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# The Energy Choices in Life Path: Modeling and Simulation under different Scenarios

Elie Lacroix

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Elie Lacroix. The Energy Choices in Life Path: Modeling and Simulation under different Scenarios. Economics and Finance. Université Paris sciences et lettres, 2016. English. NNT : 2016PSLED052 . tel-01560654

**HAL Id: tel-01560654**

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# THÈSE DE DOCTORAT

de l'Université de recherche Paris Sciences et Lettres  
PSL Research University

Préparée à l'Université Paris-Dauphine

Les choix énergétiques dans les trajectoires de vie :  
modélisations et simulations selon différents scénarios

École Doctorale de Dauphine — ED 543

Spécialité **Sciences économiques**

**Soutenue le 30.11.2016**  
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LES CHOIX ENERGETIQUES DANS LES TRAJECTOIRES DE VIE :  
MODELISATION ET SIMULATIONS SELON DIFFERENTS SCENARIOS

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## Les remerciements

Tout d'abord, je souhaiterais remercier et exprimer toute ma gratitude à mon équipe encadrante tant universitaire que professionnelle, Bertrand Villeneuve, Corinne Chaton et Florence Jusot, sans qui la réalisation de cette thèse n'aurait été possible. Je tenais à les remercier pour leurs précieux conseils, orientations et leur soutien tout au long de ce projet. D'autre part, cette thèse n'aurait pu voir le jour sans la confiance qui m'a été accordée par le projet précarité énergétique, notamment par Odile Estibals, et par EDF par l'intermédiaire duquel j'ai été financé. Egalement, comment aurait-je mené à bien ce projet sans la présence au quotidien des personnes de mon département d'adoption, EFESE ? Les innombrables échanges et discussions, qui ont fait mon quotidien, m'ont permis de mener à bien ce projet dans la sérénité, la bonne humeur et l'envie. Je souhaiterais donc remercier l'ensemble des personnes du département EFESE pour leur accueil chaleureux et leur joie de vivre au quotidien. Je souhaiterais remercier tout particulièrement Alvaro Andaluz Alcazar et Claire-Marie Bono pour leur soutien durant ces trois dernières années de thèse. Ils ont su m'aider, me conseiller et m'épauler dans les moments les plus délicats. Egalement, cette thèse a été l'occasion de « débriefer<sup>1</sup> » entre « thésards » de notre thèse et des difficultés auxquelles nous faisons face mais toujours avec le sourire<sup>2</sup>. Un grand merci à Robin, Nuno, Salah et Marie.

J'ai enfin une pensée émue pour ma famille et Capucine Villy qui grâce à leur soutien indéfectible ma permit de mener à bien ce projet si cher à mes yeux.

Cette thèse est dédiée à ma grand-mère Léontine Bazin (*Requiescat in Pace*)

« Le souvenir, c'est la présence invisible », Victor Hugo.

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<sup>1</sup> « Pourquoi je fais une thèse en fait ? », « Tu es en retard dans ta thèse ? », « Il te reste combien de temps avant de soutenir ? », « J'ai probablement un biais dans mon estimation mais je n'arrive pas à trouver une condition d'exclusion exogène ».

<sup>2</sup> Pas toujours quand même !

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# Introduction générale

Dans un contexte socio-économique français difficile, marqué notamment par un fort chômage (10,3 % en France métropolitaine<sup>3</sup> en 2015), une paupérisation grandissante de la population (14% de la population au seuil de 60% du revenu médian en 2013<sup>4</sup>), et un accroissement du mal logement (3.8 millions de personnes mal logés<sup>5</sup> en 2015), une nouvelle dimension de la précarité retient l'attention des pouvoirs publics : la précarité énergétique.

Le phénomène de la précarité énergétique n'est pas aisé à délimiter dans la mesure où une multitude d'éléments la définit. Ces multiples facteurs, la porosité et les interactions entre eux constituent un objet d'étude complexe.

En 2010, Boardman, identifie les trois éléments majeurs caractérisant le phénomène de la précarité énergétique et ce qui le différencie de la précarité sociale<sup>6</sup>. La vulnérabilité économique des ménages en constitue le premier élément. Assurément, les ménages en situation de précarité énergétique recoupent très largement les ménages en situation de précarité sociale car le revenu (ou niveau de vie) constitue un élément clé de ces deux types de précarités. Toutefois, un mauvais niveau d'efficacité énergétique de l'habitat peut constituer un facteur aggravant. Celui-ci constitue le deuxième élément relevé par Boardman. Enfin, le troisième élément tient au prix de l'énergie consommée. En effet, de forts tarifs couplés aux deux éléments précédemment énoncés peuvent provoquer le renforcement ou développement de nouvelles inégalités portant par exemple sur le montant de la part du budget allouée par les ménages aux dépenses énergétiques, mais également sur la satisfaction des besoins exprimés par les ménages (i.e., la température à l'intérieur de mon logement me convient-elle ?).

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<sup>3</sup> Source : Institut National de la Statistique et des études économiques (INSEE).

<sup>4</sup> Source : INSEE.

<sup>5</sup> L'état du mal logement en France, 21<sup>e</sup> rapport de la fondation abbé Pierre, 2016

<sup>6</sup> « La précarité est l'absence d'une ou plusieurs des sécurités permettant aux personnes et aux familles d'assumer leurs responsabilités élémentaires et de jouir de leurs droits fondamentaux. L'insécurité qui en résulte peut être plus ou moins étendue et avoir des conséquences plus ou moins graves et définitives. » (i.e., WRESINSKI, 1987).

En 2010, la loi Grenelle II<sup>7</sup> définit la précarité énergétique comme suit : « Est en situation de précarité énergétique au titre de la présente loi une personne qui éprouve dans son logement des difficultés particulières à disposer de la fourniture d'énergie nécessaire à la satisfaction de ses besoins élémentaires en raison de l'inadaptation de ses ressources ou de ses conditions d'habitat ». Cette définition de la précarité énergétique laisse apparaître l'aspect multidimensionnel du phénomène ainsi que les éléments fondamentaux le caractérisant, comme nous les avons énoncés précédemment (i.e., vulnérabilité économique, mauvaises conditions d'habitat et un coût trop important de l'énergie). De plus, l'action interventionniste de l'Etat français pour éradiquer la précarité énergétique sous-entend que le principe d'équité dans ce domaine est non satisfait. Il convient de rappeler qu'elles sont les mesures d'aides actuellement mise en place pour lutter contre ce phénomène, celles-ci étant au nombre de quatre. La première mesure concerne les tarifs sociaux de l'énergie. Il est qualifié de Tarif de Première Nécessité (TPN) pour la fourniture d'électricité et de Tarif Spécial de Solidarité (TSS) pour la fourniture de gaz. Notons que le TPN prend la forme d'une déduction forfaitaire qui est fonction du nombre de personnes composant le foyer bénéficiaire et de la puissance souscrite. Il correspond à une réduction sur la facture pouvant être comprise entre 71 € et 140 € par an. Le TPN est financé par la contribution au service public de l'électricité (CSPE). 3 millions de ménages bénéficie actuellement de cette mesure. Concernant le TSS, tout comme le TPS, prend la forme d'une déduction forfaitaire dépendant de la tranche de consommation et de la taille du foyer et pouvant correspondre à une réduction de facture comprise entre 23 € et 185 € par an. Il est financé par la contribution au tarif spécial de solidarité (CTSS) payée par les fournisseurs de gaz. Cette aide bénéficie à environ 4 millions de ménages. Bien que ce dispositif compte un grand nombre de bénéficiaires, ces dispositifs permettent de réduire de moins de 10% le montant des factures énergétiques des ménages

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<sup>7</sup> <http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id>

(environ 90€ annuels par ménages (Tyszler et al., 2013)). De plus celui-ci exclut les ménages utilisant d'autres sources d'énergie (bois, fioul ou charbon). Ceci mettant l'accent sur le relatif faible impact de cette aide et son caractère inégalitaire. Notons que ce dispositif des tarifs sociaux va être remplacé début 2018 par le chèque énergie. Celui-ci pourra être utilisé pour le paiement total ou partiel de la facture énergétique et ceux quelque soit le type d'énergie utilisée par le ménage) ou pour l'achat d'équipement énergétique moins énergivores visant à l'amélioration de la qualité environnementale du logement. Les critères d'obtention seront identiques à ceux pour les tarifs sociaux de l'énergie. Cette mesure vise à une meilleure égalité de traitement quant aux différents types d'énergies utilisées par les ménages. Une seconde mesure existante est appelée le Forfait de charges liés aux allocations logement. Celle-ci est versée par la Caisse d'Allocation Familiales (CAF), elle est attribuée sous condition de ressources et concerne les ménages locataires et propriétaires accédant. Jacquot et al. (2004) relèvent que cette aide sous-évalue le niveau de dépenses énergétiques pour certains ménages modestes en notant l'insuffisance quant à la prise en compte du nombre d'individus dans le ménage et de ses caractéristiques propres. Cette aide est attribuée sous forme forfaitaire. L'objectif affichée par les pouvoirs publics est identique à celui des tarifs sociaux de l'énergie, la réduction des coûts engendrées par les dépenses énergétiques pour les ménages. Enfin, la troisième mesure est le Fonds de Solidarité pour le Logement (FSL). Cette aide correspond à l'obtention de prêts ou subventions pour accéder à un habitat et pouvant également être utilisé pour le paiement d'impayés d'énergie, d'eau ou de téléphone. En 2009, le montant de l'aide perçu par les bénéficiaires est très hétérogène (33€ dans le département de la Vienne et 1293€ en moyenne pour le département du Tarn (Lenfant et al., 2014). L'objectif de cette mesure est de proposer un dispositif d'aide face aux situations d'urgence. Toutefois, les écueils réalisés à l'égard de ce dispositif sont le manque d'uniformisation des critères d'attribution entre département, allant à l'encontre du principe d'égalité et de réelles

difficultés quant au délai d'obtention de cette aide. La présentation de ces différentes mesures de lutte contre la précarité énergétique révèle l'intérêt porté par les pouvoirs publics à cette question et son désir de poursuite de l'équité (i.e. chèque énergie). Toutefois, ces mesures souffrent d'insuffisances et d'un manque d'équité comme précédemment énoncé. De plus, le concept d'équité appliqué à la précarité énergétique ou plus précisément lié à l'accès et au financement du bien énergie n'a pas encore été énoncé. Toutefois, dans un premier temps, il convient de rappeler la distinction existante entre le concept d'équité et d'égalité. Lalande (1926) définit l'équité de la façon suivante, il s'agit du « sentiment sûr et spontané du juste et de l'injuste, en tant surtout qu'il se manifeste dans l'appréciation d'un cas concret et particulier ». Par conséquent, l'équité implique un jugement de valeur induisant donc qu'une inégalité pourra être considérée comme légitime ou non. C'est en cela que l'équité est à distinguer de l'égalité.

De plus, au sein même du concept d'équité, deux notions peuvent être distinguées : l'équité verticale de l'équité horizontale.

L'équité horizontale induit un traitement identique (i.e., également) pour des individus semblables. L'équité verticale quant à elle conduit à traiter différemment (i.e., inégalement) des individus hétérogènes. Ces deux types d'équité font référence au principe de justice distributive défini par Aristote.

A titre d'exemple, au sein du système de santé français, la recherche d'équité horizontale prévaut pour le système d'accès aux prestations de soins alors que la recherche d'équité verticale prévaut pour le système de financement des soins de santé. Ainsi, la recherche d'équité horizontale pour le système de soins français recherche la mise en place et l'obtention d'un traitement égal pour des individus ayant des besoins de santé égaux, quel que soit le niveau de revenu des individus. A titre d'exemple deux individus ayant les mêmes états

de santé (i.e., donc les mêmes besoins), mais dont les caractéristiques socio-économiques et sociodémographiques peuvent différer, devraient pouvoir bénéficier des mêmes soins de santé.

Concernant la recherche du principe d'équité verticale, elle est motivée par la détermination des différents niveaux de contribution financière des ménages au système de santé compte tenu du fait que les ménages détiennent des capacités financières variables. Autrement dit, elle cherche à savoir comment des ménages ayant des contributions financières différentes doivent contribuer inégalement au financement du système de santé (à travers l'impôt, cotisations sociales etc., Lachaud, C. & Rochaix, L., 1995). Autrement dit, deux individus possèdent des propensions à payer différentes (respectivement une forte et une faible), leurs contributions au financement du système de soins seront différentes, l'individu ayant une plus forte propension à payer participera financièrement plus au financement du système de soins que l'autre individu. Ainsi, la Couverture Maladie Universelle en France incarne la poursuite par l'Etat de cet objectif d'équité verticale dans la propension à payer et la progressivité dans le financement de celui-ci. En effet, celle-ci favorise l'accès et le recours aux soins pour les individus les plus démunis.

Par conséquent, l'application de ces principes d'équité (i.e., horizontale et verticale) au champ de la précarité énergétique prendrait la forme suivante. D'une part, la recherche de l'équité horizontale quant à l'accès au bien énergie se manifesterait par la mise place de mesures visant à l'éradication des restrictions individuelles sur le niveau d'énergie consommé afin que les propres besoins et désirs individuels soient satisfaits. D'autre part, la recherche de l'équité verticale lié au financement de cette consommation d'énergie, elle aurait comme finalité de limiter à un montant jugé acceptable (et juste) par la société le coût de ce poste de dépense pour un ménage. Notons qu'il ne s'agit pas ici nécessairement d'atteindre une égalité parfaite des montants d'énergie consommés entre les individus. En effet, la dimension de besoins

individuels de consommation d'énergie doit être développée. Autrement dit, il s'agit de discuter de la concordance des besoins de consommation énergétique et le recours effectif à la consommation de ce bien. Une consommation supérieure d'énergie pourra être jugée acceptable pour des ménages vivant dans des logements dont la superficie est supérieure. Néanmoins, à besoins énergétique identiques, une consommation en niveau différente serait jugée inacceptable. Ainsi, si les inégalités de consommation d'énergie ne sont pas dues à des différences dans les besoins des individus mais à des caractéristiques socio-économiques et sociodémographiques propres (i.e., niveau de revenu) alors la présence de ces inégalités indiquera la non-satisfaction du principe d'équité horizontale quant à l'accès au bien énergie.

Par ailleurs, au regard des multiples facettes composant la précarité énergétique, la question des instruments de mesure à utiliser se pose. Deux grandes catégories d'indicateurs de mesure peuvent être identifiées. D'une part, les indicateurs subjectifs étant aux nombres de trois, tous déclaratifs. Le premier interroge les ménages sur la sensation de froid ressenti au sein de leur foyer au cours de l'hiver dernier (i.e.,  $\approx 14\%$  des ménages français via l'Enquête sur la Santé et la Protection Sociale (ESPS) de 2010). Aussi, les raisons pour lesquelles ces ménages ont souffert du froid peuvent être demandées. Les modalités proposées sont soit pour raisons financières (i.e.,  $\approx 4.5\%$  des ménages Français, ESPS (2010)) de la population, pour une mauvaise qualité d'isolation du logement (i.e.,  $\approx 7\%$  des ménages Français, ESPS (2010)), due à une panne des installations de chauffage du logement (i.e.,  $\approx 3\%$  des ménages Français, ESPS (2010)), une installation de chauffage insuffisante (i.e.,  $\approx 4.5\%$  des ménages Français, ESPS (2010)), ou pour d'autres raisons (i.e., intempéries par exemple,  $\approx 2.5\%$  des ménages Français, ESPS (2010)). Un second interroge les ménages sur leur capacité à payer leur facture énergétique à temps ( $\approx 7\%$  des ménages Français, Statistiques sur les Ressources et les Conditions de Vie des ménages, SRCV, 2011). Enfin, un troisième correspond à la capacité financière des ménages à maintenir leur logement à une température adéquate (i.e.,

≈ 5.5% des ménages Français, (SRCV, 2011) ou si leur logement est difficile ou trop coûteux à chauffer (i.e., ≈ 25% des ménages Français, SRCV, 2011). Notons également qu'un proxy de la précarité énergétique est également utilisé, celui-ci interroge les ménages sur la présence d'humidité dans de multiples endroits dans le logement des individus (i.e., ≈ 3% des ménages Français, ESPS 2010). D'autre part, les indicateurs dits « objectifs » sont au nombre de trois.

Le premier, le plus couramment utilisé et celui utilisé par l'INSEE, correspond au taux d'effort énergétique. De façon conventionnelle, un individu sera considéré comme précaire énergétique si celui-ci alloue plus de 10% de son revenu aux dépenses énergétiques<sup>8</sup> (i.e., ≈ 14% des ménages Français, Enquête Nationale Logement, 2006).

Un second, dit indicateur de « Hills » (Hills, 2012) a recours à l'utilisation de deux seuils relatifs pour caractériser un individu en situation de précarité énergétique. Un seuil de revenu, correspondant à 60% du revenu médian, auquel est ajouté la facture énergétique modulée et normalisée du ménage, et un seuil de montant de dépenses énergétiques minimal correspondant à la médiane observée sur la population<sup>9</sup>.

Egalement, l'indicateur de « Moore » (Moore, 2012) considère qu'un individu est précaire énergétique, si le revenu disponible auquel sont soustraits les coûts liés au logement ainsi qu'un niveau de revenu minimum permettant de couvrir les besoins vitaux (hors dépenses énergétiques), ne permet pas de couvrir ses dépenses énergétiques qui ont été au préalable normalisées et modulées<sup>10</sup>.

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<sup>8</sup> Le seuil retenu de 10% correspond au double de la médiane du taux d'effort énergétique calculé à partir de l'enquête budget des familles au Royaume-Uni en 1988 (B.Boardman, 1991).

<sup>9</sup> Cet indicateur estime qu'en 2012 environ 10% des ménages Anglais sont considérés comme précaire énergétique avec cet indicateur (i.e., Hills, 2012).

<sup>10</sup> En 2008, il est estimé qu'environ 17% des ménages anglais considérés comme précaires énergétiques (Moore, 2012).

Comme nous le mentionnions précédemment, la littérature économique traitant du sujet de la précarité énergétique est marquée par une absence de consensus sur le type d'indicateur devant être privilégié pour analyser ce phénomène. Toutefois, la précision du concept d'équité horizontale lié à l'accès au bien énergie et de l'équité verticale lié au financement de celui-ci, illustre que chaque indicateur de mesure de la précarité énergétique peut être un instrument d'évaluation du degré d'équité (horizontale pour l'accès à l'énergie et verticale concernant son financement). En effet, l'indicateur interrogeant les ménages sur le froid ressenti dans leur logement (i.e., ESPS, 2010) révèle l'insatisfaction des besoins relatifs au bien énergie. Ainsi, le principe d'équité horizontale quant à l'accès au bien énergie est ici bafoué (non vérifié). D'autre part, l'indicateur du taux d'effort énergétique de Boardman<sup>11</sup> nous enseigne (indique) que si ce seuil est dépassé, le principe d'équité verticale ne sera pas vérifié.

L'Etat providence que constitue l'Etat français, à inspiration Bismarckienne et Beveridgienne, se doit d'être un acteur de la solidarité publique<sup>12</sup> et un garant de la cohésion sociale<sup>13</sup> et par conséquent de l'équité. Les mesures de redistribution verticale et horizontale des revenus par exemple constituent les deux principaux instruments pour garantir l'équité et pour lutter contre les inégalités. De plus, l'accès et le financement du bien énergie rentrent dans le champ d'action de l'Etat dans la lutte pour la réduction des inégalités (i.e., chèque énergie, 2015 ou encore « bouclier énergétique », 2015). Ainsi, aborder le phénomène de précarité énergétique sous l'angle de l'équité horizontale et verticale permettrait de caractériser de façon multidimensionnelle ce phénomène afin que les mesures mises en place pour contrecarrer ce phénomène soit plus ciblées et efficace. L'analyse de la précarité énergétique à travers les concepts l'équité horizontale et verticale apparaît alors résolument pertinente.

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<sup>11</sup> Celui-ci fixe à 10% le pourcentage maximal de son revenu « socialement » acceptable qu'un individu devrait allouer à la consommation du bien énergie.

<sup>12</sup> « La Nation proclame la solidarité et l'égalité de tous les Français devant les charges qui résultent des calamités nationales. », Préambule de la constitution du 27 octobre 1946.

<sup>13</sup> <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000806166&categorieLien=id>

Cette thèse cherchera à répondre à la question suivante :

**L'analyse du phénomène de la précarité énergétique via la recherche de l'équité horizontale et/ou verticale est-elle pertinente compte tenu de l'aspect multidimensionnel de ce phénomène ?**

D'une part, une discussion de ce phénomène en termes d'équité permettra de mettre en exergue l'existence ou non d'inégalités, justifiant ainsi la mise en place de mesures complémentaires, voire nouvelles, en faveur d'une plus grande équité entre individus concernant le bien énergie. La caractérisation de la dynamique de ce phénomène dispensera également de précieuses informations sur le type de mesures (i.e., aides au paiement de factures, modes de paiement de facture innovants, aides à la rénovation du logement) pouvant être mises en place pour contrecarrer ce phénomène, et ainsi participer à la poursuite des objectifs d'équité sous-jacents.

D'autre part, l'étude des conséquences de la précarité énergétique sur d'autres dimensions que celles faisant référence à l'énergie (i.e., santé) permettrait d'interpeller les décideurs politiques sur son aspect multidimensionnel et poreux avec d'autres dimensions de la précarité sociale. Ce phénomène pourrait être un vecteur concourant à l'aggravation d'autres inégalités (i.e., inégalités de santé), pouvant ainsi compromettre la poursuite de l'objectif d'équité des décideurs publics.

Enfin, l'étude de nouveaux moyens de paiement innovants du bien énergie, à moindres coûts, pourrait concourir et participer à l'atteinte des objectifs respectivement d'équité horizontale et verticale.

Cette thèse s'articulera donc autour de quatre chapitres :

## **1. Existe-t-il, en France, des inégalités liées aux dépenses énergétiques ?**

Alors que la part budgétaire moyenne allouée par les ménages aux dépenses énergétiques semble stable depuis 20 ans (Merceron & Theulière, INSEE, 2010), cette même étude indique que l'étendue entre les plus forts et les plus faibles niveaux de consommations s'est accru. Il s'agit d'une première indication de l'existence d'inégalités de consommation du bien énergie. Ainsi, ce premier article propose une analyse approfondie de l'existence d'inégalités de dépenses énergétiques en 2011 en France. Les contributions de ce chapitre tiennent à l'utilisation de données plus récentes sur le France et où l'analyse des inégalités de dépenses d'énergie et du poids qu'elles génèrent est mener en absolue mais également de façon relative au niveau de vie. L'objectif de cette étude est d'identifier l'amplitude, la concentration et les déterminants des inégalités ayant attrait aux dépenses énergétiques (or dépenses de mobilité) et au poids qu'elles constituent pour le budget des individus.

