supply only one good of efficiency ϕ^S . The monopolist could increase the profit earned from consumers h by extending its product line to include ϕ_h^{ME} . With this new constraint, the only way to minimize the total deadweight loss is to eliminate the deadweight loss from good l . After Equation (18), this can only be done by setting the standard at ϕ_l^* .

4.2. Energy tax

This instrument is also widely applied. Most European countries, Japan and a few other countries have implemented important fuel taxes in the transport sector. These taxes were found to efficiently restrain fuel demand (Sterner 2007).

Energy taxes here are assumed to be funded by lump-sum subsidies.

4.2.1. Second stage: Monopolist's response

A tax on energy at rate t would lead to the following first-order conditions (superscript T denotes equilibrium outcomes):

$$-c'(\phi_h^T) = (g + t)\beta_h \quad (20)$$

$$-c'(\phi_l^T) = (g + t) \left(\beta_l - \frac{n_h}{n_l}(\beta_h - \beta_l) \right) \quad (21)$$

The tax would increase the energy efficiency of the two goods:

$$\frac{d\phi_h^T}{dt} = \frac{-\beta_h}{c''(\phi_h^T)} < 0$$

$$\frac{d\phi_l^T}{dt} = \frac{-1}{c''(\phi_l^T)} \left(\beta_l - \frac{n_h}{n_l} (\beta_h - \beta_l) \right) < 0$$

As discussed in Appendix A3, the tax has an ambiguous effect on product prices.

4.2.2. First stage: Regulator's intervention

The optimal tax rate to address the two market failures is the one that maximizes social welfare, including energy-use externalities. This leads to the following first-order condition:

$$n_h [-(g + \gamma)\beta_h - c'(\phi_h^T)] \frac{d\phi_h^T}{dt} + n_l [-(g + \gamma)\beta_l - c'(\phi_l^T)] \frac{d\phi_l^T}{dt} = 0$$

Identifying the $c'(\phi_i^T)$ with the right-hand sides in Equations (20) and (21), we end-up with the following equality:

$$t = \gamma + \frac{(g + \gamma)n_h(\beta_h - \beta_l) d\phi_l^T/dt}{n_h\beta_h d\phi_h^T/dt + (n_l\beta_l - n_h(\beta_h - \beta_l)) d\phi_l^T/dt} > \gamma$$

Unless the two consumers are identical ($\beta_h = \beta_l$), the optimal tax rate is larger than γ . If it were equal to γ , external costs would be internalized but there would still remain some deadweight loss from price-quality discrimination. Further energy taxation could reduce the deadweight loss on the quality of good l , up to the point that the marginal welfare gains are offset by the marginal welfare loss of an inefficiently high quality of good h .

This result differs from Lombardini-Riipinen (2005) who finds a second-best tax equal to the social valuation of the externality γ . Besides, both results differ from the classical one in the environmental economics literature that under full information, homogeneous goods and oligopolies with symmetric firms, the second-best tax should be smaller than the externality so as to balance the output contraction effect of the tax (Baumol 1988). However, such an effect

could not occur in our model, which does not accommodate the extensive margin of investment.

4.3. Subsidies

Overall, six types of single-instrument subsidies can be thought of. Subsidy rates can target uniformly both goods or specifically either of the two goods. In each case, the rates can be ad valorem or per-quality.

Much of the analysis carried out in Section 3 carries over to the second-best analysis. The monopolist's responses to each of these instruments have already been analyzed in the second stages of the games. The difference in the second-best setting is that in the first stage of the games, the regulator maximizes total surplus with respect to one instrument variable only.

For subsidies specifically targeting the low-end good (either ad valorem or per-quality) and per-quality subsidies targeting the high-end good, the analysis directly derives from Section 3. Recall from the second stages of the games that these subsidies do not interfere with the good they are not targeted for. Therefore, in a second-best setting, the best the regulator can do is to set their rates at their socially optimal level.

More analysis is needed for uniform subsidies (either ad valorem or per-quality) and ad valorem subsidies on the high-end good, which is the object of the present section.

4.3.1. Uniform ad valorem subsidies

Such a policy is perhaps the most widespread. For instance in France, home energy retrofits benefit from a reduced VAT rate (5% against a normal rate of 20%), irrespective of the level of energy savings achieved.

The monopolist's response to a uniform ad valorem subsidy rate ϵ is directly given by Equations (10) and (11), with $\epsilon_h = \epsilon_l \equiv \epsilon$. The comparative statics of equilibrium efficiencies is (superscript A denotes equilibrium outcomes):

$$\frac{d\phi_h^A}{d\epsilon} = \frac{-g\beta_h}{c''(\phi_h^A)(1-\epsilon)^2} < 0$$

$$\frac{d\phi_l^A}{d\epsilon} = \frac{-g}{c''(\phi_l^A)(1-\epsilon)^2} \left(\beta_l - \frac{n_h}{n_l}(\beta_h - \beta_l) \right) < 0$$

In the first stage of the game, by the same type of reasoning as for the tax, the regulator will set the subsidy at a larger rate than the one needed to specifically internalize energy-use externalities:

$$\epsilon = \frac{\gamma}{g + \gamma} \left(1 + \frac{g}{\gamma} \frac{n_h(\beta_h - \beta_l) d\phi_l^A/d\epsilon}{n_h\beta_h d\phi_h^A/d\epsilon + n_l\beta_l d\phi_l^A/d\epsilon} \right) > \frac{\gamma}{g + \gamma}$$

It can be shown that with a more restrictive quadratic cost assumption, both this subsidy and the energy tax lead to the same equilibrium outcome. Consumer h 's surplus and profits are then higher with this subsidy than with the energy tax.

4.3.2. *Ad valorem subsidy on the high-end good*

The recent evolution of the French tax credit program resembles such an instrument. Only the best available technologies are incentivized (e.g. condensing boilers, etc.) with a 30% price cut.

Recall from Section 3.2.1 that an ad valorem subsidy on good h deteriorates the quality of good l ($d\phi_l^H/d\epsilon_h > 0$, where superscript H denotes equilibrium outcomes). Therefore, here, in equilibrium the quality of good h will be below its socially optimal level ϕ_h^* and the quality of good l will be even below its laissez-faire level ϕ_l^{ME} .

With the same type of reasoning as with the tax, in the first stage of the game the regulator sets the ad valorem incentive at the following rate:

$$\epsilon_h^H = \frac{\gamma n_h \beta_h d\phi_h^H/d\epsilon_h + (\gamma n_l \beta_l + g n_h (\beta_h - \beta_l)) d\phi_l^H/d\epsilon_h}{(\gamma + g) n_h \beta_h d\phi_h^H/d\epsilon_h + (\gamma n_l \beta_l + g n_h (\beta_h - \beta_l)) d\phi_l^H/d\epsilon_h}$$

Since the $d\phi_i^H/d\epsilon_h$ have opposite signs, the sign of this expression is ambiguous. If it is negative, a tax on good h would be preferred over a subsidy. This occurs if and only if the numerator and the denominator have opposite signs. Since the denominator is smaller than the

numerator, this condition is equivalent to having a positive numerator and a negative denominator. Therefore:

$$\epsilon_h^H < 0 \leftrightarrow 0 < \gamma n_h \beta_h \frac{d\phi_h^H}{d\epsilon_h} + (\gamma n_l \beta_l + g n_h (\beta_h - \beta_l)) \frac{d\phi_l^H}{d\epsilon_h} < -g n_h \beta_h \frac{d\phi_h^H}{d\epsilon_h} \quad (22)$$

This condition is likely to hold if γ is small enough and type I consumers dominate the market. To see this, assume γ is negligible. The condition boils down to:

$$0 < 1 - \frac{\beta_l}{\beta_h} < -\frac{d\phi_h^H/d\epsilon_h}{d\phi_l^H/d\epsilon_h} = \frac{n_l}{n_h} \frac{\beta_h}{\beta_h - \beta_l} \frac{c''(\phi_l^H)}{c''(\phi_h^H)}$$

We know from Equations (10) and (11) that $\phi_l^H > \phi_h^H$, but without further assumptions on $c'''(\cdot)$, we do not know how $c''(\phi_l^H)/c''(\phi_h^H)$ compares to 1. Still, if n_l is sufficiently larger than n_h , the right-hand side of the inequality will be larger than 1 and the inequality will be satisfied.

This outcome can be rationalized as follows. If the externality is very small, then the high-end good is very close to its socially optimal level, while the low-end good is very far from its socially optimal level. Therefore, the tax has a first-order effect on good l but only a second-order effect on good h . In other words, with the tax, the marginal welfare gain from improving good l is larger than the marginal welfare loss from deteriorating good h . The fact that n_l is larger than n_h only amplifies this effect.

It should be kept in mind though that having a small γ and a large n_l is neither a necessary nor a sufficient condition for the optimal incentive to be a tax. Clearer conditions can be derived using a more restrictive quadratic cost assumption. Hence, the second derivative of cost is constant so the last fraction drops from the inequality, which becomes:

$$\gamma n_l \left[\left(1 - \frac{\beta_l}{\beta_h}\right)^2 + \frac{\beta_l}{\beta_h} \right] < g n_h \left(1 - \frac{\beta_l}{\beta_h}\right)^2 < \gamma n_l \left[\left(1 - \frac{\beta_l}{\beta_h}\right)^2 + \frac{\beta_l}{\beta_h} \right] + g n_l$$

The interior condition $\beta_l/\beta_h \geq n_h$ implies $g n_l \geq g n_h (1 - \beta_l/\beta_h)^2$, hence the right inequality. Therefore, with quadratic costs, the left inequality right above is sufficient for the incentive to be a tax.

4.3.3. Per-quality subsidy on the high-end good

In France, a 1,350€ subsidy on energy efficiency investment was introduced in 2014 for middle- and low-income households undergoing home energy retrofit works. The program has similar eligibility requirements as the most recent version of the tax credit program. It can be seen as a per-quality subsidy on the most energy efficient goods.

With a per-quality subsidy on good h , the quality of good h will be socially optimal (ϕ_h^*) and the quality of good l will be unchanged (ϕ_l^{ME}). This instrument therefore strictly dominates the second-best ad valorem subsidy on good h , which brings both goods to lower quality levels. Yet if the ad valorem subsidy turns out to be a tax (under Condition (22)), the comparison with the per-quality subsidy is no longer obvious. According to the comparative statics of quality levels with respect to ϵ_h (Equations (12) and (13)), the tax will push the quality of good h away from its socially optimal level (which is worse than the per-quality equivalent) but bring the quality of good l closer to its socially optimal level (which is better than the per-quality equivalent). In Appendix A4, we confine our attention to quadratic costs and further discuss the conditions under which one instrument dominates the other. Overall, this result contributes to the literature comparing ad valorem and per-quality instruments, which mostly focuses on taxes (Keen 1998).

4.3.4. Uniform per-quality subsidies

The monopolist's response to such a subsidy is the same as the one described in Section 3.1.1. By the same reasoning as before, the regulator will set the uniform per-quality tax at the following level:

$$\sigma^P = \sigma_h^{PP} \frac{n_h d\phi_h^P/d\sigma}{n_h d\phi_h^P/d\sigma + n_l d\phi_l^P/d\sigma} + \sigma_l^{PP} \frac{n_l d\phi_l^P/d\sigma}{n_h d\phi_h^P/d\sigma + n_l d\phi_l^P/d\sigma} < \sigma_h^{PP} + \sigma_l^{PP}$$

The payment to consumers is lower than the one that would be needed to address the two externalities ($\sigma_h^{PP} + \sigma_l^{PP}$).