Nous montrerons l'existence d'un fort niveau d'inégalités concernant le niveau de dépenses énergétiques et sur le poids engendré par celles-ci sur le niveau de vie des individus. Entre autres, la contribution des dépenses énergétiques pour motif de chauffage (ou eau chaude sanitaire), non incluses dans les dépenses d'électricité ou de gaz, aux inégalités globales de dépenses énergétiques est la plus forte. Par ailleurs, l'étude révèle une plus forte concentration des niveaux élevés de dépenses énergétiques chez les individus les plus aisés. De plus, celles-ci sont marquées par une absence de progressivité. A contrario, les individus à faibles revenus concentrent des taux d'efforts énergétiques plus élevés par rapport aux individus à fort niveau de revenu et ceci en dépit de niveau de dépenses énergétiques inférieures en valeur absolue pour les individus à faibles revenus.

Enfin, le manque de pouvoir d'achat apparaît comme étant le déterminant majeur du différentiel du niveau de dépenses énergétiques moyen entre individus pauvres et non

pauvres<sup>14</sup>. La constatation de l'existence d'inégalités brutes et relatives au revenu concernant les montants de dépenses énergétiques et de leur poids engendré sur le niveau de vie des ménages, justifie de concentrer l'analyse sur la précarité énergétique via l'équité (i.e., horizontale et verticale). Ainsi, une compréhension de la dynamique, plus que statique, de la précarité énergétique et de ses déterminants semble primordiale pour un meilleur ciblage et un gain d'efficacité de politiques publiques à mettre en place pour contrecarrer ce phénomène et garantir l'équité à la fois sur l'utilisation (i.e., équité horizontale) et le financement (i.e., équité verticale) du bien énergie.

## **2. La précarité énergétique : un phénomène transitoire ou permanent (immuable, chronique) ?**

Alors que la majeure partie de la littérature économique traite le sujet de la précarité énergétique de façon statique, excepté Phimister et al. (2014), la connaissance et la caractérisation de ce phénomène comme transitoire ou chronique, ainsi que l'identification des facteurs d'entrée, de sortie de l'état de précarité énergétique et les déterminants de stabilité dans cet état semblent nécessaires au bon ciblage de politiques publiques pour éradiquer ce phénomène, et mener à bien l'objectif d'équité. Cette étude constitue une analyse originale de la dynamique de la précarité énergétique à partir de données françaises. La précarité énergétique est approchée via l'équité horizontale et verticale. En effet, un premier état de précarité énergétique dit « *simple* » est défini via la difficulté à maintenir son logement à la bonne température même si les ressources financières détenues par l'individu sont suffisamment élevées pour faire face à ses dépenses de chauffage. Un second état de précarité énergétique dit « *sévère* » caractérise les individus qui rapportent des difficultés à maintenir leur logement à la bonne température et ne détiennent pas les ressources financières suffisantes pour faire face à leurs dépenses de chauffage. La dichotomie de la précarité

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<sup>14</sup> Notons que les seuils de 50% et 60% du revenu médian sont utilisés dans les estimations.

énergétique en deux états permet la prise en compte des deux principes d'équité (i.e., horizontale et verticale). En effet, rapporter des difficultés à maintenir son logement à la bonne température, dont les raisons peuvent être diverses (logement mal isolé, les tarifs des énergies considérés comme trop importants etc...) illustrent l'insatisfaction des besoins des individus quant à l'utilisation du bien énergie, sachant que la capacité financière des individus leur permet d'y faire face. Ainsi, le principe d'équité horizontale, quant à l'utilisation du bien énergie, n'est ici pas respecté, alors que le principe d'équité verticale portant sur le financement de celui-ci l'est. En revanche, l'état de précarité énergétique révèle la non-satisfaction des deux dimensions, horizontale et verticale de l'équité.

Les résultats de cette étude indiquent que la proportion d'individus vulnérables à la précarité énergétique simple ou sévère est non négligeable ( $\approx 15\%$ ). Le phénomène de précarité énergétique semble être plus transitoire que chronique, même si les proportions estimées d'individus enclavés dans ces états de précarité énergétique ne sont pas négligeables. Pour les individus transitant entre les différents états (i.e., n'étant pas en situation chronique de précarité énergétique), nous observons que les probabilités de transition entre eux sont élevées. Ceci se traduit par de fortes probabilités d'aller-retour entre état de non-précarité énergétique et état de précarité « *simple* » principalement. Ainsi, un individu considéré aujourd'hui comme précaire énergétique, ne le sera pas nécessairement demain.

Enfin, l'identification des déterminants de stabilité et de transition en situation de précarité énergétique enrichissent par ailleurs la caractérisation de la dynamique du phénomène. Ainsi, des facteurs socio-économiques tel qu'un faible niveau de revenu, un faible niveau d'éducation, une situation de chômage, vivre dans un appartement ou vivre seul, affectent profondément le risque de stabilité et de transition vers une situation de précarité énergétique.

La mise en perspective de cette étude semble justifier la mise en place de mesures d'aide de court terme (i.e., aide au paiement de facture) et de plus long terme (i.e., rénovation du logement) ainsi que la complémentarité de celles-ci afin de répondre aux besoins d'une part des individus expérimentant la précarité énergétique de façon transitoire ou de façon chronique. Toutefois, un effort plus marqué devrait être mené pour les mesures de soutien de court terme compte tenu du caractère plus transitoire que chronique du phénomène de précarité énergétique.

Après avoir caractérisé la dynamique du phénomène de la précarité énergétique ainsi que les déterminants de stabilité et de transition entre les différents états, l'étude des conséquences de la précarité énergétique sur d'autres dimensions semble pertinent dans la mesure où celle-ci pourrait rendre difficile la poursuite des objectifs d'équité dans d'autre domaine que celui de l'énergie (i.e., secteur de la santé). En effet, la précarité énergétique pourrait entraîner un niveau de chauffage trop faible qui aurait comme impact direct une détérioration ou aggravation de l'état de santé des individus y étant exposés. D'autre part, une portion trop importante du revenu allouée aux dépenses énergétiques entraînerait une diminution du budget alloué à d'autres postes de dépenses par le ménage tels que le budget alloué aux dépenses de santé.

### **3. La précarité énergétique est-elle nocive pour la santé ?**

En 2012, 26.7 % de la population métropolitaine âgée de 18 à 64 ans déclarait avoir renoncé à au moins un soin pour des raisons financières au cours des douze derniers mois<sup>15</sup>, ceci participant à l'accroissement des inégalités de santé et mettant en échec la réalisation du principe d'équité horizontale quant à l'accès aux soins. Dès lors, compte tenu du jeu de vases communicant, l'étude de l'impact de la précarité énergétique sur la santé permettrait de

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<sup>15</sup> [http://www.drees.sante.gouv.fr/colloque-renoncement-aux-soins\\_10120.html](http://www.drees.sante.gouv.fr/colloque-renoncement-aux-soins_10120.html) (Actes du colloque « Renoncement aux soins » du 22 novembre 2011 publiés par la Drees)

d'identifier si la précarité énergétique peut être un facteur d'aggravation des inégalités dans d'autres domaines socio-économiques.

Un travail préliminaire intitulé : « Fuel poverty has a major determinant of perceived health : the case of France<sup>16</sup> » identifiait une corrélation négative claire entre la précarité énergétique<sup>17</sup> et la santé auto-déclarée des individus y étant exposés. Dans cette thèse, un travail d'approfondissement (i.e., Chapitre 3) s'intéresse à la quantification de la précarité énergétique sur différentes dimensions de la santé et le traitement d'un biais d'endogénéité potentiel. En effet, un facteur individuel non observable pouvant détenir une influence conjointe, à la fois sur l'évaluation de la précarité énergétique telle qu'elle est mesurée dans cette étude et le caractère subjectif des mesures de l'état de santé que nous utilisons (i.e., santé auto-déclarée, souffrir d'une affection de longue durée --ALD-- et avoir un mauvais score de santé mentale) a été identifié. Le degré de sensibilité au froid peut effectivement venir altérer la capacité des individus à correctement évaluer leur situation de précarité énergétique mais également altérer leur jugement quant à l'évaluation de leur état de santé objectif. Ainsi, la non prise en compte de ce facteur confondant pourrait conduire à une sous-estimation ou à une surestimation de l'impact de la précarité énergétique sur les différentes mesures de santé.

Nous montrons que la précarité énergétique telle qu'elle est mesurée dans cette étude a un impact significatif et prépondérant sur la probabilité de déclarer une ALD, de déclarer un mauvais état de santé et d'obtenir un mauvais score de santé mentale. Cette étude identifie donc la précarité énergétique comme un facteur participant à l'accroissement des inégalités de santé. L'identification de conséquences délétères de la précarité énergétique sur différentes dimensions de santé nous pousse à rechercher des solutions concrètes pour la contrecarrer. De

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<sup>16</sup> Lacroix, E. & Chaton, C., 2015, "Fuel poverty has a major determinant of perceived health: the case of France ", Public Health, Elsevier, 21-37.

<sup>17</sup> La précarité énergétique est mesurée à travers la sensation de froid ressenti au sein du logement durant au moins 24 heures durant l'hiver dernier (ESPS, 2010).

plus, les coûts générés par les mesures d'aides pour réduire la précarité énergétique<sup>18</sup> justifient la poursuite d'un objectif de grande efficacité et d'efficience de ces mesures d'aides. Ainsi, dans un souci d'efficacité et de poursuite des objectifs d'équité horizontale et verticale, la recherche de solutions de paiements innovants semble judicieuse.

#### **4. Pourquoi le prépaiement et post-paiement ne sont pas équivalents ?**

##### **Conséquences pour la tarification sociale**

La théorie économique traditionnelle du comportement du consommateur qualifié de rationnel nous enseigne que les individus sont les mieux placés pour gérer leurs dépenses et que contraindre les choix individuels de consommation serait défavorable et sous-optimal. Toutefois, de nombreuses constatations révèlent que les consommateurs à faible niveau de revenu peuvent, sous la pression de l'urgence et sous des contraintes de liquidité marquées, faire des choix personnels inférieurs (sous-optimaux).

Des moyens financiers supplémentaires octroyés à ces ménages au mauvais moment, ou sous la mauvaise forme, pourraient manquer d'efficacité. Ainsi, cet article propose de comprendre les différents types d'arbitrage que la précarité énergétique peut entraîner.

Nous modélisons pour un consommateur l'arbitrage budgétaire intertemporel entre deux biens : un bien dit composite et un bien énergie. Nous introduisons l'incohérence temporelle sur le bien énergie dans cette modélisation, et non pas sur l'ensemble des biens. Cette incohérence qui diffère selon les biens est par ailleurs un élément de modélisation qui n'a pas encore été employé dans la littérature.

Ainsi, l'individu aura tendance soit à surpondérer soit sous-pondérer le niveau d'utilité associé à la consommation immédiate de ce bien énergie. Enfin, différents « *timing* » de

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<sup>18</sup> Trois milliards d'euros sont dépensés chaque année dans sa seule dimension logement (Erard et al., 2015).

paiement du bien énergie sont modélisés: le paiement mensuel de la quantité du bien énergie consommée (à chaque période), le paiement ex-post (les quantités consommées sont payées à la dernière période) et le prépaiement (disponibilité du bien uniquement en première période).

Les résultats indiquent que le système de prépaiement atténue (corrige en partie) l'incohérence temporelle des individus qui en souffrent. Egalement, la comparaison des niveaux d'utilité intertemporelle entre les différents moyens de paiement nous indique que malgré le caractère contraignant du prépaiement, celui-ci sera toujours préféré par les individus incohérents temporellement dans notre modélisation sous certaines conditions très peu contraignantes. Rappelons que lorsque l'incohérence temporelle est absente, les individus sont indifférents entre les différents moyens de paiement pouvant être choisis, comme il l'est prévu par la théorie économique du consommateur rationnel.

Par conséquent, le prépaiement pourrait être un outil d'aide à la gestion budgétaire pour les individus en situation de précarité énergétique, et aider à la poursuite des objectifs d'équité, mais également contribuer à l'instauration de solutions et mesures efficaces à moindres coûts pour les décideurs publics.

# *Chapitre 1: Energy expenditures in France: an inequality analysis<sup>19</sup>*

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<sup>19</sup> The views, assumptions and opinions expressed in this paper are those of the authors.

# 1. Introduction

In the political debate over energy policies, the social dimension is becoming more and more important. The Energy Transition Law for Green Growth (2015) promotes social discussions about the energy good because the protection of vulnerable customers is one of the government's goals<sup>20</sup>. In 2010, the Grenelle II <sup>21</sup> defined the fuel poor as follows: “*a household that has difficulties disposing of the necessary energy to satisfy its basic needs due to the inadequacy of its resources or its living conditions is in fuel poverty under this Act*”.

In contrast to other common goods, the energy good is considered a basic commodity<sup>22</sup>, and the number of households experiencing fuel poverty has been increasing for several years<sup>23</sup>. This means that the financial burden of energy expenditures is not equal among households with different levels of income. Moreover, living at an indoor temperature that is too low has negative consequences for health (i.e., E. Lacroix & F. Jusot, 2015), and the financial burden of energy expenditures may have deleterious consequences for general living conditions. Thus, the issue of inequality in energy expenditures, and the vulnerability that it can generate, must be tackled.

The French National Institute of Statistics and Economics (INSEE) indicates that the share of income dedicated to energy expenditures (both residential and transport uses) has been constant for 20 years according to national accounts data (2015). In 2015, energy expenditures represented 8.8% of the average household budget (divided into 5% for residential use and 3.8% for transport). In 2006, energy expenditures represented (on average) the sixth most

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<sup>20</sup> [https://www.legifrance.gouv.fr/eli/loi/2015/8/17/2015-992/jo/article\\_3](https://www.legifrance.gouv.fr/eli/loi/2015/8/17/2015-992/jo/article_3)

<sup>21</sup> <http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id>

<sup>22</sup> <https://www.legifrance.gouv.fr/affichCodeArticle.do?cidTexte=LEGITEXT000023983208&idArticle=LEGIARTI000023986686&dateTexte=&categorieLien=cid>

<sup>23</sup> Studies by the French National Institute of Statistics and Economics (INSEE) estimate that 15% of the French population was fuel poor in 2008, whereas the percentage of fuel poor in 1996 was 10.9%. Note that the definition of fuel poverty used for this study is the following: a household is fuel poor if it spends more than 10% of its income on fuel expenditures (Boardman, 1991).

important expenditure item (out of 13 items) for a household in France.<sup>24</sup> (Merceron & Theulière, INSEE, 2010). Even if the share of income allocated to energy expenditures for residential use is constant, a study by Merceron & Theulière (INSEE, 2010) indicated that the gap in the level of energy expenditures between low-income households and high-income ones has tended to increase over time. Moreover, there could exist a potentially strong heterogeneity behind the average 8.8% allocated by a household to energy expenditures. Indeed, different living conditions, as well as different consumption choices across individuals or social groups, have a strong influence on energy expenditures.

The issue of inequality in energy expenditures has not been fully explored in the economic literature. As far as we know, to date there is no existing analysis of social inequalities in energy expenditures and their determinants. This article proposes an analysis of inequalities in energy expenditures for residential use in France for the year 2011 (the most recent data available). A better understanding of these energy expenditure inequalities and their determinants could provide valuable information to public decision makers.

We use Lorenz curves (i.e., subsection 2.3) and Gini decompositions by source to determine whether energy expenditure inequalities exist across populations (i.e., subsection 2.4). Additionally, econometric regressions are performed to determine the profile of the fuel poor and the profile of those individuals with high energy expenditures (i.e., subsection 2.4). Finally, this analysis is enriched by using concentration curves (i.e., subsection 3.1), a concentration index (i.e., subsection 3.1) and its decomposition (i.e., subsection 3.1), and Kakwani (i.e., subsection 3.2) and Blinder-Oaxaca decompositions to identify whether socioeconomic inequality in some energy expenditures exists; whether energy expenditures are progressive or not; and finally, to explain inequalities between poor and better-off households (i.e., subsection 3.3).

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<sup>24</sup> The first and most important item for a household budget is food/nutrition.

## **2. Distribution analysis of energy expenditures and their budget shares in France in 2011**

### **2.1. Data**

This study is conducted based on data from the 2011<sup>25</sup> wave of the Statistics on Resources and Living Conditions (SRCV) survey conducted by the French National Institute of Statistics and Economic Studies (INSEE). This survey is part of the European Union Statistics on Income and Living Conditions (EU-SILC), which uses face-to-face interviews to collect information on income distribution, poverty, social exclusion and living conditions. It is considered a reference for income distribution comparisons among European Union member states and for community actions against social exclusion. The longitudinal component of this survey consists of a sample of all individuals older than 15 who live in 16,000 dwellings (selected from the master sample) and a sampling frame for new housing<sup>26</sup>.

Energy expenditure information (i.e., electricity consumption, gas consumption and heating expenditures) is collected using the following six questions:

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<sup>25</sup> Latest data available.

<sup>26</sup> All of these individuals are followed over time, even when they move to other dwellings.

Type of household	Electricity expenditures	Gas Expenditures	Heating or hot water expenditures not already included in electricity or gas expenditures
-If the head of household is the homeowner and does not pay condominium fees	How much do you spend per year for electricity? (MELEC)	How much do you spend per year for gas? (MGAZ)	How much do you spend per year for heating or hot water (excluding electricity or gas expenditures previously reported)? (MCHAUF)
-If the head of household is the homeowner and pays condominium fees <b>or</b> -If the head of household is a tenant and pays rental charges but these charges (condominium fees, rental charges) do not include electricity bills	How much do you spend per year for electricity? (MIELEC)	How much do you spend per year for gas? (MIGAZ)	How much do you spend per year for heating or hot water (excluding electricity or gas expenditures previously reported)? (MICHAUF)

Adding these different components gives the total sum of energy expenditures:

$$Total\ Energy\ Expenditures = MELEC + MIELEC + MGAZ + MIGAZ + MCHAUF + MICHAUF \quad (1)$$

Note that some observations are dropped in three different cases<sup>27</sup>:

1. If there is no answer to the previous questions. (205 observations);
2. If the head of household declares that their electricity or gas expenditures were included in their condominium fees or rental charges (177 observations);
3. If the head of household declares that their electricity or gas expenditures were not included in their condominium fees or rental charges, but they did not answer these questions. (MIELEC, MIGAZ) (764 observations).

Finally, the study sample contains 20,562 observations. The next sub-section provides a descriptive analysis of energy expenditures in France in 2011.

## 2.2. Descriptive statistics

The following table gives descriptive statistics regarding socio-economic and socio-

<sup>27</sup> Descriptive statistics of dropped observations are available in appendix 1.

demographic variables:

<b>Net income</b>	1 <sup>st</sup> quintile 20.03%	2 <sup>nd</sup> quintile 20.23%	3 <sup>rd</sup> quintile 19.36%	4 <sup>th</sup> quintile 20.72%	5 <sup>th</sup> quintile 19.66%		
<b>Level of education</b>	No education 24.76%	Lower secondary 16.31%	Higher secondary 48.20%	Post-secondary 10.73%			
<b>Status on the labour market</b>	Employed 49.57%	Student 9.56%	Unemployed 9.15%	Retired 5.63%	Homemaker 28.36%	Inactive 4.64%	Others 2.25%
<b>Type of household</b>	Single person 14.45%	Single parent family 7.50%	Couple without children 31.37%	Couple with children 43.69%	Others 2.98%		
<b>Occupancy status</b>	Owner 70.42%	Tenant 27.58%	Free of charge 2%				
<b>Area of the dwelling</b>	-50 m <sup>2</sup> 4.78%	[50-100 m <sup>2</sup> ] 40.85%	[100-150 m <sup>2</sup> ] 33.97%	[150-200m <sup>2</sup> ] 11.52%	+200m <sup>2</sup> 8.87%		
<b>Type of dwelling</b>	Farm, house 51.20%	Town, adjacent house 21.63%	Apartment 27.17%				

Table 1: Descriptive statistics by socio-economic and socio-demographic variables

Therefore, 75% of individuals live with a partner (with or without children); 70% are homeowners; and 50% of individuals are employed. In addition, almost 48% of individuals have a higher secondary level of education. Additionally, only 27% live in an apartment.

Table 2 presents household energy expenditures in 2011 regarding the main dwelling.

Median	Average	Min	Max	P1%	P5%	P25%	P75%	P95%	P99%
1412€	1523€	116€	4260€	190€	350€	902€	1980€	3000€	3730€

Table 2: Descriptive statistics for energy expenditures in 2011

We identify a very high disparity in the distribution of energy expenditures across the sample. Indeed, the range in the level of energy expenditures is equal to 4144€. Additionally, individuals in the 99<sup>th</sup> percentile have a level of energy expenditures that is 21.14 times higher than those in the first percentile, for example, in 2011. This result is probably due to the difference in dwelling area between P1% and P99%. Indeed, individuals in P1% have, on

average, a dwelling area equal to 80 m<sup>2</sup>, while individuals in P99% have an average dwelling area equal to 185 m<sup>2</sup>.

To enhance this analysis, we produce descriptive statistics of the budget share allocated to energy expenditures, sorted by socio-economic and socio-demographic variables. The budget share allocated to energy expenditures

Table 3 reports these descriptive statistics:

<b>Level of income<sup>28</sup></b>		<b>Type of dwelling</b>	
<D1	0.087	Detached house	0.049
D1-D2	0.060	A town house, semi-detached	0.050
D2-D3	0.053	Apartment	0.03
D3-D4	0.045	<b>Type of household</b>	
D4-D5	0.042	Single person	0.06
D5-D6	0.038	Single parent family	0.05
D6-D7	0.036	Couple without children	0.044
D7-D8	0.032	Couple with children	0.038
D8-D9	0.028	Others	0.05
>D9	0.019	<b>Area</b>	
<b>Status on the labour market</b>		-50 m <sup>2</sup>	0.035
Employed	0.038	[50-100 m <sup>2</sup> [	0.042
Apprentice	0.034	[100-150 m <sup>2</sup> [	0.045
Student	0.042	[150-200 m <sup>2</sup> [	0.045
Unemployed	0.05	+200 m <sup>2</sup> [	0.052
Retired	0.052	<b>Level of education</b>	
Homemaker	0.05	High post-secondary level	0.033
Others	0.06	High secondary level	0.039
<b>Living area</b>		Low secondary level	0.049
Ile de France	0.03	No education	0.055
Parisian basin	0.051		
North	0.052		
East	0.051		
West	0.045		
South West	0.049		
South East	0.044		

<sup>28</sup> To compare the standards of living of households of different sizes or compositions, it is unnecessary to use a measurement of income corrected by the consumption unit using an equivalence scale. The OECD scale is currently the most widely used scale and uses the following weighting: 1 CU for the first adult in the household; 0.5 CU for other persons aged 14 years or older; -0.3 CU for children under 14 years of age.