5. Conclusions

Energy efficiency markets are commonly subject to both energy-use externalities and price-quality discrimination. How do energy efficiency policy instruments compare in such a market environment? To answer this question, we have examined a broad set of first-best and second-best policy interventions in a unified framework. We have paid particular attention to energy efficiency subsidies, an instrument frequently encountered in practice but, by contrast, little studied in the market environment considered here. We have built on the model of Fischer (2005), which features two types of consumers, a monopolist which can imperfectly price discriminate and two levels of energy efficiency which are positively correlated with quality.

From a normative perspective, the two levels of energy efficiency are undersupplied in *laissez-faire*. This so-called energy efficiency gap can be addressed with energy efficiency subsidies, the rate of which is differentiated across energy efficient goods. Subsidy schedules can be either per-quality or *ad valorem*, with different consequences. We find that with *ad valorem* subsidies, the rate on the more energy efficient goods interferes with the provision of less energy efficient goods. The rates should always be decreasing in energy efficiency. With per-quality subsidies, there are no such interferences and the rates can be increasing if the marginal external cost of energy use is large enough relative to the market share of low-type consumers. This is at odds with actual practice in which differentiated subsidies tend to be *ad valorem* with increasing rates.

From a positive perspective, for a variety of informational, institutional or political reasons, single instruments are more likely to be implemented. We find that a minimum quality standard may be set at the high-end of the product line if consumers are not too dissimilar. An energy tax should be set above the marginal external cost of energy use. Similarly, a uniform *ad valorem* subsidy should be set above the subsidy that would be needed to specifically internalize energy-use externalities. Lastly, if, as is often observed in practice, only the high-end good is to be incentivized, a per-quality schedule should be preferred over an *ad valorem* one. An *ad valorem* tax may even be preferred over an *ad valorem* subsidy if the externality is small enough and low-end consumers dominate the market.

6. Appendix

A1. Proof on the binding constraints

Be the four constraints (IR = the individual rationality constraint or the participation constraint and IC: the incitation constraint)

$$\text{IR}_l: \beta_l(v - (g + \gamma)\phi_l) \geq p_l$$

$$\text{IR}_h: \beta_h(v - (g + \gamma)\phi_h) \geq p_h$$

$$\text{IC}_l: \beta_l(v - (g + \gamma)\phi_l) - p_l \geq \beta_l(v - (g + \gamma)\phi_h) - p_h$$

$$\text{IC}_h: \beta_h(v - (g + \gamma)\phi_h) - p_h \geq \beta_h(v - (g + \gamma)\phi_l) - p_l$$

Step 1: In a separating equilibrium (in which $p_h \neq p_l, \phi_h \neq \phi_l$), IC_h and IC_l cannot both bind.

Proof: By contradiction:

If IC_h and IC_l bind:

$$CS_{ll} - CS_{lh} = 0 \Leftrightarrow -\beta_l g = \frac{p_l - p_h}{\phi_l - \phi_h} \Rightarrow \beta_h = \beta_l \text{ contradiction.}$$

$$CS_{hh} - CS_{hl} = 0 \Leftrightarrow -\beta_h g = \frac{p_l - p_h}{\phi_l - \phi_h}$$

Step 2: IC_h and IR_h cannot be both non-binding (Same thing for IC_l and IR_l).

Otherwise, the firm can increase profit by slightly increasing p_h .

Step 3: IC_l does not bind.

Proof: By contradiction:

If IC_l binds, IR_h does not bind:

$$\begin{aligned}
& CS_{hh} \\
&= \beta_h(v - g\phi_h) - p_h \\
&> \beta_l(v - g\phi_h) - p_h, (\beta_h > \beta_l) \\
&> \beta_l(v - g\phi_h) - p_h, (CS_h = CS_{lh}) \\
&> 0
\end{aligned}$$

And if IR_h does not bind, IC_h binds (step 2). But from step 1, if IC_l binds, IC_h does not bind.

Contradiction.

Step 4: IR_h does not bind.

From step 3, IC_l does not bind, then IR_l binds (by step 2).

$$\begin{aligned}
& CS_{ll} \\
&= \beta_h(v - g\phi_h) - p_h \\
&\geq \beta_h(v - g\phi_l) - p_l, (CS_{hh} \geq CS_{hl}) \\
&> \beta_l(v - g\phi_l) - p_l, (\beta_h > \beta_l) \\
&= 0, (CS_{ll} = 0)
\end{aligned}$$

Therefore, IR_h does not bind.

Step 5: IR_l and IC_h bind.

Proof: Steps 2 and 3 imply that IR_l binds. Steps 2 and 4 imply that IC_h binds.

A2. Effect of ad valorem subsidies on product prices

Equilibrium prices are:

$$\begin{aligned}
p_l^{AA} &= \frac{\beta_l(v - g\phi_l^{AA})}{1 - \epsilon_l} \\
p_h^{AA} &= \frac{g\beta_h(\phi_l^{AA} - \phi_h^{AA}) - \beta_l(v - g\phi_l^{AA})}{1 - \epsilon_h}
\end{aligned}$$

Comparative statics of the price of good l is as follows:

$$\frac{dp_l^{AA}}{d\epsilon_l} = \frac{1}{1 - \epsilon_l} \left(p_l^{AA} - g\beta_l \frac{d\phi_l^{AA}}{d\epsilon_l} \right) > 0$$

$$\frac{dp_l^{AA}}{d\epsilon_h} = \frac{-g\beta_l}{1 - \epsilon_h} \frac{d\phi_l^{AA}}{d\epsilon_h} < 0$$

Both subsidies have an opposite effect on the price of good l, which reflects their opposite effect on the quality of good l.