Mediterranean	0.043
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Table 3: Budget share allocated to energy expenditures by socio-economic characteristics in average

We clearly identify that the lower the decile of income, the higher the budget share allocated to energy expenditures, and conversely for the last decile of income. Status on the labour market shows that students, the unemployed, the retired and homemakers have a higher budget share allocated to energy expenditures than do other categories. Additionally, individuals with no education have a higher budget share allocated to energy expenditures compared to educated individuals. It also seems that the living area does not play a major role in the budget share allocated to energy expenditures for residential use. As for the dwelling type, it appears that households living in a house (detached or not) have a higher budget share allocated to energy expenditures than households living in an apartment. And not surprisingly, the lower the level of income, the higher the budget share allocated to energy expenditures. These results are confirmed by the literature addressing the determinants of fuel poverty (Healy and Clinch, 2004; Waddams et al., 2012; Scott et al., 2008).

Following this descriptive analysis, we examine more precisely the distribution of these energy expenditures to identify whether inequalities exist.

### 2.3. Lorenz curve representation

The Lorenz curve “plots the percentage of total incomes earned by various portions of the population when the population is ordered by the size of their income” (Gastwirth, 1971). It is a common tool used to perform inequality analyses of income distribution. Gastwirth (1971) gives a compact mathematical expression of the Lorenz curve:

$$L(p) = \frac{\int_0^p q(t)dt}{\int_0^1 q(t)dt} \quad (1)$$

The numerator sums the incomes of the bottom  $p$  proportion of the population. The denominator reports the global level of incomes held by the total population. In other words,

$L(p)$  indicates the cumulative percentage of total income held by a cumulative proportion  $p$  of the population, when individuals are ordered by increasing income values.

Jacobson et al. (2005) were the first authors to suggest that tools such as the Lorenz curve and Gini coefficient (i.e., subsection 2.4) could be applied to energy expenditures: they performed an inequality analysis for residential electricity in five countries (Norway, the United States of America, El Salvador, Thailand and Kenya). Applied to energy expenditures, the Lorenz curve reports the distribution of the population ranked by the size of energy expenditures (x-axis) against the cumulative percentage of the energy expenditure distribution (y-axis). Finally, the 45° line represents the perfect equality repartition of energy expenditures among the population. In other words, the 45° line is the no-inequality line and any movement away from this line can be interpreted as inequality. The following figures present the Lorenz curve for energy expenditures for the budget share allocated to energy expenditures and for the standards of living in 2011.

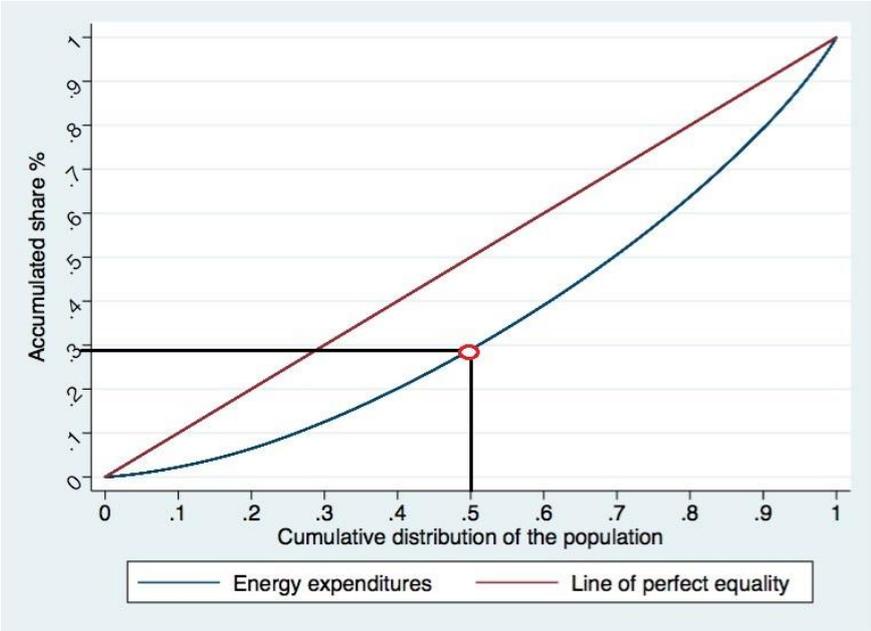


Figure 1: Lorenz curve for energy expenditures for residential usage in 2011

The gap between the diagonal line and the Lorenz curve for energy expenditures is fairly large, meaning that there are substantial inequalities. Perfect equality would mean that 50% of

the population would account for 50% of total energy expenditures. However, in France, in 2011 for instance, 50% of the population accounted for approximately 30% of total energy expenditures.

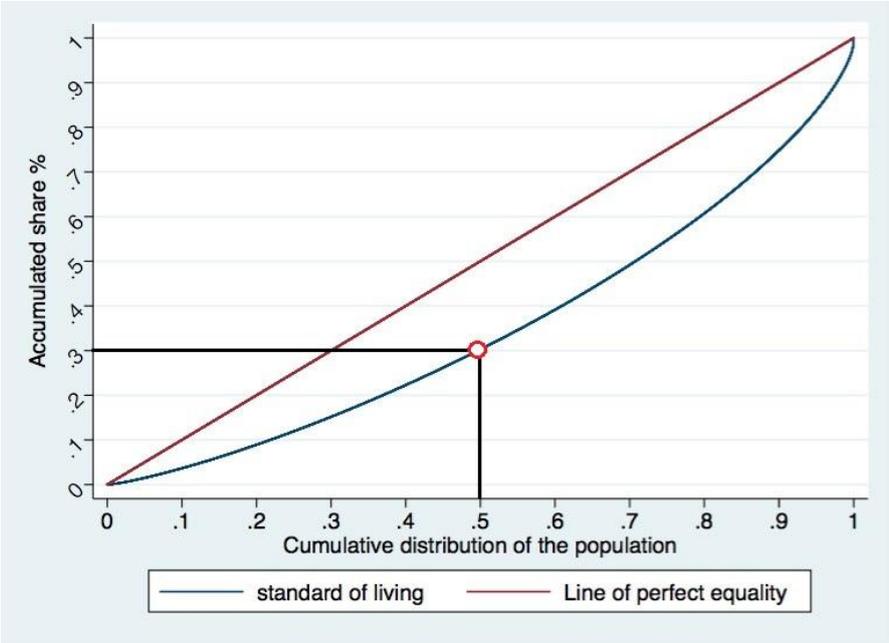


Figure 2: Lorenz curve for standards of living in 2011

Regarding the Lorenz curve for standards of living, the level of inequality is quite similar to the level of inequality in energy expenditures.

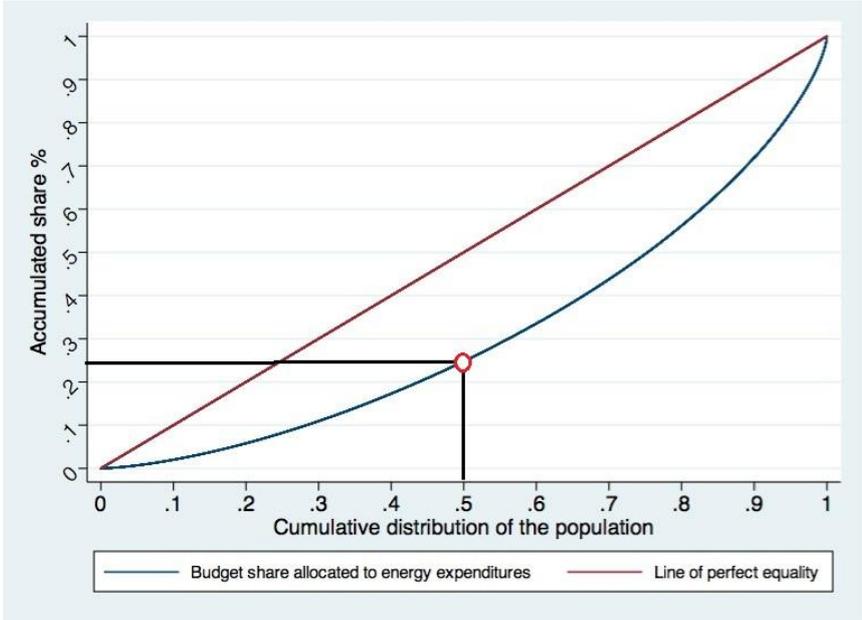


Figure 3: Lorenz curve for budget share allocated to energy expenditures for residential usage in 2011

Looking at the Lorenz curve for budget shares allocated to energy expenditures, we notice that 50% of the population represents approximately 25% of the budget share allocated to energy expenditures.

Finally, the Lorenz curves for energy expenditures and standards of living dominate the Lorenz curves for the budget share allocated to energy expenditures. In other words, the distribution of the budget share allocated to energy expenditures is more unequal than other distributions (i.e., energy expenditure and standard of living distributions). We go a step further in understanding these inequalities by calculating the Gini coefficient and its decomposition, by energy source, for energy expenditures.

## 2.4. Gini index

The Gini coefficient is related to the Lorenz curve and measures the area between the Lorenz curve and the diagonal line (i.e., 45% line). Formally, the Gini index can be deduced to the Lorenz curve as follows<sup>29</sup>:

$$Gini\ index = 2 \int_0^1 (p - L(p)) dp = 1 - 2 \int_0^1 L(p) dp \quad (2)$$

In other words, this formula computes the average distance between the perfect line of equality (i.e., when  $L(p) = p$ ) and the Lorenz curve (i.e.,  $L(p)$ ). The Lorenz curve having a normalized surface equal to 1, the surface of the triangle above the line of perfect equality is thus  $\frac{1}{2}$ . So, to obtain a value of the Gini index between 0 and 1, it is necessary to take twice the integral of  $p - L(p)$ .

In this study, we estimate and decompose the Gini index of energy expenditures by energy sources. Lerman and Yitzhaki (1984, 1985) were the first to suggest a decomposition of the Gini coefficient by income sources. The Gini decomposition provides the contribution of

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<sup>29</sup> Xu, 2003 gives a clear overview of the different perceptions and writings of the Gini index.

income source  $k$  to global inequalities. In this study, we produce a Gini decomposition for total energy expenditures. In other words, the Gini decomposition shows the contribution of energy source  $k$  to global energy expenditure inequalities.

Finally, the Gini coefficient for total energy expenditure inequalities can be written as follows (Gerardo Esquivel, 2001):

$$G = \sum_{k=1}^K S_k G_k R_k, \quad (3)$$

where  $K$  = number of energy sources;  $S_k$  = the share of energy expenditure  $k$  in total energy expenditures (i.e., “the importance of the energy expenditure source among total energy expenditures” (Gerardo Esquivel, 2001));  $G_k$  = Gini coefficient of the energy expenditure component  $k$  (i.e., “how unequally distributed the energy source is” (Gerardo Esquivel, 2001));  $R_k$  = correlation between energy component  $k$  and total energy expenditures (i.e., “how correlated the energy source and the distribution of total energy expenditures are” (Gerardo Esquivel, 2001)). By combining these coefficients, we defined “ $C_k$ ” (Garner, 1993), which represents the contribution of each budget component to total inequality ( $C_k = S_k G_k R_k$ ). Regarding the “*Share*” parameter, it simply reports the contribution of each  $k$  to the global inequality level (i.e.,  $C_k/G$ ). Finally, the parameter called “% *change*<sup>30</sup>” refers to the relative percentage variation in inequality if the energy expenditure for component  $k$  increases. In other words, this means that policy makers must promote changes in those expenditure items (i.e., increase or decrease) that strongly contribute to the overall level of inequality but whose share in the total level of expenditure is the lowest.

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<sup>30</sup> The mathematical calculation is:  $\text{Share} - S_k$ .

An application of the Gini decomposition by energy source<sup>31</sup> is performed. The following two tables report the Gini coefficient and its decomposition for the year 2011.

2011 without gas access	$C_k$	$S_k$	$G_k$	$R_k$	Share	% change
Electricity expenditures	0.121	0.662	0.371	0.493	0.445	-0.217
Gas expenditures	.	.	.	.	.	.
Heating expenditures (or hot water) not already included in electricity and gas expenditures	0.151	0.3383	0.700	0.638	0.555	0.217
Total Gini Index	0.272					

Table 4: Gini index decomposition in 2011 for individuals without gas access

2011 with gas access	$C_k$	$S_k$	$G_k$	$R_k$	Share	% change
Electricity expenditures	0.079	0.464	0.351	0.486	0.286	-0.178
Gas expenditures	0.094	0.345	0.585	0.467	0.3406	-0.004
Heating expenditures (or hot water) not already included in electricity and gas expenditures	0.103	0.192	0.823	0.656	0.373	0.182
Total Gini Index	0.277					

Table 5: Gini index decomposition in 2011 for individuals with gas access

According to table 4 and table 5, in 2011 the total Gini index was equal to 0.272 for people without gas access and equal to 0.277 for people with gas access. This means that the overall level of inequality is relatively high, but these inequalities are quite similar for individuals with gas access. Focusing on individuals without gas access (table 4), the parameter “*Share*” indicates that extra heating expenditures account for 55.500% of the total Gini index. However, the amount of extra heating expenditures represents only 33.830% of total energy expenditures (i.e.,  $S_k$ ). So, this means that global inequalities in energy expenditures are disproportionately due to extra heating expenditures. Regarding the  $G_k$  parameter, as Garner

<sup>31</sup> Note that we distinguish between households with and without gas access. This distinction is needed to avoid considering inequality in gas expenditures when this inequality could stem from having no access to the gas network rather than non-consumption of gas while having gas access.

(1993) said: “high  $G_k$ 's are an indication that there are differences in consumption expenditures”. So, regarding our results for individuals without gas access, the  $G_k$  is equal to 0.70 for heating expenditures. This means that there is a large disparity across the population for extra-heating expenditures. Nevertheless, it appears that electricity expenditures are more equally distributed (i.e.,  $G_k=0.371$ ). Finally, “% change parameter” indicates that increasing the electricity share of energy expenditures would decrease the overall inequality level, *ceteris paribus*. In contrast, increasing the share of extra heating expenditures would induce a higher level of inequality for individuals without gas access. Given these results, discouraging extra heating expenditures (i.e., reducing heating's share in total energy expenditures) could reduce the overall level of inequality.

Focusing on people with gas access (i.e., table 5), we find that extra heating expenditures still have a disproportionate impact on inequality, contrary to electricity expenditures. In addition, it appears that gas expenditures contribute more to the overall level of inequality compared to electricity expenditures, despite the fact that gas expenditures represent a lower share of overall energy expenditures. As discussed previously, it appears that increasing the share of electricity as part of total energy expenditures would decrease the overall level of inequality, *ceteris paribus*. On the other hand, adjusting gas expenditures to reduce the overall inequality level would have a very limited (negligible) impact (i.e., -0.004).

In contrast, increasing the share of extra heating expenditures would induce a higher inequality level for individuals with gas access (i.e., 0.182).

Additionally, we can calculate the Gini index for the budget share allocated to energy expenditures and on the standards of living. The following table reports these Gini values:

Gini Index	2011
Budget share allocated to energy expenditures	0.376
Standards of living	0.299

Table 6: Gini index in 2011 for the budget share allocated to energy expenditures and for the standards of living

The Gini index indicates that the level of inequality for these two indicators is high, especially for the budget share allocated to energy expenditures. Indeed, the Gini index is equal to 0.300 for the standards of living<sup>32</sup> and to 0.38 for the budget share allocated to energy expenditures.

The next step is to characterize the determinants impacting both energy expenditures and the budget share allocated to energy expenditures to better identify the different levers that may reduce overall inequalities.

The next subsection presents an econometric analysis of these determinants *ceteris paribus*.

## 2.5. Which determinants increase energy expenditures, their budget share and fuel poverty?

Applied econometrics methods are used to identify the socio-economic determinants that increase the level of energy expenditures, the level of the budget share allocated to energy expenditures and the probability of being fuel poor in 2011 *ceteris paribus*. First, we perform an Ordinary Least Squares (OLS) on the logarithm of energy expenditures to identify the determinants having an impact on the level of energy expenditures. Note that the energy expenditures calculus are available page 27. Formally, we have:

$$y_i = X_i\beta + \varepsilon_i, \quad (4)$$

where  $y_i$  denotes the logarithm of the amount of energy expenditures consumed by an individual  $I$ ;  $X_i$  represents a vector of exogenous variables containing socioeconomic characteristics (e.g., income level, status on labour market, and financial difficulties) and

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<sup>32</sup> These results are quite similar compared to the literature (C. Houdré and al., 2013)

socio-demographic characteristics (e.g., education level and living area);  $\beta$  represents the vector of coefficients associated with variables and  $\varepsilon_i$  the error term (independent and identically distributed). Regarding the econometric specification of the budget share allocated to energy expenditures<sup>33</sup>, we estimate the following OLS specification:

$$z_i = X_i\alpha + \gamma_i, \quad (4)$$

where  $z_i$  represents the budget share allocated to energy expenditures by an individual  $i$ ;  $X_i$  is the same vector of exogenous variables as above;  $\delta$  the coefficients vector and  $\gamma_i$ , the error term (iid). Finally, we perform a probit for the probability of being fuel poor<sup>34</sup>. The logistic specification model estimates the probability of being fuel poor given several exogenous variables that are represented in the  $X_i$  vector for the  $i^{\text{th}}$  individual with the same variables as previously presented. Let  $Fuel\ poor_i$  be a binary variable that equals 1 if the  $i^{\text{th}}$  individual is in fuel poverty and 0 otherwise. The observable outcomes are represented by a binary indicator variable,  $Fuel\ poor_i$ , as follows:

$$Fuel\ poor_i = \begin{cases} 1 & \text{if } Fuel\ poor_i^* \geq 0 \\ 0 & \text{if } Fuel\ poor_i^* < 0 \end{cases} \quad (5)$$

$$\Pr(Fuel\ poor_i = 1|X_i) = 1 - \Phi[-X_i'\phi], \quad (6)$$

$$\Pr(Fuel\ poor_i = 0|X_i) = \Phi[-X_i'\phi], \quad (7)$$

Where  $Fuel\ poor_i^*$  is a latent dependent variable; Pr denotes probability; and  $\Phi$  is the cumulative distribution function of the standard normal distribution ( $N(0,1)$ ).  $Fuel\ poor_i$  is generated by the following linear regression model:

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33 It represents the percentage of income, measured as household income divided by the Organization for Economic Cooperation and Development (OECD) equivalent scale (i.e. footnote number 28, which a household allocates to meet its energy needs.

34 Households that spend more than x% of their income on energy bills are considered to be experiencing fuel poverty. The threshold x used is the double of the median level of income allocated to energy expenditures for each year.

$$Fuel\ poor_i^* = X_i\delta + \mu_i \quad (8)$$

Due to climate differences between the different living areas in France, note that we introduce the living area variable to control for potential bias in coefficients estimation. Table 7 reports the regression estimations.

	<b>Ln(energy expenditures)</b>		<b>Budget share allocated to energy expenditures</b>		<b>Being fuel poor</b>	
	Marginal effect	Standard error	Marginal effect	Standard error	Marginal effect	Standard error
Ln(Level of income by UC)	0.123***	0.009	-0.420***	0.0005	-0.287***	0.006
Age	0.003***	0.00045	0.0003***	0.00002	0.002***	0.0002
Area of dwelling	0.0002***	0.000035	0.00001***	0.00002	0.00002***	0.00001
Type of dwelling						
Farm, house	REF	REF	REF	REF	REF	REF
Town, adjacent house	-0.056***	0.011	-0.003***	0.001	-0.030***	0.006
Apartment	-0.675***	0.012	-0.026***	0.0006	-0.145***	0.005
Type of household						
Single person	REF	REF	REF	REF	REF	REF
Single parent family	0.285***	0.0204	-0.015***	0.001	-0.102***	0.013
Couple without children	0.248***	0.014	-0.011***	0.001	-0.110***	0.01
Couple with children	0.412***	0.015	-0.023***	0.001	-0.195***	0.01
Others	0.521***	0.029	-0.018***	0.001	-0.200***	0.013
Level of education						
High level of education	REF	REF	REF	REF	REF	REF
High secondary level of education	-0.026*	0.014	-0.004***	0.001	0.001	0.009
Secondary level	-0.031**	0.012	-0.005***	0.001	-0.001	0.007

of education						
No education	-0.005	0.017	-0.004***	0.001	0.004	0.01
Living area						
Ile de France	REF	REF	REF	REF	REF	REF
Parisian basin	0.104***	0.0157	0.001	0.001	0.021**	0.01
North	0.128***	0.02	0.001	0.001	0.019	0.011
East	0.201***	0.018	0.005***	0.001	0.058***	0.011
West	0.011	0.016	-0.004***	0.001	-0.032***	0.01
South West	0.025	0.017	-0.002**	0.001	-0.008	0.01
South East	0.082***	0.017	-0.0002	0.001	0.020*	0.011
Mediterranean	0.007	0.017	-0.002**	0.001	-0.012	0.01
Status on the labour market						
Employed	REF	REF	REF	REF	REF	REF
Apprentice	0.130*	0.039	0.004	0.004	-0.011	0.049
Student	0.169***	0.018	0.01***	0.001	0.036**	0.012
Unemployed	0.010	0.0197	-0.002	0.0011	0.004	0.01
Retired	-0.004	0.015	-0.003***	0.001	-0.001	0.008
Homemaker	0.024	0.021	-0.002	0.001	-0.005	0.01
Others	0.021	0.034	0.003	0.002	0.026	0.017

Table 7: Econometric regression for  $\ln(\text{energy expenditures})$  for the level of budget share allocated to energy expenditures and for the probability of being fuel poor in 2011

Following these results, several remarks can be made. First, the level of income is highly correlated to each of the three dependent variables: ( $\ln(\text{energy expenditures amount})$ , budget share allocated to energy expenditures and being considered fuel poor). Indeed, the higher the level of income, the higher the amount of energy consumed (in absolute terms). Nevertheless, the higher the level of income, the lower the level of the budget share allocated to energy expenditures (in relative terms) and the lower the probability of being considered fuel poor in 2011. Indeed, if the level of income increases by 1%, the level of energy expenditures increases by 0.123%, the level of the budget share allocated to energy expenditures decreases

by 0.004, and finally the probability of being fuel poor decreases by 28.7 points. Unsurprisingly, the level of income was a main determinant of the probability of being fuel poor for financial reasons (Healy & Clinch, 2004a; Waddams & al., 2012; Scott & al., 2008). Furthermore, the level of education had an impact on the probability of being fuel poor; individuals with a primary, college or higher secondary level of education had a lower probability of being fuel poor compared to individuals without education.