The price of good h increases with ϕ_h^{AA} :

$$\frac{dp_h^{AA}}{d\epsilon_h} = \frac{1}{1 - \epsilon_h} \left(p_h^{AA} - g\beta_h \frac{d\phi_h^{AA}}{d\epsilon_h} + g(\beta_h + \beta_l) \frac{d\phi_l^{AA}}{d\epsilon_h} \right) > 0$$

It is decreasing with ϕ_l^{AA} :

$$\frac{dp_h^{AA}}{d\epsilon_l} = \frac{g(\beta_h + \beta_l)}{1 - \epsilon_h} \frac{d\phi_l^{AA}}{d\epsilon_l} < 0$$

A3. Effect of an energy tax on product prices

The effect of the tax on the price of good l is ambiguous. Recall that $p_l^T = \beta_l(v - (g + t)\phi_l^T(t))$. Differentiating, we obtain:

$$\frac{dp_l^T}{dt} = -\beta_l \phi_l^T (1 + \mu_l) \text{ with } \mu_l = \frac{d\phi_l^T}{dt} \frac{t}{\phi_l^T}$$

Variable μ_l is the elasticity of the supply of energy efficiency with respect to the price of energy. If $-1 < \mu_l < 0$, a “normal” rebound effect occurs. If $\mu_l \geq 0$, a “backfire” rebound effect occurs. Recall that $d\phi_l^T/dt$ is negative, hence so is μ_l . Therefore, $d\phi_l^T/dt$ is negative if there is a “normal” rebound effect and positive if there is no rebound effect ($\mu_l \leq -1$).

The price of good h will vary with even more ambiguity. Recall that

$$p_h^T = p_l^T + \beta_h(g + t)(\phi_l^T(t) - \phi_h^T(t)).$$

Differentiating and using the same elasticity formulas as before, we obtain:

$$\frac{dp_h^T}{dt} = -(\beta_h - \beta_l)\phi_l^T(1 + \mu_l) - \beta_h\phi_h^T(1 + \mu_h)$$

A4. Ad valorem versus per-quality high-end subsidy with quadratic cost

Here we assume that:

$$c(\phi_j) = \frac{(\Phi - \phi_j)^2}{2}$$

The value of the externality above which the ad valorem incentive on good h would be a subsidy is noted γ_1 :

$$\gamma_1 \equiv g \frac{n_h(\beta_h - \beta_l)^2}{n_l(\beta_h^2 - \beta_h\beta_l + \beta_l^2)}$$

Recall that the per-quality subsidy on good h improves the efficiency of good h without changing that of good l. A natural question is how this kind of subsidy, independent from the price of the subsidized good, compares to the ad valorem subsidy when both subsidy rates are set at their optimal level. This question is related to the debate between specific and ad valorem taxes which has generated numerous contributions (see Keen (1998) for a review).

In our model, the optimal per-quality subsidy rate is simply $\gamma\beta_h$. The difference between the ad valorem and the per-quality subsidy on good h can be written as a two degrees polynomial of γ :

$$\begin{aligned} \Delta_{AH-SH} = & \frac{g^2 n_h^3 (\beta_h - \beta_l)^4}{2n_l(n_l\beta_h^2 + n_h(\beta_h - \beta_l)^2)} - \gamma \frac{gn_h^2(\beta_h - \beta_l)^2(\beta_h^2 - \beta_h\beta_l + \beta_l^2)}{n_l\beta_h^2 + n_h(\beta_h - \beta_l)^2} \\ & - \gamma^2 \frac{n_h(\beta_h - \beta_l)(n_h\beta_h^2(\beta_h - \beta_l) + n_l\beta_l(2\beta_h^2 - \beta_h\beta_l + \beta_l^2))}{2(n_l\beta_h^2 + n_h(\beta_h - \beta_l)^2)} \end{aligned}$$

Without externality ($\gamma = 0$), Δ_{AH-SH} is positive, but it decreases with γ . The positive root of this polynomial, above which Δ_{AH-SH} is negative i.e. the per-quality subsidy performs better, is:

$$\gamma_2 = \frac{g^2 n_h^2 (\beta_h - \beta_l)^3}{\sqrt{g^2 n_h^2 n_l \beta_h^2 (n_l \beta_h^2 + n_h (\beta_h - \beta_l)^2) (\beta_h - \beta_l)^2 + g n_h n_l (\beta_h - \beta_l) (\beta_h^2 - \beta_h \beta_l + \beta_l^2)}}$$

It can be shown that $\gamma_1 > \gamma_2$, so if γ is high enough for $\epsilon_h^{AH} > 0$ i.e. it is a subsidy, then this subsidy is always dominated, in welfare terms, by a per-quality subsidy.

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Conclusion générale

Cette thèse s'intéresse aux déterminants de l'efficacité énergétique dans le secteur résidentiel. Un premier axe porte sur l'analyse des déterminants de l'investissement dans la rénovation énergétique tandis qu'un second axe, majoritaire dans la thèse, évalue l'efficacité des politiques publiques visant à promouvoir ce type d'investissement.

Le premier axe correspond au 1^{er} chapitre. Alors que la littérature conçoit le plus souvent l'investissement dans l'efficacité énergétique soit au niveau global sur l'ensemble des secteurs, soit au niveau d'une seule technologie, ce chapitre met à profit un jeu de données original permettant d'étudier la spécificité technologique de certains déterminants de l'investissement. L'enquête « Maîtrise de l'Energie » de l'ADEME, réalisée annuellement depuis plus de 10 ans auprès d'un échantillon partiellement renouvelé chaque année de 10000 ménages, offre un niveau d'information et une période d'observation sans précédent, du moins au sein des sources statistiques françaises. Un modèle économétrique du choix d'investissement est estimé, combinant des variables socioéconomiques et techniques avec des variables subjectives issues des déclarations des ménages quant à leurs motivations. Ce travail établit une première distinction entre le remplacement des systèmes énergétiques et les mesures d'isolation de l'enveloppe du bâtiment étant donné l'importance spécifique accordée à la durée de vie des équipements dans la dynamique de remplacement des systèmes. Les rénovations « multiples », celles se rapprochant le plus des rénovations complètes permettant d'atteindre un niveau BBC, sont quant à elles fortement impactées par les spécificités du marché de l'immobilier, que ce soit par ses dynamiques propres (transfert de location ou de propriété) ou par la valorisation de l'efficacité énergétique (la valeur verte) sur ce marché. D'autres distinctions s'opèrent, entre systèmes conventionnels et systèmes innovants notamment. Ce chapitre montre également comment l'influence des caractéristiques

socioéconomiques, telles que le revenu du ménage, sa catégorie socioprofessionnelle, ou encore son cycle de vie reflété par l'âge et la taille du foyer, est technologiquement déterminée.