We also find that the weight of energy expenditures is more important for older individuals both in absolute and relative terms and that these individuals are more exposed to fuel poverty than younger ones.

Second, the type of dwelling is significantly associated with the three outcomes. So, living in an apartment rather than a house reduces the level of energy expenditure by 67.5%. Living in an apartment rather than a house reduces the level of the budget share allocated to energy expenditure by 0.026 and reduces by 0.145 the probability of being fuel poor.

Third, single parent families or individuals living in couples (with or without children) have a significantly higher level of energy expenditures compared to single persons. Nevertheless, these types of households (i.e., single parent families or couples (with or without children)) have a significantly lower level of their budget shares allocated to energy expenditures and also a significantly lower probability of being fuel poor.

Finally, regarding status on the labour market, being a student or an apprentice compared to being employed increases the probability of having a higher level of energy expenditures, of having a higher budget share allocated to energy expenditures and of being fuel poor. Indeed, students (or apprentices) usually live in more substandard and less isolated dwellings. Students face a higher probability of being fuel poor compared to employed individuals as they have less stable financial situations.

Previous results revealed that the level of income, the type of dwelling, type of household and status on the labour market play a major role in the level of energy expenditure for residential use, in the level of the budget share allocated to energy expenditures and in the probability of being fuel poor in 2011. These results corroborate the findings in the literature regarding the determinants of energy expenditures and fuel poverty (Healy et Clinch, 2004a; Waddams et al., 2012; Scott et al., 2008).

These econometric results highlight that level of income plays a key role in energy expenditures (in absolute and relative terms) and in the probability of being fuel poor. Given that there are inequalities in energy expenditures, a more in-depth study of these disparities relative to levels of income could provide a better understanding of horizontal and vertical equity principles regarding energy expenditures. Indeed, studying the concentration of high energy expenditures and of high budget shares allocated to energy expenditures and finding the major determinants that explain the average difference in energy expenditures between the poor and non-poor would allow us to know whether or not the vertical equity and horizontal equity principle regarding energy expenditures is satisfied. For example, if people with low incomes (who have a lower ability to pay for energy expenditures compared to better-off people) show a concentration of higher budget shares allocated to energy, this means that the vertical equity principle regarding the financing of energy expenditures is not satisfied.

### **3. Inequality related to standards of living**

#### **3.1. Concentration curves, concentration index, its decomposition and Kakwani index**

The concentration curve (CC) (Kakwani 1977; Kakwani et al. 1997; Wagstaff et al. 1991) represents the cumulative percentage of a variable (y-axis) and the cumulative percentage of the population, ranked by living standards, starting with the poorest individuals and finishing with the richest individuals (x-axis) (Van Doorslaer et al., 2008). So, the concentration curve

shows the distribution of a variable among quantiles of living standards. As for the Lorenz curve, the 45° line represents the line of equality. Nevertheless, if the concentration curve is above [resp. under] the 45° line, it indicates that the studied variable takes higher [resp. lower] values among poorer individuals.

The concentration index (CI) (Kakwani, 1977), directly deduced from the concentration curve, “quantifies the degree of socioeconomic-related inequality” for a variable (Van Doorslaer et al., 2008). If the concentration curve is above [resp. below] the 45° line, the concentration index takes a negative [resp. positive] value and takes the value 0 if there is no inequality. For example, for the energy expenditures variable, if energy expenditures are disproportionately concentrated among richer people, the concentration index will be negative. Note that the CI is close to the Gini index but differs in the way in which the variable of interest and the ranking variable are different. So, the CI measures inequality in one variable related to the ranking of another variable, in contrast to the Gini index, which measures inequality in one variable but does not relate this to a ranking variable.

The mathematical expression is as follows:

$$CI = 1 - 2 \int_0^1 L_{energy\ variable}(p) dp, \quad (9)$$

where  $L_{energy\ variable}$  represents the concentration curve for an energy variable and  $CI \in [-1,1]$ .

In addition, in this study, we perform a decomposition of this concentration index. Wagstaff et al. (2003) demonstrate that “the health concentration index can be decomposed into the contributions of individual factors to income-related health inequality, in which each contribution is the product of the sensitivity of health with respect to that factor and the

degree of income-related inequality in that factor". So, they consider a traditional additive linear econometric model:

$$y_i = a + \sum_k \beta_k x_{ki} + \varepsilon_i. \tag{10}$$

The concentration index of  $y$  can then be decomposed (Wagstaff et al., 2003):

$$CI = \sum_k \left( \frac{\beta_k \bar{X}_k}{\mu} \right) C_k + \frac{GCI_\varepsilon}{\mu} = \sum_k \eta_k CI_k + \frac{GCI_\varepsilon}{\mu}, \tag{11}$$

where  $\mu$  is the mean of  $y$ ,  $\bar{X}_k$  is the mean of  $x_k$ ,  $CI_k$  is the concentration index for  $x_k$ ,  $GCI_\varepsilon$  is the generalized concentration index for the error term, and  $\eta_k$  is the elasticity of  $y$  with respect to  $x_k$ .

Figure 4 reports concentration curves for energy expenditures, for budget share allocated to energy expenditures, and the Lorenz curve for standards of living. Individuals are ranked by their living standard (proxied by level of income).

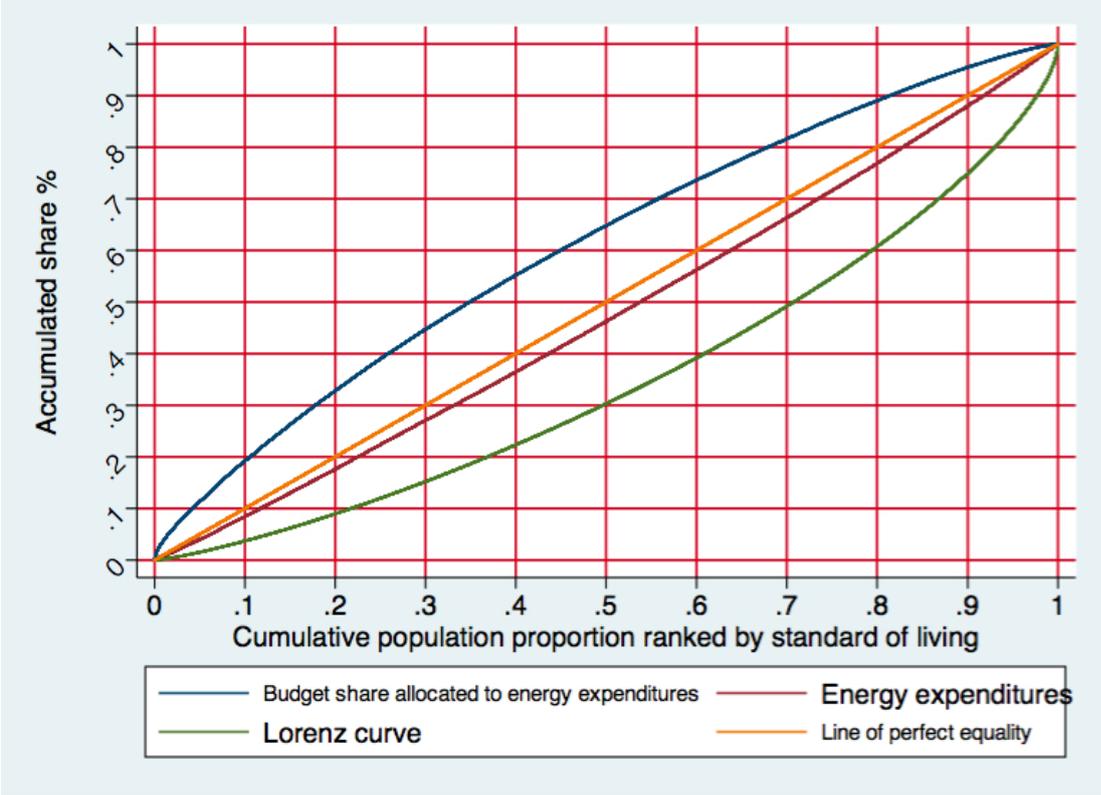


Figure 4: Concentration curve for energy expenditures and budget share allocated to energy expenditures, ranked by standards of living and Lorenz curve in 2011

Complementarily to the figure, table 8 quantifies the graphical results by reporting the Concentration Index (CI) and its decomposition in 2011 for our variables of interest. The entries in each column are derived from equation 10 and give, first, the elasticity of each studied variable with respect to each factor, second, the concentration index for each factor, and finally, the contribution of each factor to the studied variable's concentration index.

	Elasticities	CI	Contributions
<b>Budget share allocated to energy expenditures</b>			
Ln(Level of income by UC)	-9.2273	0.0286	-0.2640
Area	0.0289	0.0633	0.0018
Apartment	-0.133	-0.166	0.022
No education	0.0257	0.3179	0.0082
Student	0.0067	-0.145	-0.0001
Couple with children	-0.1065	-0.0125	0.0013
Age	-0.0772	0.0242	-0.0018
Age <sup>2</sup>	0.2282	0.0332	0.0076
TOTAL			<b>-0.235</b>
<b>Energy expenditures</b>			
Ln(Level of income by UC)	1.1855	0.0286	0.0339
Area	0.0397	0.0633	0.0025
Apartment	-0.1406	-0.093	0.013
No education	0.00013	0.3179	0.00004
Student	0.0138	-0.145	-0.002
Couple with children	0.0681	-0.012	-0.0008
Age	-0.0025	0.0242	-0.0001
Age <sup>2</sup>	0.0649	0.0332	0.0021
TOTAL			<b>0.049</b>

Table 8: Decomposition concentration index in 2011 for the budget share allocated to energy expenditures and for energy expenditures

The concentration curve for the budget share allocated to energy expenditures is above the 45% line. This means that inequalities are more concentrated among the poorest individuals, a result confirmed by the CI value of -0.235.

The opposite finding is observed for the level of energy expenditures. This means that high energy expenditure levels are more concentrated among rich individuals (cf. CI value equal to +0.049)

Values of concentration indexes indicate, however, that inequalities are more sizeable with respect to the budget share allocated to energy expenditures than for energy expenditures in absolute terms. This means that there is a stronger disadvantage for poor people in terms of the budget share allocated to energy expenditures than for the level of energy expenditures in absolute terms.

Table 8 also provides detailed results enabling the identification of the underlying factors impacting these inequalities.

Most of the consumption-related inequality in budget share allocated to energy expenditures is explained by the direct effect of household income. The large elasticity of the budget share allocated to energy expenditures is responsible for its large contribution to the budget share allocated to the energy expenditures concentration index. In addition, we find that inequalities are stronger for individuals with a low education level (CI=0.318), who are students (CI=-0.145), or who live in apartments (CI=-0.166). Nevertheless, the budget share allocated to energy expenditures shows little sensitivity to variation in these factors (i.e., low elasticity values), so their contributions to the total concentration index remain low.

We repeat this type of analysis for energy expenditures (electricity, gas and extra heating), recalling that better-off individuals bear higher energy expenditures than worse-off individuals *ceteris paribus*. As discussed previously, we find that the direct effect of the level of income explains the major part of the consumption-related inequality in energy expenditures (due to its large elasticity). Nevertheless, it appears that living in an apartment does make a non-negligible contribution to the energy expenditures concentration index.

Now, we must investigate the question of progressivity or regressivity (i.e., Kakwani index) of these expenditures.

The Kakwani index informs on the progressivity or regressivity of a measure. This index represents twice the area between the concentration curve of the energy expenditures, or the budget share allocated to energy expenditures, and the Lorenz curve of the standard of living variable. In other words, Kakwani indexes are calculated as follows:

$$\kappa_{energy\ expenditures} = CI_{energy\ expenditures} - G_{standard\ of\ living}, \quad (12)$$

$$\kappa_{TEE} = CI_{TEE} - G_{standard\ of\ living}, \quad (13)$$

where  $\kappa_{energy\ expenditures}$  represents the Kakwani index for the energy expenditures and  $\kappa_{TEE}$ , the Kakwani index for the budget share allocated to energy expenditures,  $CI_{energy\ expenditures}$  represents the concentration index for the energy expenditures for residential usage,  $G_{standard\ of\ living}$  represents the Gini index for the standard of living variable and  $CI_{TEE}$  represents the concentration index for the budget share allocated to energy expenditures.

Table 9 reports these Kakwani indexes for 2011.

Kakwani indexes	2011
Energy expenditures for dwelling usage	-0.533
Budget share allocated to energy expenditures for dwelling usage	-0.251

Table 9: Kakwani index for energy expenditures for dwelling usage and for the budget share allocated to energy expenditures in 2011

The Kakwani indexes for energy expenditures and for budget shares allocated to energy expenditures confirm previous results obtained with concentration curves and concentration indexes. Negative values for the Kakwani index indicate that energy expenditures and the budget share allocated to energy expenditures are regressive<sup>35</sup>; meaning that pre-existing inequalities in level of income are aggravated by energy expenditures.

The level of income appears as the major contributing factor to the energy expenditures concentration index. This indicates that the horizontal equity principle is not satisfied. Indeed, the horizontal equity principle dictates that if individuals have the same “needs”, they should also have the same energy consumption. But, level of income does not represent an energy need in the same way as low energy efficiency of the dwelling, for example. A horizontal equity index<sup>36</sup> (i.e., see Wagstaff and van Doorslaer (2000) for an application of health care utilization) could be calculated regarding energy expenditures. However, with our database, we cannot estimate, without bias, true “needs” in terms of energy utilization.

The budget share allocated to the energy expenditures concentration index provides information concerning the vertical equity concept applied to energy financing. The vertical equity concept applied to energy financing would induce a different treatment for different individuals. So, if individuals do not have the same ability to pay for energy expenditures, the vertical equity concept dictates that the better-off individuals should contribute more to energy financing than the poorer individuals. Nonetheless, we observe that high budget shares

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<sup>35</sup> Carraro and al, 2012 found the same results regarding electricity and gas expenditures for Italians households.

<sup>36</sup> The horizontal equity index represents the difference between the concentration index for actual utilization and that for need-predicted utilization (i.e., see Wagstaff and van Doorslaer (2000) for an application to health care utilization). The main concern of this method is that “need variables” (i.e., justified energy utilization) introduced in the regression must control for all “needs”. So, any residual variation in energy utilization is due to “non-need variables” (i.e., unjustified energy utilization). However, in practise, it is very difficult to obtain a database with all “needs” indicators regarding energy utilization. So, it is a strong assumption to estimate controlled estimations for all “needs” variables. The main consequence would be a biased measurement of horizontal inequity if unobservable variation in “need” were correlated with “non-need” variables, for example.

allocated to energy expenditures are more concentrated across individuals with lower levels of income. This remark indicates that the vertical equity concept is not completely satisfied. Indeed, individuals with a lower ability to pay face a higher financial burden induced by energy expenditures compared to better-off individuals. Consequently, policy makers in the energy sector must go further to reduce the financial burden induced by energy expenditures on low income individuals. For example, the Energy Transition Law for Green Growth (2015) – article 201<sup>37</sup> – has proposed the creation of an “energy voucher<sup>38</sup>” to assist households experiencing fuel poverty. This measure embodies the vertical equity target regarding energy financing that is being pursued by policy makers.

The last step is to identify determinants that explain these inequalities between poorer and better-off individuals regarding the level of energy expenditures for residential use.

The next sub-section presents a Blinder-Oaxaca decomposition to identify the main determinants of these energy expenditure inequality gaps between the poor and better-off and between the fuel poor and non-fuel poor.

### **3.2. Blinder-Oaxaca decomposition**

We performed a Blinder-Oaxaca decomposition regarding the level of energy expenditures<sup>39</sup> between poor<sup>40</sup> and non-poor individuals.

The Blinder-Oaxaca decomposition is commonly used to identify the determinants of inequalities among different individuals. Historically, this method was introduced by Ronald

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[https://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=A23BA8049EF501DF7E68479A4BBF24F7.tpdila17v\\_2?idArticle=JORFARTI000031045817&cidTexte=JORFTEXT000031044385&dateTexte=29990101&categorieLien=id](https://www.legifrance.gouv.fr/affichTexteArticle.do;jsessionid=A23BA8049EF501DF7E68479A4BBF24F7.tpdila17v_2?idArticle=JORFARTI000031045817&cidTexte=JORFTEXT000031044385&dateTexte=29990101&categorieLien=id)

<sup>38</sup> This “energy voucher” might be used to pay a part of the household’s energy bills or a part of expenditures incurred to improve the energy efficiency of the dwelling.

<sup>39</sup> A similar analysis of budget share allocated to energy expenditures would prove irrelevant due to the ambivalence of the level of income (both in the dependent variable and the selection variable for the two sub-groups).

<sup>40</sup> The poverty threshold retained is 60% of the 2011 median level of income. Note that the same decomposition with 50% of the 2001 median level of income is available in appendix 2.

Oaxaca in 1973<sup>41</sup> and at the same time by Alan Blinder<sup>42</sup>. Oaxaca's original research question was the wage differential between black and white people. Regarding, Blinder' research question was the wage differential between men and women.

The method is based on the following formula (O'Donnell, Doorslaer and al., 2008):

$$y^{non-poor} - y^{poor} = \Delta x\beta^{poor} + x\Delta\beta^{poor} + \Delta x\Delta\beta = E + C + CE \quad (14)$$

$y$  represents the level of energy expenditures,  $x$  represents the covariates,  $\beta$  represents the coefficient value associated with the  $x$  covariates.  $E$  represents the gap in endowments (standards of living, status on the labour market, etc.);  $C$ , the gap in coefficients and  $CE$ , the gap due to the interaction between endowments and the coefficients gap.

Performing a Blinder-Oaxaca decomposition regarding the level of energy expenditures between the poor and non-poor gives the following results (i.e., table 10): an estimate of the mean values of  $\ln(\text{energy expenditures})$  for the poor and non-poor; the difference between them; and an estimate of the contribution resulting from the gaps in endowments ( $E$ ), the coefficients ( $C$ ), and the interaction ( $CE$ ). With endowments being assimilated to socioeconomic characteristics (e.g., level of income, level of education, etc.), the Blinder-Oaxaca decomposition will explain how much of the gap regarding energy expenditures can be attributed to socioeconomic characteristics (i.e.,  $X$ 's) and how much results from behaviours (i.e., coefficient  $\beta$ 's or *unexplained gap*). We retain the following as endowments (socioeconomic criteria):

1. Standards of living;

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<sup>41</sup> Oaxaca, R., 1973, "Male-female wage differentials in urban labor markets", *International economic review*, JSTOR, 693-709.

<sup>42</sup> Blinder, A. 1973, « Wage Discrimination: Reduced Form and Structural Estimates », *Journal of Human Resources*, vol. 8, no 4, 1973, p. 436-455.

2. Status on the labour market: Employed, apprentice, student, unemployed, retired, homemaker, other;
3. Level of education: High post-secondary level, high secondary level, low secondary level, no education;
4. Area of the dwelling;
5. Type of household: Single, Single parent family, couple without children, couple with children, others;
6. Age;
7. Type of dwelling: Farm/house, Town/adjacent house, apartment;
8. Occupancy status: Homeowner, usufructuary, tenant, free of charge;

Table 10 reports the results for our Blinder-Oaxaca decomposition.

<i>Ln</i> (energy expenditures)		
	Coeff	Sd
Non-poor	7.142***	0.0056
Poor	6.939***	0.0171
Difference	0.213***	0.018
Endowments (E)	0.404***	0.0628
Coefficients (C)	-0.063***	0.0195
Interaction (EC)	-0.127**	0.0633

Table 10: Results of the Oaxaca decomposition for energy expenditures between poor and non-poor

There is a significant difference between the poor and non-poor regarding the average level of energy expenditures: the non-poor consume 1.63 times more energy than the poor<sup>43</sup>. Regarding endowments, this means that if the poor had the same characteristics as the non-poor, their mean level of energy expenditures would increase by 49%<sup>44</sup>. Now, if the coefficients of the non-poor (i.e., behaviour) were applied to the characteristics of the poor, their energy expenditures would be reduced by 6%<sup>45</sup>. As we can see, a variation in socioeconomic variables (i.e., characteristics (X's)) has a greater impact on the average gap in energy expenditures than a variation in behavioural components (i.e., coefficients ( $\beta'$ )).

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<sup>43</sup>  $\frac{\text{Exp}(7.142)}{\text{Exp}(6.939)}$

<sup>44</sup>  $\frac{\text{Exp}(6.939+0.404)}{\text{Exp}(6.939)}$

<sup>45</sup>  $\frac{\text{Exp}(6.939-0.063)}{\text{Exp}(6.939)}$

So, the endowment results indicate that characteristics ( $X$ 's) better explain the existing gap between poor and non-poor than do the different coefficients ( $\beta$ 's).

A closer look at the endowments/coefficients can provide valuable information about which characteristics have the most explanatory power in terms of the mean difference in energy expenditure levels between the poor and non-poor<sup>46</sup>.

The two histograms below (i.e., Figure 5) represent the contribution of the most significant (higher P-value) covariates ( $x$ ) and coefficients ( $\beta$ ) with respect to the mean gap in energy expenditures between the poor and better-off<sup>47</sup>.