Les trois chapitres suivants se concentrent sur l'efficacité des politiques publiques, en intégrant leurs impacts sur les côtés offre et demande des marchés de l'efficacité énergétique. Au vu du poids important des subventions dans les programmes mis en œuvre mais également de la grande diversité et plasticité des dispositifs de subvention observés, une attention particulière leur est accordée. La politique de subventions est analysée à la fois en rapport à d'autres types d'instruments mais également en son sein, en fonction de ses modalités d'application, i.e. de son « design ».

Côté demande, le chapitre 2 poursuit l'exploration des données de l'enquête « Maîtrise de l'Energie » pour fournir une évaluation économétrique ex-post du Crédit d'Impôt Développement Durable (CIDD), la politique publique majeure sur la période observée, les années 2000, que ce soit en termes de notoriété ou de dépenses publiques. L'identification de l'effet du CIDD sur l'investissement est obtenue par une estimation en différence sur données de panel, en contrôlant de l'évolution temporelle des autres variables explicatives et en se concentrant sur les mesures d'isolation. Ce chapitre montre que le CIDD a eu un effet positif significatif sur l'investissement à la marge extensive, i.e. sur la probabilité d'investir, mais seulement deux ou trois ans après l'entrée en vigueur de la politique. La part des ménages bénéficiaires « inframarginaux » ou « free-riders », i.e. qui auraient de toute façon investi même en l'absence de la subvention, est une mesure de ce que l'on appelle l'effet d'aubaine. Elle est estimée entre 85 à 60% à partir de 2007 et se révèle décroissante dans le temps. Cette inertie du dispositif se retrouve dans d'autres études, celles de Daussin et Mauroux (2012, 2014) sur le même dispositif CIDD notamment, et suggère donc de mettre en place des dispositifs clairs, pour en faciliter l'appropriation par les ménages, et durables dans le temps. En outre, étant donné que les temps de maturation des projets de rénovation énergétique sont très longs, on peut supposer que les « free-riders » sont les plus prompts à bénéficier des programmes de subvention. Si l'on considère de plus que les investissements de rénovation énergétique durent au moins une dizaine d'années, rendant ainsi difficile les comportements de free-

riding « récidivistes»²¹¹, pérenniser les dispositifs est donc une façon d'accroître l'efficacité des subventions. La temporalité de l'effet du CIDD est aussi positivement corrélée avec des changements dans le niveau du taux de subvention, occasionnés notamment par l'inclusion des frais de main d'œuvre en 2009. Cela suggère une efficacité des subventions croissante avec leur niveau de taux, même si des études complémentaires seraient nécessaires pour bien identifier l'influence du niveau de subvention.

L'additionnalité des subventions, reflétée ici par une mesure de l'effet d'aubaine, semble également varier en fonction de caractéristiques socio-économiques des ménages. L'effet d'aubaine est relativement plus faible chez les ménages au revenu modeste, chez les employés (par rapport aux entrepreneurs ou aux inactifs), ainsi que chez les ménages en situation de mobilité dans leur logement (emménagement récent). Ces résultats revêtent des implications quant au design des subventions. Hunt et al. (2015) évaluent les gains d'efficacité à différencier les subventions selon les ménages (« tagging ») plutôt qu'à conserver des subventions uniformes. Dans un cadre d'analyse théorique, ils montrent qu'en présence de barrières à l'investissement hétérogènes, il est d'autant plus profitable en termes de bien-être social de cibler les subventions sur les ménages les plus sujets aux distorsions lorsque la réponse de ces ménages en termes d'investissement additionnel est supérieure à celle des autres ménages. Au vu de cette analyse, nos résultats suggèrent donc de différencier les subventions selon le niveau de revenu. L'intérêt à différencier semble plus discutable s'agissant des situations de mutation. Ces dernières sont plutôt synonymes de barrières à l'investissement plus faibles (moindres contraintes de liquidité en cas d'achat immobilier, moindre inconfort des travaux d'ampleur, etc.), alors même que l'additionnalité y semble plus importante. Ces résultats doivent cependant continuer d'être discutés, au regard de ceux de Daussin-Benichou & Mauroux (2014) notamment. En regardant l'effet d'une hausse du taux de subvention du CIDD de 15 points de pourcentage, elles trouvent au contraire que l'effet est non significatif pour les ménages sujets aux plus fortes barrières à l'investissement, tels que les ménages modestes, i.e. les deux premiers quintiles de revenus, ou encore ceux vivant en appartement, les personnes seules sans

²¹¹ C'est d'autant plus vrai que les dispositifs mettent en place des restrictions concernant le cumul des subventions dans le temps.

enfant, les jeunes et les vieux. L'effet est en revanche plus important chez les ménages relativement riches (du 2^{ème} au 4^{ème} quintile de revenu). Ces divergences viennent peut-être du fait que Daussin-Benichou & Mauroux (2014) regardent l'effet sur l'investissement à la marge intensive (i.e. sur le niveau de dépenses des ménages)²¹².

En marge du chapitre, certains résultats statistiques sur les systèmes énergétiques concordent avec l'hypothèse formulée au chapitre 1 sur l'hétérogénéité des effets du CIDD en fonction du type d'investissement. L'influence prédominante de la vétusté des systèmes énergétiques dans la décision d'investissement révélée au chapitre 1 pourrait en effet expliquer l'absence d'impact significatif sur l'investissement à la marge extensive sur ces systèmes, contrairement aux investissements dans l'isolation. Cette distinction technologique justifierait aussi pourquoi d'autres travaux empiriques qui ne distinguent pas les types de travaux (Mauroux 2012²¹³ ou Risch 2013), ne trouvent quasiment aucun impact du CIDD sur l'investissement à la marge extensive. Enfin, ces résultats suggéreraient d'adapter les dispositifs de subventions. Comme le montre le chapitre 1, la décision d'investir est fortement déterminée par la vétusté pour les systèmes énergétiques et par des dynamiques propres au marché de l'immobilier pour les travaux de rénovation globale intégrant de l'isolation. Ce constat invite les régulateurs à ne pas subventionner ces « situations spécifiques » dans le but de déclencher la prise de décision. La subvention peut cependant continuer d'impacter l'investissement à la marge intensive dans ces « situations spécifiques » mais surtout l'investissement « aux deux marges » pour les autres types de situations. Peut-être faut-il alors réfléchir à des subventions différenciées selon le contexte, plus exigeantes en termes de performance énergétique en situation de mutation ou en cas de remplacement des systèmes par exemple. Ces « situations spécifiques » sont également caractérisées par des barrières à l'investissement moindres, ce qui peut expliquer une moindre inacceptabilité des propositions de mesures de régulation ou de taxation telles que l'obligation de travaux d'efficacité énergétique en situation de mutation ou à

²¹² De plus, si l'on suppose qu'un nombre d'investissements supplémentaires est réalisé grâce au CIDD, mais seulement chez les ménages les plus modestes, et que ces investissements additionnels représentent des dépenses moins élevées que les autres, alors cela peut faire diminuer la dépense moyenne des investissements chez ces ménages, conduisant à un effet non significatif sur l'investissement à la marge intensive.

²¹³ Le fait que Mauroux estime simplement l'effet d'une hausse marginale de taux est un autre facteur de divergence important.

la modulation des droits de mutations lors des transactions immobilières. Néanmoins, dans le cas des situations de mutation en particulier, ces politiques comportent un risque de rigidification du marché de l'immobilier, ce qui serait préjudiciable étant donné l'importance des dynamiques du marché de l'immobilier pour l'investissement dans les rénovations énergétiques globales (cf chapitre 1).²¹⁴

Le chapitre 3 prolonge l'analyse de l'efficacité des politiques publiques du côté de la demande en adoptant une méthodologie empirique alternative. Le recours au modèle de simulation MENFIS (Modèle ENergie FIScalité), élaboré en collaboration avec le Service Economie et Prospective de l'ADEME, permet de se tourner vers l'évaluation prospective tout en considérant des instruments alternatifs inobservables dans l'analyse ex-post. Etant donné la teneur des programmes de politiques publiques actuels, à savoir i) une priorité donnée aux subventions uniformes, ii) une recherche de diminution des coûts de financement à travers les mécanismes de Tiers-Financement et le renforcement de l'Eco Prêt à Taux Zéro (EcoPTZ), et iii) l'absence d'instrument type taxe Pigouvienne volontariste²¹⁵, ce chapitre cherche tout d'abord à comparer ces trois instruments. Les résultats montrent que les politiques annoncées et étendues jusqu'en 2025 ne permettront pas d'atteindre la cible légale de 38% de réduction de consommation énergétique d'ici 2020, surtout si l'EcoPTZ continue d'afficher un taux de recours aussi faible qu'aujourd'hui. La combinaison de l'EcoPTZ une fois les contraintes d'accès levées et de la taxe carbone telle que recommandée par le rapport Quinet (2008) s'avère être la meilleure politique, tant du point de vue de la réduction des consommations énergétiques, que de l'analyse coût-bénéfice des investissements générés et de l'équilibre budgétaire public. L'ajout des subventions dans ce scénario conduit à des gains minimes que ce soit en termes de réductions de consommations ou en termes de coût-bénéfice, bien qu'engendrant naturellement un surcroît de dépenses publiques. Ces résultats recommandent donc d'orienter les politiques vers la baisse des coûts du financement de l'investissement et la mise en place de signal prix type taxe carbone pour limiter l'effet rebond. Les résultats relatifs à la taxe carbone

²¹⁴ La modulation de la taxe foncière pourrait alors être privilégiée pour cette raison (Kieffer 2013).

²¹⁵ Ainsi qu'expliqué dans l'introduction du chapitre 3, d'autres politiques mineures sont mises en place dans la loi sur la Transition Énergétique et la Croissance Verte et les lois de Finance pour 2014 et 2015 ont introduit une composante carbone dans les accises énergétiques, mais bien en deçà des recommandations du rapport Quinet.

concordent avec des travaux antérieurs, ceux de Giraudet (2011) notamment. Les résultats sur l'EcoPTZ sont plus novateurs. C'est la relation explicite dans le programme de décision des ménages entre le taux d'actualisation et les variables financières (taux d'intérêt et de rémunération du capital) qui permet une modélisation de l'EcoPTZ distincte de celle des subventions à l'investissement et qui lui confère cette supériorité. Cela explique notamment la divergence des résultats avec ceux du modèle Res-IRF, qui n'opère pas cette distinction, montrant ainsi l'importance des hypothèses de modélisation sur ce point.