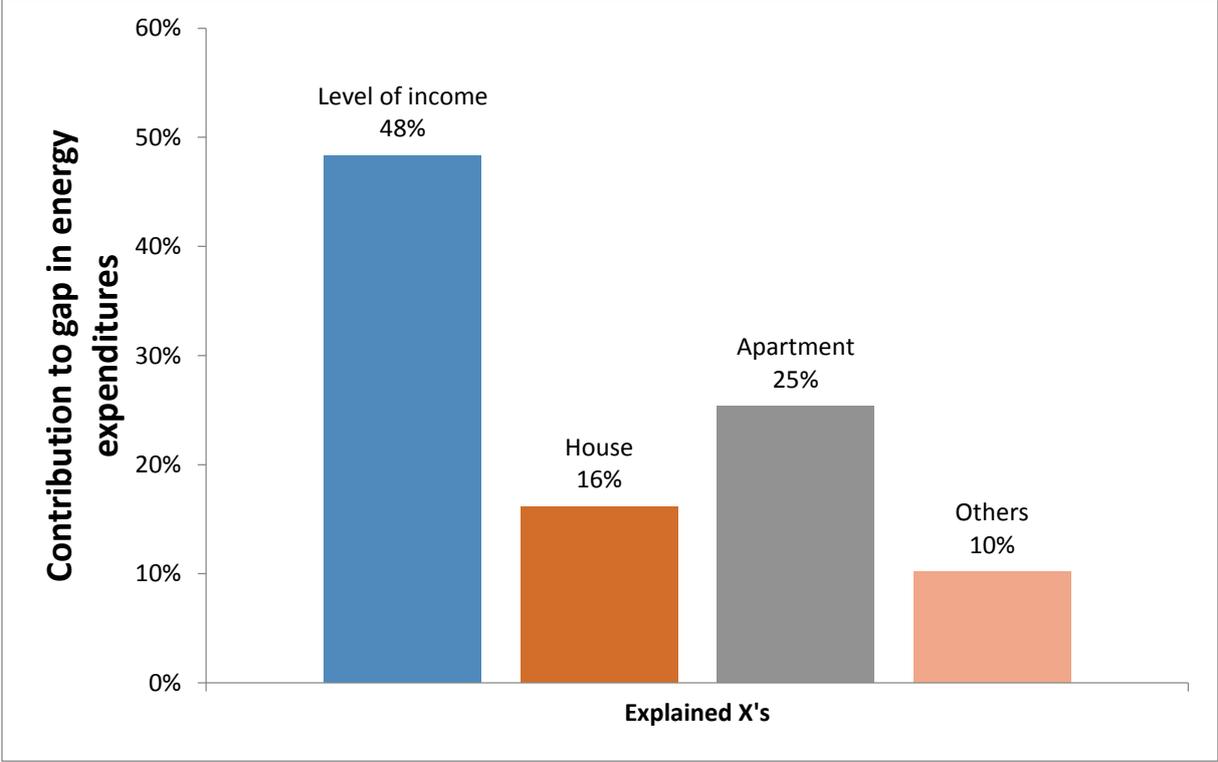


Figure 5a: Contributions of Differences in Endowments in Means to the Poor–Non-poor Difference in Mean energy expenditures

<sup>46</sup> Note that this decomposition is path-independent because when the order in which the different elements of the detailed decomposition are computed does not affect the results of the decomposition.

<sup>47</sup> Note that a bar chart with all variables is available in appendix 3.

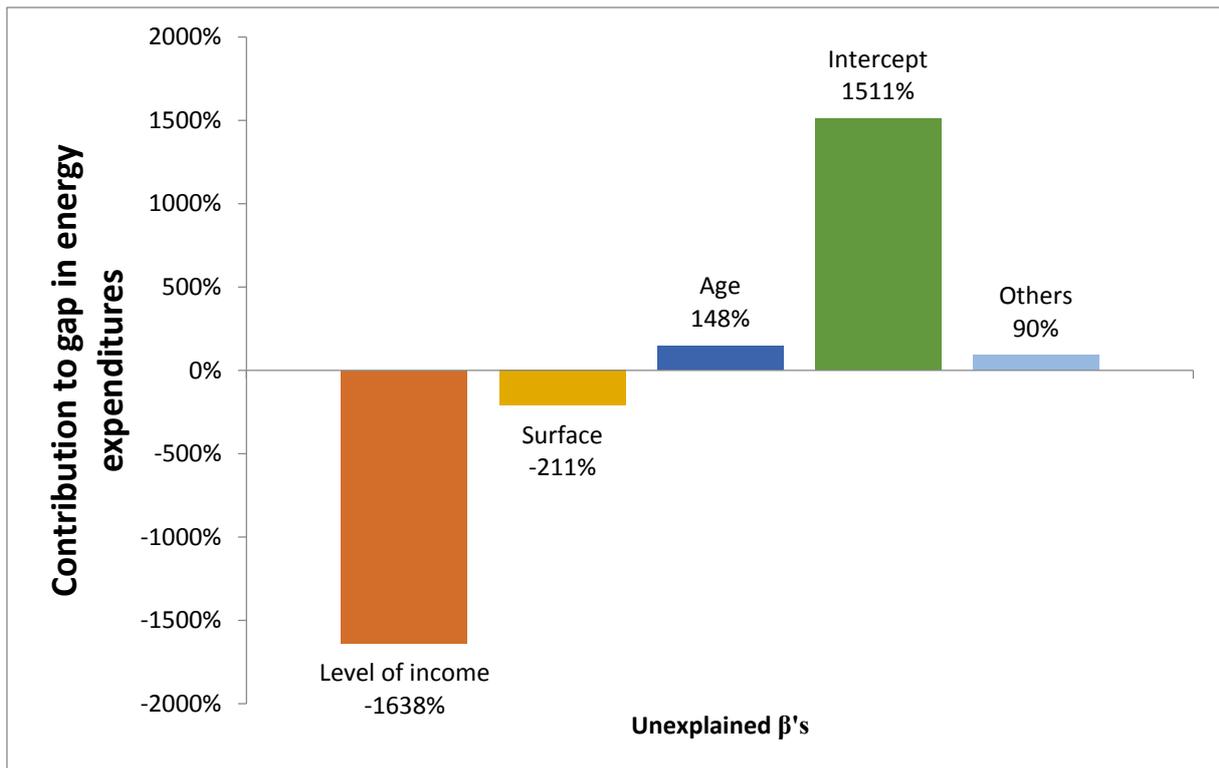


Figure 5b: Contributions of Differences in Coefficients in Means to the Poor–Non-poor Difference in Mean energy expenditures

The first histogram (Figure 5a) highlights that the level of income (living standard) explains the major part of the gap between the non-poor and poor. In other words, the major part of the gap in energy expenditure inequalities comes from gaps in the  $x$ 's but not in the  $\beta$ 's. Additionally, living in an apartment or a house explains a non-negligible part of the gap (i.e., Figure 5a). Overall, inequality in energy expenditures is mainly due to a “lack” of income between the poor and better-off.

The fact that the unexplained portion (i.e.,  $\beta$ 's) represents a low amount of the total gap is due to the inner compensation between  $\beta$ 's (cf. figure 5b). Indeed, the intercept is very high in the energy expenditure equation for the poor, but this effect is offset by the fact that the level of income is lower for poor compared to non-poor individuals.

These results confirm that policy makers should prioritize financial measures (energy vouchers, etc.), the main goal being to harmonize social economic conditions across the

population. So, implementing behavioural policies (educating the population so that they change their initial behaviour) should remain a secondary tool, as their efficiency would remain very limited.

## **4. Conclusion**

This paper proposes an analysis of inequalities in energy expenditures and analyses income-related inequality using standard instruments such as the Lorenz curve, the Gini coefficient, a concentration curve and its decomposition, the Kakwani index and the Blinder-Oaxaca decomposition.

This article shows that there is a high level of inequality regarding energy expenditures and regarding the budget share allocated to energy expenditures. It appears that extra heating expenditures (or hot water) are the main components of these inequalities (i.e., Gini decomposition index by source). Likewise, this study illustrates the need to think both in absolute and in relative terms: even if better-off individuals face higher energy expenditures in absolute terms, poorer individuals concentrate the highest budget share allocated to energy expenditures. These results confirm that policy makers must shape their anti-fuel-poverty policy around the notion of relative energy expenditures (share of energy expenditures) out of total income.

Additionally, it appears that most of the inequality related to the budget share allocated to energy expenditures, regarding the decomposition of the concentration index, is explained by the direct effect of the level of income. In addition, the Kakwani index indicates that energy expenditures for residential usage are not progressive and that the vertical equity principle is not satisfied.

Additionally, the main determinant that explains inequalities in energy expenditures between the poor and non-poor is a “lack” of purchasing power, not some kind of behavioral

difference. The discrepancy between income levels is the main explanatory factor observed in terms of energy expenditures. The most efficient way for the government to reduce energy inequalities is to push for a harmonization of social economic conditions across populations. Additionally, it appears that the vertical equity concept is not satisfied. Indeed, the financial burden induced by high energy expenditures, specifically on people with lower incomes, could have critical consequences on other expenditure items for these households and ultimately increase other inequalities (e.g., health inequalities, food inequalities). In this way, setting up an "Energy voucher" seems to be appropriate for vulnerable (poor) households. It would help to reduce the impact of energy expenditures on poorer households' budgets and on other expenditure items (health expenditures for example). The Energy Transition Law for Green Growth (2015) – article 201<sup>48</sup> – has proposed the creation of an “energy voucher” to assist households experiencing fuel poverty in replacing social energy tariffs. Its average amount will depend on the income tax reference and the number of individuals in the household. This “energy voucher” might be used to pay part of the household's energy bills or to pay part of the expenditures incurred to improve the energy efficiency of their dwelling. Thus, if there are major inequalities regarding levels of energy expenditures and their impact on households' levels of income, taking a closer look at the fuel poor would be relevant. A better understanding of the dynamics of this phenomenon would be useful in drafting public policies to pursue equity targets regarding the use (i.e., horizontal equity) and the financing (i.e., vertical equity) of energy.

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## *Chapitre 2: Does France have a fuel poverty trap?<sup>49</sup>*

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# 1. Introduction

In mainland France, 5.1 million households (12.5 million people or approximately 19% of the total population) experienced fuel poverty in 2013 (ONPE, 2016). That same year, according to the first barometer of fuel poverty published by the King Baudouin Foundation (2015), 21.3% of Belgian households were experiencing fuel poverty. In 2014, 34.9% of Scottish households were fuel-poor and 9.5% were living in extreme fuel poverty (Scottish Government, 2015). Who are these households? What is fuel poverty? The matter is not a simple one because this phenomenon is difficult to qualify and quantify.

Fuel poverty can take many forms because it involves so many different interrelated factors such as poor energy efficiency; poor housing conditions; cold and damp living conditions; increasing unavoidable expenditure and less purchasing power and health problems. Thus, the above ONPE estimate is based on a set of indicators including, *inter alia*, the income level and feeling cold, just as there is no an official indicator for national statistics on fuel poverty in France. The Buildings Performance Institute Europe (BPIE, 2014) assesses the problem in European countries using three indicators: “*the inability of people to keep their homes adequately warm, to pay their utility bills and to live in a dwelling without defects (leakages, damp walls, etc.)*.” According to Eurostat data, in 2014, 10.2% of Europeans were unable to keep their homes adequately warm, 9.9% were in arrears on their utility bills and 15.7% lived in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floors. On the one hand, these percentages are not close; on the other hand, the individuals concerned only partially overlap and their characteristics can vary widely. These percentages vary greatly from country to country; Bulgaria, Greece and Hungary are among the countries that seem most affected by fuel poverty.

Fuel poverty measurement is therefore difficult because it is difficult to quantify what has not been properly defined and because in many countries such in France, national statistics have

not explicitly considered this phenomenon. This may partially explain why there is no common European definition of fuel poverty. The lack of consensus on a definition obviously makes it difficult to determine how to measure fuel poverty. Despite this twofold problem of qualification and quantification, many players have emerged to confront the rise in fuel poverty. Moreover, the existence of substantial percentages of households in fuel poverty can lead to governmental responses.

In France, the 12 July 2010 definition of national commitment to the environment (Article 11, Grenelle II law<sup>52</sup>) is as follows: “*a household that has difficulties disposing of the necessary energy to satisfy its basic needs due to the inadequacy of its resources or its living conditions is in fuel poverty under this Act*”. Therefore, this definition focuses on housing and ignores the energy cost of necessary mobility (i.e., the daily commute to and from the office, health, public services...). Once a fuel poverty definition has been chosen, one or more indicators should also be chosen to identify and characterise households in fuel poverty and to examine the dynamics of this poverty. The goal is to analyse fuel poverty not as an immutable and irreversible state but as a dynamic process.

Whereas other goods and services can often be substituted by cheaper alternatives, households in fuel poverty can be locked into their position. They do not have the resources to improve their homes' energy efficiency (Boardman 2010, Hills 2011). Increased income (the direct policy) could have a temporarily positive impact on the ability to pay bills, whereas improved energy efficiency (the indirect policy) will contribute to a permanent and sustainable reduction in fuel poverty (Hills 2011). However, for poor households living in highly energy-efficient housing, that is to say, for households in social insecurity but not fuel poverty, the opposite approach applies. Thus, these households' situations can be improved by increasing their income: improving their homes' energy efficiency is unnecessary (Hills 2011).

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<sup>52</sup><http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id>

To mitigate the impact of energy prices on vulnerable households, France established two types of means-tested assistance: the special gas solidarity tariff<sup>53</sup> (Tarif Spécial de Solidarité - TSS) and the basic necessity tariff<sup>54</sup> (Tarif de première nécessité - TPN) for electricity. These social arrangements in favour of the poorest households, which are direct policies, are not gas / electricity supply offers as such but flat-rate reductions that apply to the annual bill. These short-term measures shall expire on 31 December 2017, and should be replaced by an energy voucher. Thus, because 1 May 2016, the energy voucher, new aid for payment of gas and electricity bills, has been available in 4 of France's 101 departments. One of the most important novelties of France's policy is that this aid concerns not only electricity and gas bills but also wood and fuel oil bills. The voucher used to pay bills has a temporary positive effect. It can also be used to fund energy-efficiency work in the home, thus providing a permanent effect. As a result, a voucher that represents a short-term measure to fight fuel poverty can be used as a long-term measure. Other long-term measures, such as the programme "to live better" (the indirect policy), partially funds renovations if they reduce energy consumption by at least 25%, are offered to low-income households.

This study on the dynamics of fuel poverty and identifying key determinants of either remaining fuel-poor or moving in and out of fuel poverty will provide relevant information to policy makers who wish to implement effective policies for reducing fuel poverty through a better targeting of people who are fuel-poor. Indeed, if fuel poverty is a transitory state, short-term measures such as direct subsidies for energy costs might be the most appropriate. However, if fuel poverty is a chronic phenomenon, long-term measures such as improving buildings' energy performance, must be taken. Nevertheless, for low-income households living in energy-inefficient housing, short- and long-term measures can be complementary.

As Roberts et al. (2015) note, it is important to understand the dynamics of fuel poverty

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<sup>53</sup> This tariff was set up by the Decree of 13 August 2008.

<sup>54</sup> This tariff was set up by the Decree of 8 April 2004.

*“because the welfare implications and thus policy measures will be different depending on how such poverty is experienced. For example, if many households experience fuel poverty for a short period of time, the required policy response will be different to that required if a small number of households experience fuel poverty persistently.”* These authors investigate urban/rural differences in fuel poverty levels and dynamics in the UK through both a descriptive analysis of the British Household Panel Survey and the estimation of discrete hazard models of energy poverty exit and re-entry. They note, *inter alia*, that on average, fuel-poor households in urban areas remain in their condition longer than fuel-poor households in rural areas. The latter nevertheless appear to be more vulnerable to rising energy prices. The authors conclude that policy effectiveness might be different in rural and urban areas.

Nevertheless, most studies on fuel poverty rely on one-time surveys—in other words, surveys in a static context (e.g., housing surveys)—instead of panel data. Consequently, few studies on fuel poverty have been carried out in a dynamic environment.

To the best of our knowledge, aside from Roberts et al. (2015), there is only one study on the dynamics of fuel poverty that uses longitudinal data. Phimister et al. (2014) analyse transitions into and out of fuel poverty in Spain from 2007-2010 using a Markov matrix that provides the probabilities of moving from fuel poverty to non-fuel poverty and vice versa. They observe, *“the proportion of the sample that can be characterised as persistently energy poor is substantially less than the proportion that is persistently income poor.”*

Our study’s objective is similar to that of Phimister et al. (2014) and Roberts et al. (2015). Indeed, we want to know whether fuel poverty is transitory or chronic. However, our approach is slightly different than those mentioned above. On the one hand, we calculate the probability of moving from a fuel poverty situation (or state) to a non-fuel-poverty state, or vice versa, along with the probability of remaining in the same state. Indeed, contrary to Phimister et al. (2014) and Roberts et al. (2015) our statistical method (i.e. mover-stayer

model, Frydman 1987) allow us to separate, within the transitions between fuel poverty and non-fuel-poverty as observed in the database, those induced by the mobility process across the different states and those for individuals confined in the fuel poverty process.

In addition, we identify individuals who are at risk of fuel poverty. The probability calculation addresses the following question: Does France have a fuel poverty trap or is it almost in a transitory state? On the other hand, we identify the stability and mobility determinants between different states in the fuel poverty phenomenon. For this purpose, we use a mover-stayer model that divides the population into two types of individuals: those who remain in the same state during the observation period (i.e., stayers) and those who move across states (i.e., movers). Note that this model allows us to statistically identify and quantify the proportion of stayers in each state and the proportion of movers in each state, along with the transition probabilities for movers. Boag (1949)<sup>55</sup> develops this approach in the biomedical field; it has been applied both to model labour-market transitions (Blumen et al., 1955; Dunsmuir et al., 1989, Fougère and Kamionka, 1992) and to model criminal recidivism (Schmidt and Witte, 1989). The model parameters, namely, the proportion of stayers and the proportion of movers in each state, along with the interstate transition probabilities matrix for movers, are estimated via maximum likelihood methods. To apply this type of model to fuel poverty in mainland France, we use longitudinal data from the Statistics on Resources and Living Conditions,<sup>56</sup> published by the French National Institute of Statistics and Economic Studies (INSEE). After this first analysis, we perform econometric estimations (logit and multinomial logit estimations) based on the same sample to identify the determinants that influence the probability that individuals will remain in fuel poverty (stayers) and the determinants that influence the probability that individuals will move between different states (i.e., movers). This analysis formally identifies determinants of individual stability or

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<sup>55</sup>In biomedical literature, the mover-stayer model is known as the “cure model.”

<sup>56</sup>This survey is part of the European Union Statistics on Income and Living Conditions (EU-SILC).

transition.

The results show that, in France, fuel poverty is not an absorbing state. Indeed, a majority of the fuel-poor move to another, better, state. Therefore, fuel poverty is usually a transitory state and we can argue that France has no fuel poverty trap. Nevertheless, more than one-third of households are stayers in fuel poverty states and the proportion of vulnerable individuals to fuel poverty is approximately 15%. As expected, on the one hand, there is a relationship between income and the likelihood of an individual remaining in the same state. Indeed, a high income level increases the probability of remaining in the non-fuel-poverty state. In contrast, a low income level increases the probability of remaining fuel-poor. Moreover, poor housing implies a greater likelihood of stability in fuel poverty. Another result is that the deterioration in fuel poverty status seems to stem more from difficult financial situations than from bad dwelling conditions. We are finding that certain determinants (e.g., divorced, students and single-parent families) have different impacts on fuel poverty dynamics. Consequently, it is important to consider different sub-populations—i.e., the chronic fuel-poor (stayers) and the transitory fuel-poor (movers)—to best address fuel poverty.

The remainder of this paper is organised as follows. In Section 2, we discuss the main indicators of fuel poverty and explain that we use the difficulty of heating one's home because it is a proxy measure of fuel poverty. Section 2 also describes France's Survey on Income and Living Conditions, which defines three states/situations in which individuals find themselves (i.e., non-fuel poverty, fuel poverty and severe fuel poverty); a mover-stayer model and econometrical specifications are also detailed. Section 3 provides statistical analyses and discusses results and policy implications. Section 4 concludes by suggesting extensions.

## **2. Methods**

### **2.1. Data and the measurement of fuel poverty**

### **2.1.1. Database**

We use the 2009-2011 waves of France's Statistics on Resources and Living Conditions (SRCV). This survey is a part of the European Union Statistics on Income and Living Conditions (EU-SILC), which uses personal interviews to collect information on income distribution, poverty, social exclusion and living conditions. This survey is used as a reference for comparing income distributions among European Union member states and for European Community actions to combat social exclusion. It is organised around a cross-sectional component and a longitudinal component. In this analysis, we use the survey's longitudinal component. This longitudinal component includes a sample of all individuals older than 15 years of age who occupy 16,000 dwellings (selected from the master sample), with a sampling frame for new housing. All of these individuals are followed over time, even when they move to other dwellings. Individuals who answered in all three waves (2009-2011) and did not move comprise the sample used in this study. There are two reasons that our study is based on only three years. On the one hand, the survey's rotating structure restricts the length of years observed. Indeed, each individual is followed up and interviewed over a maximum of four years. Therefore, our panel data are balanced.<sup>57</sup> On the other hand, for consistent winter temperature between the various years, we only use the data from 2009-2011 because the winter temperature for 2008 is quite different than the temperatures in 2009-2011. Indeed, the deviation from the mean is equal to +1°C in 2008 and approximately -1°C for 2009, 2010 and 2011 (see Appendix 4).

Finally, we have a sample of 11,521 individuals per year; these individuals have been observed three times. Overall, our sample includes 34,563 observations.

### **2.1.2. Choice of measure for fuel poverty**

As highlighted in the introduction, there is no common European definition of fuel poverty

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<sup>57</sup> Note that we used a balanced panel because to estimate the "mover-stayer" model, we need to use data that each individual observe in each period.

and consequently, there is no consensus about the best way to determine whether a household is in fuel poverty. Numerous indicators are used to identify the fuel-poor. The most commonly used indicator is the budget share, which is an expenditure-based measure. It represents the percentage of income that a household allocates to meet its energy needs. If this rate is higher than 10%, the household is considered to be experiencing fuel poverty. Proposed by Boardman in 1991, this 10% threshold is almost twice the median percentage of income that UK households allocated to energy supply in 1988<sup>58</sup> (Boardman, 1991). This indicator was long used as the official standard for measuring fuel poverty in the UK by approximating domestic energy requirements based on normative modulated energy consumption. In response to criticism<sup>59</sup> related to this indicator, the British government adopted the Hills indicator in August 2013. According to this indicator, a household is fuel-poor if its income falls below a particular threshold<sup>60</sup> and if its normative modulated energy expenditure is higher than the energy expenditure threshold<sup>61</sup> (Hills, 2011).

France does not have an official indicator for national statistics on fuel poverty. However, a 10% threshold of actual energy expenditures has been used in various studies (e.g., Devalière et al., 2011). In these studies, the energy effort rate is calculated based on actual reported consumption, given the difficulty of modelling normative consumption with the French data that are available. As a result, some atypical behaviours (e.g., restriction/deprivation or excess) that could be corrected with the original indicator (calculated via modulated normative expenses) are not excluded. Thus, the energy effort rate that is calculated based on actual expenditures should not be used. In addition, it can be questioned whether it is appropriate to use the 10% threshold for a country in which climatic conditions, housing

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<sup>58</sup>In 1988, 30% of the poorest households in UK had an energy effort rate of 10%.

<sup>59</sup>For example, (1) there is a fixed threshold of 10% (threshold supported by data dating back to 1988), and (2) better-off households that over-consume are not excluded.

<sup>60</sup>This threshold is equal to the relative poverty line, which is set at 60% of the national median income after housing costs (e.g., rent or mortgage payments) and energy costs (e.g., electricity bills) are deducted.