Le chapitre 3 s'intéresse ensuite à l'analyse intra-instrument, en revenant sur les modalités d'application des subventions. Il montre que pour un même montant de dépense publique sur 2008/2025, il serait économiquement plus efficace de mettre en place des subventions proportionnelles aux économies d'énergie qu'un système reposant sur un taux de subvention uniforme tel que pratiqué actuellement. Le ratio entre les coûts d'investissement et le volume d'économies d'énergie théoriquement généré, mesurant le coût-efficacité purement économique d'un scénario, est plus faible avec une subvention proportionnelle qu'en cas de subvention uniforme mais également qu'en situation de laissez-faire (sans politique), et ce pour un volume d'économies d'énergie supérieur. Bien que les gains à moduler le design des subventions semblent secondaires par rapport aux gains à changer d'instrument, ces résultats recommandent la mise en place de subventions plus progressives, dans l'esprit de celles de la KfW²¹⁶ ou des anciennes majorations de taux en cas de « bouquets de travaux » du CIDD, en veillant toutefois à assurer la clarté du dispositif. Il conviendrait en outre de discuter des éventuels effets connexes venant améliorer ou dégrader l'efficacité d'un dispositif, ce que l'on appelle respectivement les effets de crowding-in et de crowding-out dans la littérature. Selon l'analyse du CLER dans sa lettre au ministre de l'Ecologie d'octobre 2014 par exemple, « la logique des bouquets de travaux impose de comparer les offres et crée ainsi une saine concurrence entre les professionnels », facilitant également la structuration d'une offre de rénovation globale. Ou encore, comme le montre Houde (2012) sur les labels, l'absence de

²¹⁶ La banque publique d'investissement Allemande propose des subventions pour les travaux de rénovation énergétique dont le taux varie de 10 à 25% en fonction de la performance énergétique finale du logement.

progressivité dans les dispositifs peut inciter les entreprises à s'en tenir aux critères minimums, décourageant ainsi l'innovation.

Ce chapitre 3 s'efforce enfin de calibrer le modèle MENFIS à partir des sources statistiques disponibles sur la période 2008/2012 et de comparer les résultats aux travaux économétriques réalisés (chapitre 2 ou travaux externes). La comparaison de l'effet multiplicatif, à savoir le montant d'investissement privé généré par euro de dépense publique, entre les travaux économétriques (présentés en annexe du chapitre 2) et l'exercice de simulation est le dénominateur commun choisi pour évaluer la manière dont le modèle simule l'additionnalité des subventions. La comparaison entre ces deux exercices de modélisation de l'investissement des ménages dans la rénovation énergétique permet en outre de révéler les apports et les limites respectives de ces deux approches. Nous constatons notamment que l'effet du prix des énergies sur le niveau d'investissement reste important dans l'exercice de simulation, et ce même après avoir fait l'hypothèse d'une anticipation fortement myope du prix des énergies par les ménages, alors que le travail économétrique conclut à un effet non significatif du prix des énergies sur la décision d'investir. Des travaux supplémentaires seront donc nécessaires pour mieux estimer l'élasticité de l'investissement au prix des énergies, d'autant plus que très peu de résultats probants existent dans la littérature. L'exercice de simulation met également en évidence le rôle important de la décroissance du gisement d'investissements rentables à mesure que les rénovations progressent et que la performance énergétique du parc s'améliore. Cela implique de considérer attentivement la dépendance d'état dans les modèles économétriques, ce que le chapitre 2 fait à la marge faute de données suffisantes.

Le quatrième et dernier chapitre de la thèse se concentre quant à lui sur l'interaction entre les structures de marché et l'efficacité des politiques publiques. Le chapitre commence par étayer le caractère concentré des marchés de l'efficacité énergétique et la mise en œuvre probable des stratégies de discrimination en prix et en qualité des consommateurs (différenciation produit). Il reprend le modèle théorique d'économie industrielle de Mussa et Rosen (1978) constitué d'un monopole et de deux types de consommateurs hétérogènes dans leurs préférences pour la qualité. Dans notre modèle, à la manière de Fischer (2005), l'efficacité

énergétique représente la dimension qualité et une externalité négative issue de la consommation d'énergie y est introduite. Ce cadre nous permet d'analyser comment ces deux imperfections de marchés, à savoir l'externalité négative et les stratégies de discrimination prix-qualité issues la situation de monopole en information imparfaite, peuvent contribuer à l'Energy Efficiency Gap et engendrer une allocation d'efficacité énergétique sous-optimale.

Adoptant tout d'abord une approche normative à la recherche des politiques optimales, le chapitre montre que tout «binôme» d'instruments peut rétablir l'optimum social, bien que les effets distributifs puissent différer d'un instrument à l'autre. Les instruments étudiés sont les subventions, les standards et les taxes type Pigouvienne sur l'énergie. Un «binôme» d'instruments peut correspondre à la combinaison de deux instruments ou bien à un dispositif à instrument unique avec taux différenciés. Etant donné la prépondérance des subventions ad valorem, le plus souvent proportionnelles à l'efficacité énergétique des équipements, une attention particulière est accordée à la comparaison entre subvention ad valorem et spécifique (i.e. indépendante du prix), ainsi qu'au niveau de taux optimal des subventions. L'analyse des subventions ad valorem révèle notamment un effet secondaire pervers de détérioration de la qualité du bien faiblement efficace lorsqu'on cherche à subventionner le bien fortement efficace. Lorsqu'on adopte une approche plus positive, en analysant des situations plus proches des politiques observées, comme lorsque les subventions ne portent que sur le bien le plus efficace, cet effet confère un avantage comparatif à la subvention spécifique. Ce résultat recommande donc la mise en place de subventions spécifiques. Si la subvention spécifique domine la subvention ad valorem dans ces politiques de second-best, une taxe peut néanmoins prévaloir sous certaines conditions. En cas de taxe Pigouvienne sur l'énergie seule, l'analyse montre que son taux optimal est plus élevé que le niveau d'externalité négative, venant ainsi interpellé le résultat contraire classique en situation de monopole ainsi que les réflexions quant à l'existence d'un double dividende de la fiscalité écologique.

Prolongements

Les travaux économétriques portant sur l'évaluation du CIDD au chapitre 2 amènent de nouvelles questions de recherche. Concernant l'effet des prix de l'énergie sur l'investissement, il conviendrait de conduire de nouveaux travaux pour valider les résultats actuels. L'enquête « Maîtrise de l'Énergie » est réalisée depuis 1983, un prolongement du travail de valorisation des archives statistiques sur la période 1983/2000 permettrait de construire des séries temporelles longues (1983/2014), ce qui améliorerait sûrement l'estimation de l'effet prix²¹⁷. Une autre solution consisterait à utiliser des données individuelles de factures et/ou de consommations énergétiques. Mais, à moins de recourir à des méthodes statistiques correctrices, cela supposerait de recourir à d'autres jeux de données que celui de l'enquête « Maîtrise de l'Énergie ».