<sup>61</sup>The threshold is the median household energy expenditure.

structure, type of heating and energy prices vary. Moreover, there is no reason that income and energy expenditure necessarily evolve in the same way. This is particularly true in light of the fact that energy costs depend not only on changes in energy prices but also on climate and the thermal performance of housing.

Other indicators were used to assess the number of fuel-poor, including an indicator based on the minimum income level (see Moore, 2012) and another based on perceived coldness—a subjective measure of fuel poverty. According to the indicator based on the minimum income level, a household is living in fuel poverty if available income (after deducting housing costs and the minimum income level) does not cover the household's energy expenditure. The minimum income level is defined as the income that is required to meet the household's sustenance needs. This indicator provides an idea of how many households are expected to reduce their spending on other goods to meet their energy needs. Using this approach depends on the availability of data on the minimum income level. Determining what income a household requires to allow its inhabitant(s) to live a decent life is subject to normative judgements and may fluctuate over time. Moreover, from country to country, perceptions of the income required to provide minimum standards of living can diverge considerably, thus making comparisons difficult. It is possible to use subjective indicators/declaratives, i.e., those that are based on opinions or perceptions, to identify households that live in fuel poverty. Among these indicators, individuals' feelings of coldness are customary measures. Thus, Lacroix and Chaton (2015) identify a negative correlation between fuel poverty and health report issues and Lacroix and Jusot (2014) quantify the negative impact of fuel poverty indicators on various health dimensions. Measures of fuel poverty that are based on these indicators, amongst others, are often one-off measures.

In this study, we define fuel poverty as difficulty in heating one's home because this definition is similar to that given on 12 July 2010 in Article 11 of France's national

commitment to the environment (Grenelle II law), as noted in the Introduction. Waddams Price et al. (2012) argue that the overlap between the energy effort rate and measures that are based on an individual's self-reported perceptions of household heating difficulties is minimal. Indeed, amongst households that felt that they had problems maintaining warmth, fewer than half showed expenditures that would classify them as fuel-poor. Next, we concentrate on the difficulty of heating one's home, which is a proxy measure of fuel poverty<sup>62</sup> for which we have the panel data necessary to reach our goal, i.e., not only to analyse the dynamics of this precarious situation but also to identify individuals who are vulnerable to fuel poverty.

The database allows us to distinguish the following three categories of individuals: (1) the non-fuel-poor, (2) the fuel-poor and (3) the severely fuel-poor. Therefore, the following three states can be defined:

### **The fuel poverty state (FP)**

If a member of household answers “yes” to the following questions, then the household is considered to be living in fuel poverty: *Is it too difficult or costly to adequately heat your dwelling?* and *Do you have the financial means to maintain the appropriate temperature in your home?*

These households that find that it is too hard or costly to adequately heat their dwelling have experienced *difficulties obtaining the necessary energy to satisfy their basic needs*. Therefore, we consider them fuel-poor. These difficulties seem to be caused by *inadequate living conditions*. Such households may be living in housing that either is oversized or has poor thermal quality. Note that to have the financial means does not mean that they do not restrict their consumption of other goods to pay their energy bills.

### **The severe fuel poverty state (SFP)**

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<sup>62</sup>Heating expenditures represent 70% of household energy costs (INSEE, 2006).

If a member of a household answers “yes” to *Is it too difficult or costly to adequately heat your dwelling?* and “no” to *Do you have the financial means to maintain the appropriate temperature in your home?*, then the household is considered to be living in severe fuel poverty, given the financial burden implied by the answer to the second question.

We drop individuals who we qualify as “inconsistent” because they answered no to the first question but yes to the second question. We cannot treat these individuals in any category.

There are 756 such individuals over the three years studied.

### **Non-fuel-poverty state (NFP)**

The rest of the population belongs to this category.

Thus, only the severely fuel-poor cannot cope with their heating expenditures.

Do people remain in fuel poverty? As explained in the following section, the mover-stayer model relates to this issue by ascertaining whether fuel poverty is an absorbent state.

## **2.2. Models**

### **2.2.1. The mover-stayer model**

The mover-stayer model is an extension of the Markov chain model:  $X(t) \in E$  is the value at time  $t$  of a given variable that is associated with every individual in a given population, where  $E = \{1, \dots, K\}$ ,  $K \in \mathbb{N}$  is a discrete state space.  $E = \{FP, SFP, NFP\}$  is for our application.

This model allows us to consider unobserved heterogeneity in the population, which is assumed to consist of two unobserved groups: a stayer group that contains individuals with zero probability of change ( $X(t) \equiv X(0)$ ) and a mover group that follows an ordinary Markov process (with the transition matrix  $M = \|m_{ij}\|$ ,  $i, j = 1, \dots, K$ ). Let  $s_i \in [0, 1]$ , the proportion of an individual starting from the  $i^{th}$  state, be a stayer. We have at our disposal observations about  $T$  successive years ( $T = 3$  for our application). The estimation of parameters  $(s, M)$ , where  $s$  is the vector  $(s_1, \dots, s_K)$  and  $M$  is as defined above, cannot be directly estimated

because the stayers are not directly observable. Indeed, an individual who is observed to remain in his or her starting class might be a stayer, but a mover who has not moved and whose probability remains in the state  $i$  throughout the observation period is also non-zero (equal to  $m_{ii}^T, i \in E$ ).

Frydman (1984) proposes a method for estimating  $m_{ij}$  and  $s$  that is based on a recursive procedure. The maximum likelihood estimator of  $m_{ij}$  for fixed  $i$  and  $j$  varying from 1 to  $K$  is given by the following recursive equation:

$$\hat{m}_{ij} = \frac{n_{ij} \left( 1 - \hat{m}_{ii} - \sum_{k \neq i, k=1}^{j-1} \hat{m}_{ik} \right)}{\sum_{k \neq i, k=1}^K n_{ik}}, j \neq i, i, j \in E. \quad (1)$$

Starting from  $j=1$  if  $i \neq 1$  and from  $j=2$  if  $i=1$ , the estimator of  $m_{ii}$  ( $\hat{m}_{ii}$ ) is the solution comprised between  $[0,1]$  of the following equation:

$$\hat{m}_{ii} = [n_i^* - Ln_i(0)]m_{ii}^{L+1} + [Ln_i(0) - n_{ii}]m_{ii}^L + [Ln_i - n_i^*]m_{ii} + (n_{ii} - Ln_i) = 0 \quad (2)$$

where  $n_i(0)$  is the initial number of individuals in state  $i$ ;  $n_i(t)$  is the number of individuals in state  $i$  at time  $t$ ;  $n_{ij}$  is the number of individuals in state  $j$  at time  $t$ , who were in state  $i$  at time  $t-1$ ; and  $n_i$  is the number of individuals who continuously remain in  $i$  during all observation periods:  $n_{ij} = \sum_{t=1}^T n_{ij}(t)$  and  $n_i^* = \sum_{t=0}^{T-1} n_i(t)$ . And  $m_{ii} = \frac{n_i}{n_i(0)}$ .

For  $s_i$  parameters:

$$s_i = \frac{n_i - n_i(0)m_{ii}^L}{n_i(0)(1 - m_{ii}^L)}. \quad (3)$$

Kamionka and Fougère (1992) generalise Frydman's method by including cases in which some of the  $s_i$  parameters are null. They demonstrate that if  $s_i = 0$ , then

$$\forall i, j = 1, \dots, K, m_{ij} = \frac{n_{ij}}{n_i^*}. \quad (4)$$

### 2.2.2. Econometric modelling

Why are certain individuals more likely than others to remain in fuel poverty? To answer that question, we estimate two econometric models. One model identifies the determinants of *stayers*, i.e., individuals who remained in the same state during the three observation periods (2009, 2010 and 2011). The other model identifies the determinants of *movers*, i.e., individuals who moved across the different states between 2009 and 2011. In this subsection, we assume that *stayers* are directly observable, unlike in the mover-stayer model. Therefore, the probability for a *mover* to remain permanently in state  $i$  during all observation periods is positive in the mover-stayer model, (Fougère and Kamionka, 1992), whereas this probability is equal to zero in the two econometric models.

#### ***Stayer specifications***

To identify the main determinants of *stayers*, we perform logistic regressions for each state/situation. The logistic specifications model estimates the probability of an event occurring and in our case, this probability determines the likelihood of being a non-fuel-poor *stayer* ( $NFP_s$ ), a fuel-poor *stayer* ( $FP_s$ ) or a severely fuel-poor *stayer* ( $SFP_s$ ) during the three periods of observation (2009-2011), given several exogenous variables that are represented in the  $X_i$  vector for the  $i^{\text{th}}$  individual. These exogenous variables contain socio-economic characteristics (e.g., income level, occupational status, and financial difficulties) and socio-demographic characteristics (e.g., education level, marital status, and housing tenure). Let  $NFP_{si}$ ,  $FP_{si}$  or  $SFP_{si}$  be a binary variable that equals 1 if the  $i^{\text{th}}$  individual is not in fuel poverty, in fuel poverty or in severe fuel poverty, respectively, during the years of observation, and 0 otherwise. The observable outcomes (to report his/her situation) are represented by a binary indicator variable,  $Y_i$ , as follows:

$$Y_i = \begin{cases} 1 & \text{if } Y_i^* > 0 \text{ to report the same situation } Y_i \\ 0 & \text{otherwise,} \end{cases} \quad (5)$$

$$\Pr(Y_i = 1 | X_i) = 1 - \Phi[-X_i' \theta], \quad (6)$$

$$\Pr(Y_i = 0 | X_i) = \Phi[-X_i' \theta], \quad (7)$$

where  $Y_i \in \{NFP_{si}, FP_{si}, SFP_{si}\}$ ,  $Y_i^* \in \{NFP_{si}^*, FP_{si}^*, SFP_{si}^*\}$  is a latent dependent variable;  $\Pr$  denotes probability; and  $\Phi$  is the cumulative distribution function of the standard normal distribution ( $N(0,1)$ ).  $Y_i^*$  is generated by the following linear regression model:

$$Y_i^* = \alpha_{Y_i} + \beta_{Y_i} X_i' + \varepsilon_{Y_i}, \quad (8)$$

where for each  $Y_i \in \{NFP_{si}, FP_{si}, SFP_{si}\}$ ,  $\alpha_{Y_i}$  is a constant, and  $\beta_{Y_i}$  is a vector.

### **Mover specifications**

We analyse the determinants of transitions between different states ( $NFP_m$ ,  $FP_m$ ,  $SFP_m$ ). The following transition matrix represents the transition probabilities between the different states ( $FP_m, SFP_m, NFP_m$ ):

$$M = \begin{pmatrix} m_{NFP_m \rightarrow NFP_m} & m_{NFP_m \rightarrow FP_m} & m_{NFP_m \rightarrow SFP_m} \\ m_{FP_m \rightarrow NFP_m} & m_{FP_m \rightarrow FP_m} & m_{FP_m \rightarrow SFP_m} \\ m_{SFP_m \rightarrow NFP_m} & m_{SFP_m \rightarrow FP_m} & m_{SFP_m \rightarrow SFP_m} \end{pmatrix}$$

where  $(j,k) \in \{FP_m, SFP_m, NFP_m\}$  and  $t' \neq t$ :  $m_{j \rightarrow k} = P(\frac{Y_{t'}}{Y_t} = j)$ . Each  $m_{j \rightarrow k}$  can be written as a multinomial logistic regression by fixing the base outcome as the initial state. For example, the transition probability between the non-fuel-poverty state ( $NFP_m$ ) and a state ( $k$ ) is as follows:

$$\Omega_{NFP_m \rightarrow k}^{m_{j \rightarrow k}}(Y_{t+1} = k / X_t, Y_t = NFP_m) = \frac{\exp(X_t' \gamma_{NFP_m \rightarrow k})}{1 + \sum_{k \neq NFP_m} \exp(X_t' \gamma_{NFP_m \rightarrow k})}. \quad (9)$$

This specification is used to identify determinants that alter the probability of moving from one state/condition to another between 2009 and 2011. The primary determinants that increase the risk of being fuel-poor can be split in two large categories: (1) socio-economic determinants; and (2) socio-demographic determinants.

## **Control variables**

In the stayers and movers specifications, we include individual variables to control for current Social-Economic Status (SES). The economic literature is relatively rich in information on fuel poverty determinants. Although most studies that identify fuel poverty determinants have been conducted in a static context, SES is a point to which we can refer when we attempt to choose the control variables.

Income level and occupational status on the labour market are identified as the major socio-economic determinants of fuel poverty (Healy and Clinch, 2004; Waddams Price and al., 2012; Scott et al., 2008). Therefore, a low income (or unemployment) pressures household budgetary constraints. With a constant level of energy expenditures, an income decrease or a low level of income increases a household's risk of being fuel-poor. Moreover, individuals with low incomes are more likely to have energy-inefficient appliances (Devalière et al., 2011). We consider income quintiles that divide our sample into five equal-sized groups based on household income divided by the Organization for Economic Co-operation and Development's (OECD) equivalent scale<sup>63</sup>.

We can report that education level (Healy and Clinch, 2004; Huybrechs et al., 2011), household type (Healy and Clinch, 2004; Waddams Price et al., 2012; Scott et al., 2008), marital status (Healy and Clinch, 2004; Scott et al., 2008), housing tenure (Healy and Clinch, 2004; Whyley et al., 1997; Scott et al., 2008) and dwelling conditions (Whyley and Callender, 1997; Healy and Clinch, 2004; Scott et al., 2008) are the primary socio-demographic determinants. Huybrechs et al. (2011) explain that individuals with low levels of education do not have the same "capabilities" (Sen, 1999) of adopting energy-saving behaviours; as a direct

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<sup>63</sup> To compare the standards of living of households of different sizes or compositions, it is unnecessary to use a measurement of income corrected by the consumption unit using an equivalence scale. The OECD scale is currently the most widely used scale and uses the following weighting: 1 CU for the first adult in the household; 0.5 CU for other persons aged 14 years or older; -0.3 CU for children under 14 years of age.

result, these individuals may experience increases in their energy bills. We adopt four categories for the level of education (no education level, lower secondary level, higher secondary level and post-secondary level).

In addition, budgetary constraints are tighter for single-parent families than they are for households with two adults and a child. In the same way, because of the significant economic cost of marital dissolution, divorce may make some individuals vulnerable to fuel poverty (Hoffman and Duncan, 1988). We consider five categories of household: single person, single-parent family, couple without children, couple with children and other. In addition, marital status is introduced, giving us a variable with four categories: single, married, widowed and divorced.

Compared to tenants, owners have better and more precise (accurate) control over their energy consumption and heating systems. Therefore, tenants may find it more difficult to save energy or improve household energy efficiency. Finally, dwelling conditions (e.g., damp, mould, and condensation) and building age are fuel poverty determinants (Healy and Clinch, 2004; Whyley and Callender, 1997; Scott et al., 2008).

Different variables related to the dwelling are introduced. First, the type of dwelling is decomposed into three difference categories (farm/house, town/adjacent house and apartment). Second, the occupancy status is divided into three classes (owner, tenant and free of charge). Moreover, the place of residence is divided into two categories (rural and urban). Third, the dwelling surface is treated in four intervals ( $<80 \text{ m}^2$ ],  $[80-100 \text{ m}^2$ ],  $[100-130 \text{ m}^2$ ] and  $>130 \text{ m}^2$  [ ). Finally, we control these regressions through the “Study area and regional planning” variable (currently named “ZEAT”). Each “ZEAT” is a territorial subdivision of France and is the first category in the European Union’s nomenclature of territorial statistical units (NUTS 1). This variable permits to exercise the maximum control over temperature differences among France’s various regions. The main reason that we have used this

geographical information instead of department is because this latter is not available in our database.

### 3. Results and Discussion

#### 3.1. Descriptive statistics

The fuel-poor accounted for slightly more than 25% of the sample examined (see Table 1) using our definition. This proportion is significantly greater than during the last estimation of INSEE, which was 14.4% for 2006. One explanation for this gap is that INSEE uses the traditional threshold of 10% of household income for fuel expenditures to identify the fuel-poor, which does not consider restriction phenomena. Furthermore, this gap primarily exists because total family income is not adjusted for one spouse and the number of dependants under and over the age of 14.<sup>64</sup>

	<b>Non-Fuel Poor</b>	<b>Fuel Poor</b>	<b>Severe Fuel Poor</b>
<b>2009</b>	77.48%	19.30%	3.22%
<b>2010</b>	74.78%	21.95%	3.27%
<b>2011</b>	75.80%	20.98%	3.22%

Table 1: Distribution of the sample among the states

The proportion of non-fuel-poor has decreased by 1.5% between 2009 and 2011. In contrast, the proportion of fuel-poor increased by approximately 1.5%. Therefore, the proportion of severely fuel-poor remained fairly constant during this period. Some of the sample’s socio-economic and demographic information is summarised in Table 2.

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<sup>64</sup> Indeed, if we consider a household to be living in fuel poverty if  $\frac{\text{Household energy expenditure (including a correction factor for no response)}}{\text{Level of income} / \text{The number of consumption units (CUs)}} > 10\%$  then, using the same database for mainland France, 25% of households were in fuel poverty in 2009. The percentage of fuel-poor people is approximately 27% in 2011. Note that if income was not divided by consumption units, as was the case with the original indicator, the percentage of energy-insecure households would be lower (approximately divided by two) and therefore, close to the 14.4% estimated by the INSEE.

<b>Sex</b>	Female 52.47	Male 47.53			
<b>Location (population density)</b>	Rural 27.71	Urban 72.29			
<b>Type of household</b>	Single 14.36	Single-parent families 6.57	2 adults without dep. child 32.27	Two-adult family with children 43.86	Others 2.94
<b>Presence of mould and/or moisture</b>	Yes 10.35	No 89.65			
<b>Housing type</b>	A farm, house or detached house 52.58		A town house or semi-detached house 22.70		Apartment 24.72
<b>Occupancy status</b>	Owner 71.77	Tenant 25.40	Free of charge 2.83		

Table 2: Descriptive statistics on the sample used (in percentages)

Therefore, 75% of individuals live with a partner; 71% are homeowners; and 10% report the presence of mould and/or moisture in their homes. In addition, almost 47% of individuals have a lower secondary level of education.

More than 6% of individuals report at least one of the following financial difficulties:

- 1) The inability to pay taxes on time over the past 12 months because of money problems;  
and
- 2) The inability to repay credit on time because of money problems.

Based on household characteristics, Table 3 shows the individual sample distribution of the three states.

	NFP	FP	SFP
Female	51.63 %	54.23%	60.95 %
Rural	26.28%	31.76%	35.21%
Single person	13.33%	15.94%	28.42%
Single-parent families	5.96%	7.13%	17.16%
Couples without children	32.60%	33.24%	18.41%
Couples with children	45.52%	39.83%	30.83%
Financial difficulty	2.91%	5.79%	14.94%
Damp/musty conditions	6.34%	21.08%	35.75%
A farm, a house or a detached house	52.60%	53.75%	44.77%
A town house, semi-detached house	20.97%	27.52%	32.26%
Owner	74.13%	66.03%	53.08%
Tenant	23.11%	30.95%	43.70%
Employed	52.05%	43.58%	35.21%
Student	7.22%	6.95%	6.61%

Table 3: Individual sample distribution across the three states

This table indicates that 32% of couples without children and 45% of couples with children are among the non-fuel-poor; in addition, 18% of couples without children and 31% of couples with children are among the severely fuel-poor, and these couples constitute 74% of the sample. The table shows that 17% of single-parent families are among the severely fuel-poor, but this type of household constitutes less than 6.50% of the sample. The percentages confirm that housing quality has a significant impact on the fuel poverty state. Indeed, nearly 36% of individuals who claim to have mould and/or moisture problems in their homes are among the severely fuel-poor, but these individuals comprise only slightly more than 10% of the sample. Improving housing quality for some of these households could probably get them out of fuel poverty.

Do people remain in fuel poverty?

### **3.2. Fuel poverty is not a trap—it is almost a transitory state**

Using the mover-stayer model presented in Section 2.2.1, we study individual trajectories and quantify the proportions of individuals who were stayers and movers in each state. Table 4 shows the estimated **proportions of stayers** in the three states: 80% of the non-fuel-poor will

not fall into fuel poverty; 39% of the fuel-poor will remain precarious; and 33% of the severely fuel-poor will remain in that state.

Non-Fuel Poor	Fuel Poor	Severely Fuel Poor
80%	39%	33%

Table 4: Estimated proportions of stayers in each state

Therefore, fuel poverty and severe fuel poverty do not constitute irreversible states because well under half of the fuel-poor and severely fuel-poor remain in the same state over the course of the observation period. Moreover, the proportions of stayers in fuel poverty and severe fuel poverty are lower than the proportion of non-fuel-poor stayers. Additionally, the proportion of movers in the non-fuel-poverty state can be qualified as vulnerable. Indeed, these individuals are exposed to fuel poverty or severe fuel poverty. In our data, this category represents 20% of 26,274 (i.e., 5,255) non-fuel-poor, so in other words, 15% (i.e., 5255/34563) of the individuals studied are vulnerable to either fuel poverty or severe fuel poverty.

The estimated **transition probabilities** between each state (for the movers) are shown in Figure 1.

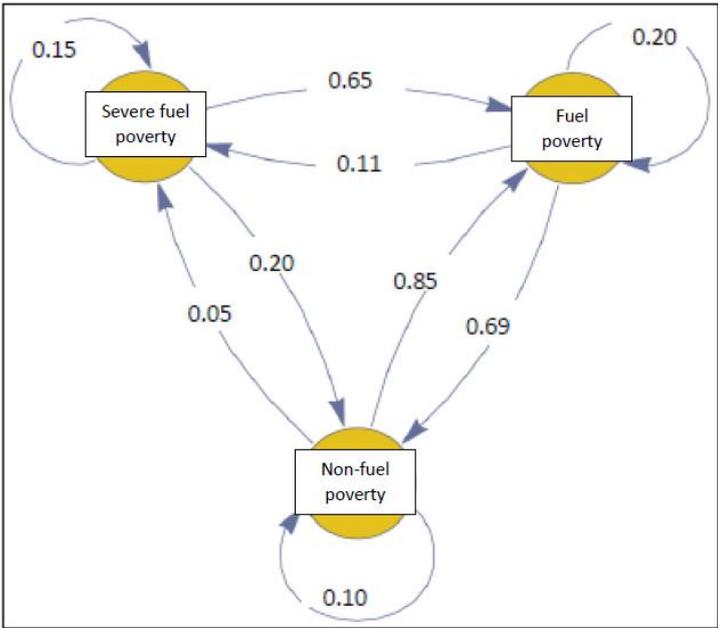


Figure 1: Estimation of ‘movers’ transition probabilities

The transition probability of moving from non-fuel poverty to fuel poverty is very high (at

0.85). For fuel-poor movers, the probability of returning to a non-fuel-poverty state is relatively high (at 0.69). In contrast, the probability of transitioning into severe fuel poverty is low (a maximum of 5%). Therefore, for movers, it is more difficult to enter the severe fuel poverty state than it is to leave it. The transition probabilities of moving from severe fuel poverty to fuel poverty and from severe fuel poverty to non-fuel poverty are different (0.65 versus 0.20). These results provide relevant information. Fuel poverty seems to be a transitory (temporary) state for movers, and the movers' mobility appears to be very high. In other words, today's fuel-poor movers will not be fuel-poor tomorrow. This observation confirms that fuel poverty is not a trap for movers. Indeed, the probability of movers remaining in fuel poverty or severe fuel poverty is low for movers (at 0.20 and 0.15, respectively). In addition, it seems that mobility among states is important. Note that we have checked the adequacy of the "mover-stayer" model on our data in Appendix 5.

Given that fuel poverty in France does not seem to be a trap, governments should generally be directed towards short-term policies, such as financial aid and more relevant approaches such as energy vouchers. For people in landlocked fuel poverty, these short-term measures could be supplemented by long-term policies such as thermal rehabilitation aids. However, to better target these policies it is necessary to understand the characteristics of both stayers and movers. The econometric analysis below highlights these characteristics.

### **3.3. Econometric results and discussion**

#### **3.3.1. Econometric results for *stayers***

Table 5 reports the logit specification estimations for people who remain in their state, i.e., stayers.

Variables	“Stables” Non Fuel Poor	“Stables” Fuel Poor	“Stables” Severe Fuel Poor
	Odd ratio (sd)	Odd ratio (sd)	Odd ratio (sd)
Net income			
1 <sup>st</sup> quartile	REF	REF	REF
2 <sup>nd</sup> quartile	1.13*** (0.06)	1.12 (0.08)	0.63** (0.12)
3 <sup>rd</sup> quartile	1.58*** (0.09)	1.02 (0.09)	0.20*** (0.07)
4 <sup>th</sup> quartile	1.91*** (0.12)	0.73** (0.07)	0.07*** (0.03)
Level of education			
No education	REF	REF	REF
Lower secondary	1.14** (0.07)	1.19* (0.11)	0.073* (0.16)
Higher secondary	1.30*** (0.10)	1.02 (0.13)	1.02 (0.31)
Post-secondary	1.23** (0.10)	1.16 (0.14)	0.61 (0.22)
Type of household			
Single person	REF	REF	REF
Single parent family	0.93 (0.10)	0.97 (0.16)	1.40 (0.44)
Couple without children	1.26** (0.12)	1.20 (0.18)	0.06*** (0.03)
Couple with children	1.28** (0.12)	1.18 (0.18)	0.23*** (0.08)
Others	0.94 (0.13)	1.29 (0.26)	0.14*** (0.08)
Marital status			
Single	REF	REF	REF
Married	1.16** (0.08)	0.98 (0.12)	1.26 (0.40)
Widow	1.01 (0.11)	1.31 (0.25)	0.31** (0.12)
Divorced	1.00 (0.10)	1.26 (0.23)	0.87 (0.26)
Status on labour market			
Employed	REF	REF	REF
Student	1.04 (0.10)	1.06 (0.18)	0.99 (0.43)
Unemployed	0.77** (0.07)	0.86 (0.13)	1.90** (0.56)
Retired	1.08 (0.09)	1.14 (0.15)	0.95 (0.39)
Homemaker	0.89 (0.09)	1.19 (0.19)	1.41 (0.57)
Others	0.77* (0.10)	1.10 (0.26)	2.89** (1.10)
Type of dwelling			

Farm, house	REF	REF	REF
Town, adjacent house	0.88** (0.05)	1.17* (0.11)	0.88 (0.23)
Apartment	1.56*** (0.12)	0.56*** (0.08)	0.45** (0.15)
Occupancy status			
Owner	REF	REF	REF
Tenant	0.57*** (0.04)	2.27*** (0.24)	0.75 (0.21)
Free of charge	0.74** (0.10)	1.38 (0.32)	0.74 (0.41)
Rural/urban			
Urban	REF	REF	REF
Rural	0.94 (0.05)	1.17* (0.10)	1.26 (0.28)
Financial difficulties			
No	REF	REF	REF
One	0.54*** (0.04)	1.36** (0.28)	2.32** (1.11)
Two	0.26*** (0.04)	1.09 (0.24)	3.50*** (2.29)
Area			
<80m <sup>2</sup> [	REF	REF	REF
[80-100m <sup>2</sup> [	0.90 (0.07)	1.08 (0.14)	0.49** (0.51)
[100-130m <sup>2</sup> [	0.70*** (0.05)	1.73*** (0.23)	0.51* (0.18)
>130m <sup>2</sup> [	0.59*** (0.05)	2.18*** (0.31)	1.37 (0.46)
Area			
Ile de France	REF	REF	REF
Parisian basin	1.08 (0.09)	1.03 (0.16)	0.99 (0.38)
North	0.78** (0.08)	1.56** (0.27)	0.55 (0.30)
Est	0.81** (0.08)	1.28 (0.21)	0.95 (0.40)
West	1.20** (0.10)	0.95 (0.15)	1.23 (0.44)
South west	0.97 (0.08)	1.23 (0.20)	1.60 (0.61)
Est centre	1.02 (0.10)	1.25 (0.21)	0.20** (0.16)
Mediterranean	1.01 (0.9)	0.84 (0.15)	2.13** (0.80)

Table 5: Econometric results for stables (regressions adjusted by age, gender; \*\*\*:p<=1%, \*\*:p<=5%, \*:p<10%)

As expected, a high income<sup>65</sup> level increases the probability of remaining in the non-fuel-poverty state. In contrast, a low income level increases the probability of remaining fuel-poor and to an even greater extent, of remaining severely fuel-poor. A high education level reduces the probability of remaining in fuel poverty or severe fuel poverty and reinforces an individual's stability in non-fuel poverty. However it appears that the effect of the level of income on the probability to remain in the simple fuel poverty state have a lower impact compared to its impact on the probability to remain in the severe fuel poverty state. This results represents the fact that the simple fuel poverty state, due to indicator<sup>66</sup> that we use, are less sensible to financial distress compared the indicator uses to defined the severe fuel poor state<sup>67</sup>.

These results seems to confirm that individuals with a high level of education compared to individuals with low level of education do not have the same level of “capabilities” (Sen, 1999) to adopt energy-saving behaviours, and the direct consequence could be an increased energy bill (Byubrechts, 2004). The analysis of an individual's status on the labour market indicates that unemployment has the strongest impact on the probability of remaining in severe fuel poverty and decreases the probability of remaining in non-fuel-poverty state or fuel poverty state. We see a vicious cycle of unemployment compared to employed individuals. Compared with having a low income level or lower education level, the existence of significant financial difficulties has a similar impact on fuel-poor stables or severely fuel-

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<sup>65</sup> Let us not forget that income is treated in four quintiles and to consider different sizes or compositions of households, we use the OECD equivalent scale.

<sup>66</sup> If a member of household answers “yes” to the following questions, then the household is considered to be living in fuel poverty: *Is it too difficult or costly to adequately heat your dwelling?* and *Do you have the financial means to maintain the appropriate temperature in your home?*

<sup>67</sup> If a member of a household answers “yes” to *Is it too difficult or costly to adequately heat your dwelling?* and “no” to *Do you have the financial means to maintain the appropriate temperature in your home?*, then the household is considered to be living in severe fuel poverty, given the financial burden implied by the answer to the second question.

poor stayers. Therefore, the higher the number of financial difficulties, the higher the probability of stability in fuel poverty or severe fuel poverty, and this effect is even more pronounced in the severe fuel poverty state. This result shows that these individuals are isolated in precariousness. Long-term policies must be developed so that these stayers in fuel poverty escape. For stayers in fuel poverty, who perhaps endure permanent poverty, *“long-term measures, including structural changes in the labour market as well as investment in education, training, and special services are needed”* (Evason, 1981).

It appears that living with a partner (with or without children) is good protection against stability in the severe fuel poverty state. In addition, living with a partner increases the probability of staying in a non-fuel-poverty state, as marriage compared to singlehood. This increase likely results from the fact that couples generally have more financial flexibility (because of cost sharing) than do single persons. In terms of marital status, the probability of staying in fuel poverty is higher among the widowed than among single persons. Nevertheless, the widowed have a lower probability of staying in severe fuel poverty than single persons. Indeed, widowhood may include the receipt of life insurance benefits from the deceased spouse, which can be substantial. Therefore, a comfortable financial position could explain a widowed person’s lower probability of staying in severe fuel poverty compared to a single person.

The probability of remaining fuel-poor is greater among renters. Tenants do not have full control of their heating consumption compared to owners (Healy and Clinch, 2004). Long-term measures that would encourage donors to improve the thermal quality of housing for these fuel-poor tenants could get them out of fuel poverty.

Compared to living in an apartment, living in a detached house or on a farm increases the probability of remaining in fuel poverty and, to an even greater extent, in severe fuel poverty. We observe that the probability of staying in fuel poverty is higher among rural residents than

among urban residents. For the other states, living in an urban or rural area does not have an impact on stability. In terms of housing surface, the size of the dwelling is more important because the probability of stability in the fuel poverty state is both important and lower than the probability of stability in the non-fuel-poverty state. Nevertheless, for the severe fuel poverty state we observe that individuals living in bigger dwellings have a lower probability of stability in this state.

### **3.3.2. Econometric results for *movers***

Table 6 reports the results of these six multinomial logistic specifications.

Variables	NFP→FP	NFP→SFP	FP→NFP	FP→SFP	SFP→NFP	SFP→FP
	Odd ratio (sd)					
<b>Net income</b>						
1 <sup>st</sup> quartile	REF	REF	REF	REF	REF	REF
2 <sup>nd</sup> quartile	1.08 (0.07)	0.60*** (0.09)	1.29*** (0.09)	0.62*** (0.10)	2.51*** (0.10)	2.50*** (0.43)
3 <sup>rd</sup> quartile	0.77*** (0.06)	0.40*** (0.07)	1.64*** (0.12)	0.49*** (0.09)	3.69*** (0.70)	2.75*** (0.54)
4 <sup>th</sup> quartile	0.62*** (0.05)	0.11*** (0.03)	2.34*** (0.20)	0.18*** (0.05)	8.48*** (2.31)	4.47*** (1.23)
<b>Type of household</b>						
Single person	REF	REF	REF	REF	REF	REF
Single parent family	1.08 (0.14)	0.84 (0.14)	1.27* (0.17)	1.01 (0.23)	1.44 (0.65)	1.02 (0.27)
Couple without children	0.99 (0.11)	0.23*** (0.07)	0.95 (0.11)	0.23*** (0.07)	5.62*** (1.70)	4.80* (1.40)
Couple with children	0.97 (0.11)	0.31*** (0.08)	1.27** (0.15)	0.33** (0.08)	6.04*** (1.67)	3.57*** (1.04)
Others	1.20 (0.12)	0.18*** (0.08)	0.92 (0.15)	0.19** (0.09)	1.51 (0.51)	1.28 (0.40)
<b>Marital status</b>						
Single	REF	REF	REF	REF	REF	REF
Married	0.72 (0.06)	0.66* (0.15)	0.89 (0.08)	0.73 (0.18)	0.64* (0.15)	0.65* (0.14)
Widow	0.90 (0.11)	0.43*** (0.11)	0.59*** (0.07)	0.29*** (0.08)	1.74* (0.53)	1.61 (0.48)
Divorced	0.82* (0.09)	1.01 (0.21)	0.75** (0.18)	0.85 (0.19)	0.96 (0.12)	0.99 (0.26)
<b>Status on labour market</b>						
Employed	REF	REF	REF	REF	REF	REF
Student	0.73** (0.10)	0.98 (0.31)	0.83 (0.10)	0.91 (0.29)	1.19 (0.39)	1.39 (0.48)
Unemployed	1.15 (0.14)	2.46*** (0.46)	1.03 (0.13)	2.26*** (0.54)	0.62* (0.16)	0.77 (0.020)
Retired	0.94 (0.09)	0.97 (0.24)	1.02 (0.10)	0.99 (0.28)	0.76 (0.19)	0.61* (0.16)
Homemaker	1.13 (0.13)	1.35 (0.38)	0.82* (0.09)	1.04 (0.30)	0.51** (0.13)	0.54** (0.14)
Others	0.95 (0.17)	2.20** (0.61)	0.80 (0.14)	1.58(0.53)	0.52* (0.18)	0.45** (0.16)
<b>Type of dwelling</b>						
Farm, house	REF	REF	REF	REF	REF	REF
Town, adjacent house	1.17** (0.07)	1.07 (0.17)	0.84** (0.05)	0.90 (0.14)	0.88 (0.15)	0.89 (0.14)
Apartment	0.58*** (0.05)	0.30*** (0.07)	1.77*** (0.16)	0.74 (0.15)	3.64*** (0.84)	1.28 (0.27)
<b>Occupancy status</b>						

Owner	REF	REF	REF	REF	REF	REF
Tenant	1.91*** (0.14)	1.45** (0.25)	0.51*** (0.04)	0.73* (0.12)	0.47*** (0.09)	1.14 (0.18)
Free of charge	1.61*** (0.23)	0.76 (0.28)	0.75** (0.11)	0.69 (0.23)	0.95 (0.37)	1.64 (0.65)
<b>Rural/urban</b>						
Urban	REF	REF	REF	REF	REF	REF
Rural	1.01 (0.05)	0.88 (0.13)	0.89* (0.05)	0.76 (0.12)	0.76* (0.11)	0.73** (0.11)
<b>Financial difficulties</b>						
No	REF	REF	REF	REF	REF	REF
One	1.12** (0.19)	3.67*** (0.86)	0.39*** (0.06)	1.98** (0.54)	0.21*** (0.05)	0.41*** (0.8)
Two	1.37*** (0.28)	8.30 (2.13)	0.41 (0.06)	3.40 (0.89)	0.09*** (0.02)	0.13*** (0.04)
<b>Area of dwelling</b>						
<80m <sup>2</sup> [	REF	REF	REF	REF	REF	REF
[80-100m <sup>2</sup> [	1.20** (0.10)	0.87 (0.16)	1.04 (0.09)	1.02 (0.20)	1.11 (0.21)	1.11 (0.21)
[100-130m <sup>2</sup> [	1.56*** (0.13)	0.82 (0.16)	0.77** (0.07)	0.79 (0.16)	1.13 (0.25)	1.13 (0.25)
>130m <sup>2</sup> [	1.95*** (0.18)	1.53** (0.31)	0.66*** (0.06)	1.12 (0.24)	0.70 (0.16)	0.70 (0.16)
<b>Area of living</b>						
Ile de France	REF	REF	REF	REF	REF	REF
Parisian basin	1.32** (0.13)	0.42*** (0.10)	1.39*** (0.13)	0.83 (0.20)	0.91 (0.24)	0.91 (0.24)
North	1.72*** (0.20)	0.63* (0.18)	1.07 (0.12)	0.72 (0.20)	1.10 (0.38)	1.10 (0.38)
Est	1.61*** (0.17)	0.65 (0.17)	0.94 (0.09)	0.62* (0.16)	1.06 (0.33)	1.06 (0.33)
West	1.01*** (0.11)	0.52** (0.21)	1.50*** (0.15)	0.82 (0.19)	1.27 (0.34)	1.27 (0.34)
South west	1.27*** (0.14)	0.76 (0.19)	1.18 (0.12)	1.15 (0.29)	0.52** (0.14)	0.52** (0.14)
Est center	1.32*** (0.14)	0.38*** (0.11)	1.23* (0.13)	0.61* (0.18)	2.07* (0.77)	2.07* (0.77)
Mediterranean	1.11 (0.12)	0.82 (0.19)	1.69*** (0.18)	1.48 (0.37)	0.57** (0.16)	0.57** (0.16)
<i>N</i>	2400	174	2509	374	124	404

Table 6: Econometric results for mobiles (regressions adjusted by age, gender;  
\*\*\*:p<=1%,\*\* :p<=5%,\* :p<10%)

Again, income level is a covariate with a very strong effect. Indeed, a high income level increases transition probabilities between states. High-income individuals are more likely than others to overcome fuel poverty or severe fuel poverty. Consequently, short-term measures such as social energy tariffs or energy vouchers can be adequate to relieve temporary distress.

Unemployed people's risk of moving from non-fuel poverty or fuel poverty to severe fuel poverty is high. Indeed, unemployment constitutes the primary contributing factor to state deterioration and increases the risk of isolation (i.e., confinement). As in the case of *stayers*, financial difficulties substantially increase the risk of falling into fuel poverty or severe fuel poverty. In contrast, the probability of overcoming fuel poverty or severe fuel poverty is low for individuals facing insolvency problems. If households not only fall into fuel poverty or severe fuel poverty but also become precarious, then increased revenues from direct measures such as income transfers can improve their situation. However, if they risk enduring permanent poverty, it is preferable to take long-term measures, just as in the case of fuel-poor stayers.

Compared with living alone, living with a partner reduces the probability of aggravating fuel poverty (i.e., moving from fuel poverty to severe fuel poverty) and increases the probability of overcoming severe fuel poverty.

Another interesting result concerns single-parent families. The probability of those living in fuel poverty transitioning into non-fuel poverty is higher among single-parent families than among single persons. This result may seem counterintuitive. However, single-parent families may restrain their heating consumption to save on costs (budget arbitrations). Therefore, single-parent families may move artificially into non-fuel poverty.

Divorced people show the lowest probability of moving from fuel poverty to non-fuel poverty, given the additional financial burden resulting from divorce (Hoffman and Duncan, 1988). In contrast, widows have the least risk of falling into severe fuel poverty; they are more likely to overcome severe fuel poverty but are at greater risk of becoming fuel-poor. Married persons are less likely to transition from non-fuel poverty to fuel poverty. Nevertheless, married persons in an initial state of severe fuel poverty have a lower probability of moving into non-fuel poverty.

Students have the lowest probability of falling into fuel poverty. This result seems to be counterintuitive, but may be potentially explained by the fact that students can either receive family financial support or restrain their heating consumption to save on costs (budget arbitrations), similar to single-parent families.

In terms of dwelling type, the results corroborate the econometric results for *stayers*. Living in an apartment seems to protect individuals against fuel poverty and severe fuel poverty.

Renting increases the probability of falling into fuel poverty, i.e., moving from non-fuel poverty to fuel poverty or severe fuel poverty. Furthermore, tenants are much less likely than owners to overcome fuel poverty or severe fuel poverty because tenants have less flexibility than owners in terms of equipment and heating consumption.

Additionally, the rural covariate corroborates the results for *stayers*. Indeed, the results show that rural residents are isolated in fuel poverty, a phenomenon that is more common in situations of severe fuel poverty. Compared to an urban resident, a rural resident in fuel poverty has a lower probability of achieving non-fuel poverty.

Finally, the larger the dwelling, the higher the probability of moving into fuel poverty for the non-fuel-poor; the smaller the dwelling, the lower the probability of leaving fuel poverty. Additionally, the non-fuel-poor who live in the largest dwellings (>130 m<sup>2</sup>) have a higher probability of moving into severe fuel poverty; the other modalities are not significant. Indeed, the largest dwellings require higher energy consumption for warming. Nevertheless, for the fuel-poor, dwelling surface does not have an impact on moving into severe fuel poverty. Then, insofar as larger units are more expensive to heat, we can see that smaller housing is important to increase the probability of passing from the non-fuel-poverty state to the fuel poverty state.

However, the deterioration of fuel poverty status (i.e., passage from a state of fuel poverty to a state of severe fuel poverty) seems more attributable to financial difficulties than to housing

conditions. If we acknowledge this result, financial assistance could be more suitable than improved housing for helping movers escape severe fuel poverty. These results show the multidimensional complexity of the fuel poverty phenomenon.

## 4. Conclusion and Policy Implications

This study is one of the few to examine the dynamics of fuel poverty. The mover-stayer model presented in Section 2.2.1 reveals that fuel poverty is an almost transitory (i.e., temporary) state. Nevertheless, it must not be forgotten that 38% are stayers in a fuel poverty state and 33% are stayers in a severe fuel poverty state. Additionally, the proportion of individuals who are vulnerable to fuel poverty is approximately 15%.

Our econometrics estimates show that for certain determinants (e.g., divorced, students and single-parent families), the impact on fuel poverty dynamics differs between *stayers* and *movers*, which underlines the need to consider different sub-populations, i.e., the chronic fuel-poor (*stayers*) and the transitory fuel-poor (*movers*). Consequently, it is necessary to take a dynamic approach to studying fuel poverty.

Our research gives the key determinants of different categories of fuel-poor (i.e., the chronic fuel-poor and the transitory fuel-poor), along with determinants that affect individuals' trajectories. A better identification of these different sub-fuel-poor populations and related determinants would enable a much more efficient and precise targeting of public policies that seek to eradicate the fuel poverty phenomenon. Therefore, the various measures in place could be adjusted for and adapted to different fuel-poor populations because their determinants are different. In addition, the results of this study could inform future prevention measures.

In conclusion, it appears that there is a need to implement short-term and long-term measures to implement jointly. In other words, short-term assistance (social energy tariff, energy vouchers) would be useful to limit the transition from the non-fuel-poor state to a fuel poverty

or severe fuel poverty state. Nevertheless, some of the long-term programmes (dwelling renovation) should be conducted in a manner that avoids making individuals stable in these states of fuel poverty. Obviously, low incomes, low education levels, financial difficulties and dampness increase the probability of staying in fuel poverty or severe fuel poverty. Furthermore, for *movers*, these determinants increase the probability of transitioning into fuel poverty or severe fuel poverty. Consequently, increased incomes, investment in education, income transfers, and improving the housing thermal quality can raise people out of fuel poverty, and sometimes even out of poverty itself.

Some extensions to this work are possible. First, it could be interesting to perform econometrical estimations in which explanatory variables represent a variation. For example, study the impact of job loss or the birth of a child during the observation period. Second, it could be interesting to extend this analysis to other European countries to identify whether the fuel poverty dynamics is similar or different and if the mobility and stability determinants are the same.

## *Chapitre 3: Fuel poverty: is it harmful for health?<sup>68</sup>*

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<sup>68</sup>The views, assumptions and opinions expressed in this paper are those of the authors.

# 1. Introduction

In the economic literature, a definition of fuel poverty has been provided by Bradshaw et al. (1983) as follows: “Individuals, families and groups in the population can be said to be in fuel poverty when they lack the resources to obtain the reasonably warm and well-lit homes that are customary, or at least widely encouraged or approved, in the societies to which they belong”. This definition highlights the fact that the fuel poverty phenomenon is principally due to a lack of resources and that someone who is fuel poor is an individual living in a “cold home” (i.e., not reasonably warm). Despite the fact that it is an old topic, France had not included fuel poverty in its laws before 2010. More recently, in 2015, this topic was introduced in the energy transition law for a green transition proposed by Segolène Royal, Minister of Sustainable Development and Energy.