Les résultats des chapitres 1 et 2 ont opéré une distinction entre les investissements dans les systèmes énergétiques et ceux dans les mesures d'isolation (et les rénovations lourdes). Puisque l'analyse de l'impact du CIDD du chapitre 2 porte essentiellement sur les mesures d'isolation, il serait intéressant d'estimer plus précisément l'effet du CIDD sur les systèmes de chauffage, ce qu'il ne fut pas possible de faire avec l'enquête « Maîtrise de l'Énergie ». Pour ce faire, les données de l'enquête annuelles réalisée par le CEREN auprès des installateurs de chauffage mériteraient d'être étudiées²¹⁸. Enfin, il serait utile de produire des statistiques annuelles sur les travaux portant sur l'enveloppe du bâti mais dépourvus d'amélioration de l'efficacité énergétique (ravalement de façade, réfection de toiture, etc.). De telles séries temporelles n'existent pas en France à ma connaissance et ce pourrait être une suggestion d'amélioration pour l'enquête « Maîtrise de l'Énergie ». Cela permettrait notamment

²¹⁷ Lors d'une présentation en décembre 2013 de cette étude économétrique aux personnes en charge de cette enquête à la TNS Sofres et à l'ADEME, cette perspective de recherche a été évoquée et semblait réalisable, bien qu'il serait plus compliqué d'accéder aux bases de données les plus anciennes. A ma connaissance, de telles séries temporelles n'ont jamais été constituées.

²¹⁸ L'enquête contient des informations sur 3 500 logements, provenant d'environ 250 installateurs, qui permettent de chiffrer les renouvellements d'équipements de chauffage, que ceux-ci s'effectuent avec ou sans changement d'énergie de chauffage. (CEREN 2014). Une demande d'accès aux bases de données du CEREN avait été formulée en début de thèse. Celle-ci avait été refusée mais il serait intéressant de la renouveler dans le cadre d'une collaboration plus étroite avec le CEREN.

de considérer les travaux d'isolation comme un sous-ensemble à composante énergétique des travaux sur l'enveloppe et de voir comment ce sous-ensemble évolue au gré des politiques publiques et du prix des énergies.

Le modèle théorique utilisé dans le chapitre 4 repose sur des hypothèses fortes, notamment s'agissant du monopole et du marché couvert avec parts de marché fixes de chaque type de consommateurs. Concernant le monopole, l'analyse de ce cas extrême ne semble pas altérer la portée qualitative des résultats, comme le montre Fischer en étudiant le même phénomène dans un cadre monopolistique puis oligopolistique (2005, 2011). S'agissant de la représentation d'un marché couvert à part de marché fixe, cela implique d'ignorer les effets revenu et l'effet des instruments à la marge extensive, i.e. sur l'entrée de nouveaux consommateurs sur le marché. En lien avec le chapitre 1 et 2, cela peut se justifier lorsqu'on est sur des cas de remplacements contraints où les subventions n'impactent l'investissement qu'à la marge intensive. Dans les autres cas, cela signifie un traitement partiel du problème qu'il s'agirait donc de compléter. La littérature comparant la fiscalité ad valorem et spécifique (Keen 1998) fait enfin état d'un effet de dégradation de la qualité du bien peu efficace en cas de subvention spécifique²¹⁹ que notre modèle ne peut représenter en raison de sa mécanique interne conduisant à des parts de marché des consommateurs fixes. La prochaine étape du travail serait donc de tester empiriquement les résultats théoriques du modèle, en particulier la sous-provision d'efficacité énergétique des biens « bas de gamme » et l'effet de détérioration des subventions ad valorem. Cette tâche reste néanmoins difficile au vu de la faible disponibilité des données, comme l'atteste la rareté des travaux d'économétrie industrielle sur les marchés d'efficacité énergétique. Ceux de Houde (2013) sont une exception, utilisant des données

²¹⁹ Soient p_H^p and p_L^p les prix des biens H et L ($p_H^p > p_L^p$). La subvention spécifique σ augmente le prix relative du bien H $p_H^c - \sigma / p_L^c - \sigma > p_H^c / p_L^c$, ce que ne fait pas la subvention *ad valorem*. La demande pour les deux biens augmente avec la subvention via un effet revenu. Par un effet substitution (appelé *downgrading effect*), ce changement dans les prix relatifs pour la subventions spécifique conduit à un report de la demande vers le bien L. Par symétrie, la taxation spécifique conduit à un "*upgrading effect* » (Keen 1998).

rarement accessibles issues de fichiers privés d'entreprises de la grande distribution. Le marché de la rénovation énergétique, surtout le marché aval des artisans et installateurs, est d'autant plus compliqué à observer qu'il est décentralisé et hétérogène.

Les apports des différents chapitres appellent enfin à intégrer de nouveaux déterminants non négligeables dans les modèles de simulation prospective tels que Menfis. L'influence du marché de l'immobilier pour les travaux de rénovation d'ampleur type BBC révélée au chapitre 1 ou l'interaction entre les structures de marché de l'efficacité énergétique et les politiques analysée au chapitre 4 seraient les deux pistes d'amélioration à privilégier.

Il faut enfin rappeler que les enjeux de l'efficacité énergétique dans le résidentiel sont liés à d'autres problématiques socioéconomiques, telles que l'activité économique, l'emploi, les inégalités (la précarité énergétique), ou encore le double dividende de la fiscalité écologique et le coût d'opportunité des fonds publics en présence de restriction budgétaire. L'efficacité des politiques publiques d'efficacité énergétique devra donc in fine s'analyser dans un cadre macroéconomique.

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