Fuel poverty was defined in Article 11 of the national commitment to the environment (Grenelle II<sup>69</sup>) on 12 July 2010: “*a household that has difficulties disposing of the necessary energy to satisfy its basic needs due to the inadequacy of its resources or its living conditions is in fuel poverty under this Act*”. The French definition of fuel poverty (i.e., Grenelle II<sup>70</sup>) then appears to connote an interaction between a household’s socio-economic situation and its conditions. Moreover, fuel poverty can be considered a component of the vulnerability framework, together with food, health, and financial vulnerability. Fuel poverty thus interacts with other types of vulnerable situations. In this manner, fuel poverty constitutes an additional detrimental factor for individuals. In more general terms, fuel poverty contributes to create an increased vulnerability to poverty. The definition of fuel poverty underlines the presence of

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<sup>69</sup> The "Grenelle II" law is French law that supplements a previous law, called "Grenelle I". This national commitment to the environment has set six major objectives: energy efficiency improvements of buildings and harmonization of planning tools, essential change in the field of transport, reduction of the energy consumption and the carbon content of the production, preserving biodiversity, risk control, waste treatment and preservation of health and finally the implementation of a new ecological governance

(<http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id>)

<sup>70</sup> <http://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434&categorieLien=id>

unmet needs, represented by inadequate warmth or other energy-related needs. Additionally, this definition identifies the main potential reasons behind fuel poverty: a lack of financial resources and/or poor living conditions.

The proportion of the French population who has unmet heat or other energy-related needs is not known. However, based on the budget share devoted to energy expenditures, the French National Institute of Statistics and Economic studies (INSEE) estimates that 14.8% of the population could be considered fuel poor in 2006 (i.e., 3.8 million households), whereas the percentage of fuel poor households was 10.9% in 1996 (Devalière et al., 2011). As proposed by Boardman (1991), a household could be considered fuel poor if it spends more than 10% of its income on fuel expenditures. From a social justice point of view, this indicator suggests that there is a maximum budget share allocated to energy expenditure that authorities deem acceptable to ensure that household energy expenditures do not represent too great a financial burden for the poorest, which could jeopardise other essential expenses. However, this measure disregards the level of consumption related to this expenditure, does not consider whether heat and energy needs are satisfied and does not allow assessments of the principle of horizontal equity in energy utilisation, which mandates equality in the satisfaction of basic needs, regardless of ability to pay. Fuel poverty may have deleterious consequences on health (WHO, 1987). Specifically, the self-restrictive behaviour required by living in conditions of low temperature may increase the severity of several cardiac and respiratory diseases. Furthermore, the financial burden induced by the high costs required to warm a household may have detrimental consequences through corresponding decreases in health expenditures and other expenditures. Nevertheless, no study to date has investigated the causal impact of fuel poverty on health, despite several studies showing a correlation between fuel poverty and prevalence of health problems (Wilkinson et al., 2001; Donalson, 2010; Davie et al., 2010; Liddell, 2010).

A growing body of literature has identified the major determinants of fuel poverty including education level (Healy and Clinch, 2004a; Huybrechs et al., 2011), level of income (Healy and Clinch, 2004a; Waddams and al., 2012; Scott et al., 2008) and dwelling condition (Healy and Clinch, 2004a; Waddams and al., 2012; Scott et al., 2008)). As evidenced by these findings, there are several common determinants between fuel poverty and health. Therefore, it is crucial to study these associations, all other things being equal, and to generate interest in the causality of these relationships. Moreover, fuel poverty seems to be a good candidate for explaining social health inequalities. Therefore, highlighting the negative consequences of fuel poverty on health could induce a greater awareness in policy makers and shed light on the high public stakes related to fuel poverty. This is particularly important in France, where a reduction in health inequalities is a major political concern due to a unique national characteristic. Indeed, the level of social inequalities is relatively high in France compared to other European countries (Mackenbach and al., 2008).

In this article, we investigate the relationship between fuel poverty and health in France. We use the 2010 French National Health, Health Care and Insurance Survey (ESPS survey). This survey is representative of the French population and provides information on health status, dwelling conditions and socioeconomic characteristics. Fuel poverty is measured by a subjective measure based on thermal discomfort due to financial reasons. By assessing the involuntary non-satisfaction with warmth and energy needs, this measure is directly related to the definitions of fuel poverty proposed by Bradshaw et al. (1983) and Grenelle II. Three health indicators are used to take into account the different dimensions of health status: long-term illness, poor self-assessed health and poor mental health score. Recursive bi-probit models are performed to address the potential endogeneity between fuel poverty and health status.

The paper is organized as follows. The first section presents the different measures of fuel poverty and provides a literature review of the influence of fuel poverty on health. The next section describes the methodology regarding the database, fuel poverty and health measures, control variables and econometric specifications. Finally, we present the descriptive statistics and the results of our estimations including robustness checks, and we conclude in a discussion section.

## **2. Background**

### **2.1. Measuring fuel poverty**

As fuel poverty is a complex and multidimensional concept, several methods of measuring fuel poverty have been proposed.

One approach to measuring fuel poverty is to refer to a normative definition of the budget share that should be allocated to energy expenditure or of the acceptable indoor temperature. One possibility is to collect objective data on indoor temperatures, and if the indoor temperature is below a certain threshold, the household is considered fuel poor. However, this indicator is rarely used and mainly on small samples because such data are difficult to collect in interview surveys. Another possibility is to ask respondents to report on their dwelling conditions, as fuel poverty can be defined through the presence of poor dwelling conditions. For instance, the 2010 ESPS survey uses the following question: "Are your walls or ceilings degraded by moisture or mould?"

Regarding the budget share allocated to energy expenditures, individuals whose fuel expenditures are too high relative to their income are considered fuel poor. Therefore, the threshold used to determine if an individual is considered in fuel poverty is crucial. Currently, the common threshold used by researchers is 10% (Boardman & al., 1991). This 10% income threshold is based on an amount that is double the median expenditure on fuel observed

during the 1988 United Kingdom Family Budget Survey. This indicator has a number of limitations. First, 10% is an “arbitrary” threshold (Hills, 2011) and is only valid for the UK. Indeed, the median level of net income spent on fuel expenditures in UK households would not be the same as the expenditure in French households. Second, the level of income can be measured before or after housing costs (rent, monthly loan payments, etc.) (Moore, 2012). Third, the threshold can be relative or absolute, similar to poverty, for instance. Finally, there is no consensual approach for these choices.

Accordingly, other normative indicators have been defined (i.e., Hills, 2012 and Moore, 2012) to address the criticisms regarding the rate of energy expenditures. Hills (2012) decided to define fuel poverty as when two conditions were met:

- First, the fuel expenditures had to be higher than the national median level.
- Second, the level of income available to the household had to be below the poverty threshold, which was set at 60% of the national median income, after deducting housing costs and energy expenditures (electricity bills, etc.).

Finally, the Moore indicator (Moore, 2012) considered individuals to be in fuel poverty if their income after deducting housing-related costs and a minimum level of income to cover basic needs (excluding energy costs), referred to as the “Standard Minimum Income,” did not cover their energy expenditures<sup>71</sup>.

Finally, subjective measures can be used to directly assess respondents’ dissatisfaction regarding their heat and energy needs. Individuals’ dissatisfaction regarding their dwelling conditions can be measured by assessing the coldness felt by the individual during the last winter. In the 2010 ESPS survey, individuals answered the following question on unmet energy needs: "Did your family suffer from feeling cold at home for at least 24 hours during

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<sup>71</sup> Note that energy expenditures are normalized regarding household size, type of dwelling, composition of the household, etc.

last winter?" Compared with objective measures of indoor temperature, this subjective approach allows the researcher to take into account individual heterogeneity in preferences regarding dwelling conditions and perceptions of cold. Living in low indoor temperatures could be for financial reasons, when individuals have to limit their consumption of heat because the cost of heating is too high. However, it could also be a deliberate choice. The 2010 ESPS survey proposed the following question on unmet energy needs for financial reasons to identify involuntary exposure to coldness: "Did your household suffer from feeling cold at home for at least 24 hours during last winter because it was too costly to warm your dwelling?"

As energy can be considered a basic commodity, its access should respect the principles of equity in financing and utilization; however, the different indicators of fuel poverty described above do not refer to the same principles. On the one hand, measures based on the proportion of energy expenditure within a household budget are consistent with the principle of vertical equity in financing, which recommends financing that increases with the ability to pay. The point of this principle is above all to guarantee equal access to energy for all people, as a result of the separation between the use of energy and the way energy is financed. This objective goes hand in hand with a final principle of equity, which aims to avoid catastrophic expenditure, i.e., an unacceptable proportion of the disposable income. The idea is to limit the financial burden induced by energy expenditure, as it may have negative consequences through subsequent decreases in health and other expenditures. However, the progressivity of energy expenditures, i.e., the fact that financing accounts for an increasing share of income and not just a constant amount, is not considered a goal because the financing of energy expenditure is not believed to be a tool of redistributive policies, in contrast with the financing of healthcare expenditures.

On the other hand, measures based on the quality of dwelling conditions (presence of mould, indoor temperature, cold sensation), regardless of their objectivity or subjectivity, are consistent with the egalitarian view that all individuals should have the same basic needs. Therefore, the provision of energy should not be distributed according to one's ability to pay consistently when the horizontal equity principle is in use. Thus, the objective is to eliminate the financial restrictions to consumption. As the primary normative objective is to guarantee equal access to a minimal level of energy consumption, this article adopts the horizontal equity approach regarding appropriate energy utilization and measures fuel poverty by the dissatisfaction with individual energy needs due to financial reasons.

## **2.2. Literature review**

### **2.2.1. Dwelling conditions and health**

A growing body of literature has focused on the consequences of dwelling conditions and exposure to low temperatures on health.

In the United Kingdom, many studies<sup>72</sup> indicated that unhealthy housing, in particular with mould or dampness, was associated with chronic respiratory diseases and infections, even after controlling for potentially confounding factors, such as income, education, smoking and unemployment. Using the LARES data (Large Analysis and Review of European housing and health Status), Ezratty et al. (2009) found a positive correlation between low energy efficiency and poor health as well as respiratory diseases. In addition, Hopton et al. (1996) estimated that dampness and mould affected mental health (stress and/or social exclusion).

Many studies have also shown the negative effects of body exposure to low temperature. The World Health Organization (WHO, 1987) reported that the impact of low temperature on health adheres to the following classifications: a temperature under 16°C causes respiratory problems, one under 12°C causes circulatory problems, and in temperatures between 5°C and

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<sup>72</sup> Bornehag & al., 2001; Peat & al.,1998; Hyndman & al.,1998; Platt & al.,1989; X.Bonnefoy, 2007; Healy & al., 2002; Howden-Chapman & al., 2007).

6°C, the risk of hypothermia becomes substantial. The Eurowinter Group (1997) “aimed to assess whether increases in mortality per 1°C decrease in temperature differed in various European regions”. They found that “high indices of cold-related mortality were associated with high mean winter temperatures, low living-room temperatures, and limited bedroom heating”. Additionally, Wilkinson et al. (2001) analysed 80,000 deaths due to cardiac disease in England between 1986 and 1996 that were linked by postcode of residence to data from the 1991 English House Condition Survey (DoE, 1993). They found a significant relationship between the indicator Excess Winter Deaths (EWDs) and living in a “*Cold Home*<sup>73</sup>”. Excess Winter Deaths is a statistical indicator calculated by the Office for National Statistics, which enables calculations of excess mortality during winter. This metric portrays the difference between the number of deaths during the winter months (December to March) and the average number of deaths during the previous four months (August to November) and following four months (April to July). Additionally, Donalson (2010) found that 40% of EWDs were due to a “*Cold Home*” in the Chief Medical Officer’s annual report in 2009.

Davie et al. (2008) reported that fuel poverty contributes to low indoor temperatures. Authors estimate, based on a negative binomial model, that low indoor temperatures have caused 1,600 deaths, corresponding to 16% of the total deaths in the United Kingdom during the winter months. In addition, body exposure to low temperature affects health. This relationship was shown by Collins (1986) in a longitudinal study conducted with 47 elderly individuals who had been exposed to low temperatures during the winter months from 1971-72 and 1975-76. The results suggested that low temperature exposure was responsible for an increase in blood pressure and blood viscosity. These two elements increase the risks of stroke and heart attack (Howieson & Hogan, 2005). The robustness of these results can be debated, as the number of observations was quite small. As observed from these findings, the impact of

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<sup>73</sup> Note that a “*Cold-Home*” is a house with a low level of energy efficiency and with low indoor temperature.

dwelling conditions on health is well documented. However, there is much less literature regarding the causal impact of fuel poverty on health.

### **2.2.2. Fuel poverty and health**

Five studies (the Warm Front scheme; the Scottish Executive Central Heating Programme (CHP); the New Zealand Housing, Insulation and Health Study (HIHS); Housing, Heating and Health Study (HHHS); US Children's Sentinel Nutritional Assessment (C-SNAP) and the National Centre for Social Research (NATCEN)) have tried to identify the causal impact of fuel poverty on health with rigorous methodology. Most of those studies used a quasi-experimental design with a treatment group (beneficiaries of an insulation programme or a substantial heating subsidy) and a control group (households that were eligible for the insulation programme or winter heating subsidy but did not benefit from them). The study designs included baseline variables that were collected before and after the dwelling insulation intervention in both study arms. Before the intervention or winter heating subsidy was implemented, data were collected on health characteristics (GHQ-12, SF-36) for the treatment group and the control group. After the intervention or heating subsidy, follow-up data were collected. This design enabled the authors to identify whether these supporting measures had a positive impact on health.

These studies used different fuel poverty indicators. The CHP and Warm Front studies considered a household to be in fuel poverty if its indoor temperature was below 16°C in either the living room or the bedrooms (i.e., temperature data were collected). For the HIHS and the HHHS, households were considered in fuel poverty if they had very specific characteristics: a low income, residence in a wooden home with no insulation and at least one member of the household who had a respiratory disease. Finally, the C-SNAP study interviewed low-income caregivers and their infants between 2000 and 2006 in 5 different

cities. This study used a 4-item Home Energy Security Indicator<sup>74</sup> that Liddell et al., 2010, used as an indicator to explore the extent to which homes had foregone heating in the last 12 months. The results indicated substantial improvement regarding mental well-being, especially for children (Green et al., 2008; Howden-Chapman et al., 2008; Frank et al., 2006), when the risks factors of fuel poverty were reduced, but they found little improvement in self-reported physical health and self-assessed health (Green et al., 2008; Shortt et al., 2007; Howden-Chapman et al., 2008).

We identify several limitations to these studies. For one, in the Warm Front scheme, the causal impact of fuel poverty on health could not be established because not all the participants were in fuel poverty (Green and al., 2008). For the HIHS and HHHS programmes, there was evident selection bias because the sample consisted of volunteers with very specific characteristics (i.e., a low income, living in a wooden home with no insulation and at least one member of the household who had a respiratory disease); therefore, the sample was not representative of the national population. Additionally, these studies were usually used to evaluate these isolation programmes or to support measures rather than truly identifying the causal impact of fuel poverty on health.

The fifth study (NATCEN) did not use a quasi-experimental design. This study compared over time the different levels of health status in children under 11 years old, based on caregiver interviews each year for five years, and whether the respondents had been able to keep their home warm during the previous winter. The results were quite similar to those of the C-SNAP study (Barnes and al., 2008). Another study (Lacroix & Chaton, 2015) used 2010 French National Health, Health Care and Insurance Survey and showed that fuel poverty, defined by thermal discomfort, was positively associated with poor self-assessed health.

Finally, a study conducted by Healy (2004b) also estimated a negative relationship between

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<sup>74</sup> The household energy security indicator includes energy-secure, no energy problems; moderate energy insecurity, utility shutoff threatened in past year; and severe energy insecurity, heated with cooking stove, utility shutoff, or  $\geq 1$  day without heat/cooling in past year (Cook John et al., 2008).

fuel poverty and health. The fuel poverty measure was based on a declared answer. Households were considered in fuel poverty if they “reported an inability to heat their home to an adequate, comfortable temperature”. For the health indicators, the author used subjective (self-assessed health status) and objective measures (number of visits to their general practitioner, A & E admittances and reported chronic health outcomes such as asthma and hypertension) to identify the impact of fuel poverty on health. Nevertheless, Healy only compared the different health indicators between fuel-poor and non-fuel-poor individuals. Additionally, it used a descriptive statistical approach, and potential problems with endogeneity between fuel poverty measures and subjective health were not taken into account. The same limitation applies to Lacroix & Chaton, 2015. A potential endogeneity problem may be observed, as fuel poverty is measured by the individual’s level of cold sensation, which will also depend on health status. Furthermore, an individual with a poor health status may not report that his perceptions of cold were determined by his health disorders rather than his housing conditions. Therefore, it is necessary to take into account the potential endogeneity between fuel poverty and health status, which is likely to misestimate the impact.

### **3. Method**

#### **3.1. Data**

The National Health, Health Care and Insurance Survey (ESPS: ‘Enquête sur la Santé et la Protection Sociale’) is a biennial health interview survey coordinated by the Institute for Research and Information on Health Economics (IRDES) conducted with a sample based on an ongoing random sample of major French health insurance beneficiaries (covering >97% of the population of private households) (Dourgnon and al., 2012). In 2010, a set of questions on dwelling conditions was added by the Institute for Health Surveillance (InVS: "Institut National de Veille Sanitaire"), including measures of fuel poverty. In total, 8,305 households were interviewed in the 2010 wave: for each household, one member answered the main

questionnaire, including questions on sociodemographics and dwelling conditions, and all household members answered a self-administered questionnaire including questions on health and health care use. We restricted our sample to individuals who responded to the fuel poverty question in the main questionnaire. In this study, fuel poverty was assessed by a question on subjective energy unmet needs, and the answer of the main respondent therefore reflected his own cold sensation and not necessarily the other household member's perspectives.

### **3.2. Measures of fuel poverty**

A subjective measure of fuel poverty was provided in the data with the following question: “Did your household suffer from being cold at home for at least 24 hours last winter? Yes or no”. If the answer was yes, the household was then asked about the reason, with several suggested reasons: “due to the inadequacy of the heating installation, due to a failure of the installation (or district heating), due to financial reasons because of the cost of heating, due to the poor insulation of the home, and other reasons”.

In this study, we considered a person to be in fuel poverty if he reported to have suffered from cold exposure for at least 24 hours during the previous winter because he was restricting the level of heating for financial reasons. This thermal discomfort reflects the financial difficulties experienced by a household in obtaining adequate warmth or energy consumption. Additionally, we used another measure of fuel poverty to assess the robustness of the definition, using answers to “Are the walls or ceilings degraded by moisture or mould?” We considered an individual to be in fuel poverty if he answered “Yes, in some or many places” to the previous question.

### **3.3. Measures of Health indicators**

We used three health indicators in our study to cover different health dimensions. We first

used data from a question on long-term illness<sup>75</sup> that was available in the main questionnaire ("Do you have a long-term illness for which your treatment is 100% supported by the National health fund? Yes or no") and from one question available in the self-administered questionnaire on self-assessed health ("How is your health in general?" with possible answers of "Very good, good, fair, poor, and very poor"). In addition, we used questions related to the mental component of the Short Form-36 score, which were included in the self-administered questionnaire. Several questions in the mental component of the Short Form-36 are used to generate the mental score. These questions assess how respondents feel and how things had been in the past 4 weeks and include the following: "Have you been a very nervous person?"; "Have you felt so down in the dumps that nothing could cheer you up?"; "Have you felt calm and peaceful?"; "Have you felt downhearted and blue?"; and "Have you been a happy person?" Six response options are provided: "all of the time, most of the time, a good bit of time, some of the time, a little of the time, none of the time". These answers are then summed to obtain a numerical value. We use a mental health indicator because experiencing fuel poverty is related with mental disorders as said before (i.e. Green, 2008 and Barnes, 2008). Indeed, Green find that increases in room temperature were associated with reduced likelihood of experiencing depression and anxiety. And Barnes find that young people who experiencing fuel poverty are more likely to be at risk of multiple mental health symptoms, experiencing four or more negative mental health symptoms.

Three binary health indicators were built:

- Long-term illness: "have a long-term illness" vs "not have a long-term illness";
- Self-assessed health: "reporting a fair, poor or very poor health" vs "good or very good health" (Cambois and Jusot, 2011);

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<sup>75</sup> The long-term illness is a French special feature. Indeed, a list of 32 special diseases gives an individual exemption from copayment.

- Score on the mental component of the Short-Form 36 “less than 44” vs “more than 44”. This cut-off was chosen because 44 corresponded to the first quartile of the SF-36 score distribution in our sample. Thus, we considered an individual to have poor mental health if his score was less than 44.

These health indicators allowed us to account for the multidimensional aspect of health<sup>76</sup>. Self-assessed health is considered a good predictor of mortality (Idler and Benyamini, 1997); long-term illness refers to a disease that has already been diagnosed, and finally mental health was measured with the mental component of the Short-Form 36 (Leplege & al., 2001).

### **3.4. Control variables**

In our model, we included individual variables to control for current socioeconomic economic status (SES). Income was categorized into five quintiles and was measured as household income divided by the Organization for Economic Cooperation and Development (OECD) equivalent scale<sup>77</sup>. An additional category was added that represented missing information. Education level was divided into seven categories (no education level, primary school, college, higher secondary level, post-secondary level, education in progress and other qualification). Occupational status was measured by the previous occupation for those who were retired or unemployed or by current occupation. We created a variable with nine categories (farmers, self-employed, skilled white collar occupation, intermediate profession, clerical employees, trade and craft employees, skilled manual workers, unskilled manual workers and inactive). Finally, we classified the gender and age of individuals into seven categories ([16-25]; [26-35]; [35-45]; [45-55]; [55-65]; [65-75]; [+75]). We included household type in five categories: single person, single parent family, couples without children, couples with children and other.

For our purposes, we divided the primary sample into 3 sub-samples: one of 8,286 individuals

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<sup>76</sup> The World Health Organization defines health as follows: "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity".

<sup>77</sup> Equaling 1 for the first household member, 0.7 for each additional adult and 0.5 for each child.

with available data on long-term illness, another of 5,837 individuals who reported their self-assessed health and one of 5,709 respondents for whom mental health scores were available. Less than 5% of our sample were considered fuel poor based on thermal discomfort for financial reasons, and more than 14% of our sample reported the presence of mould/moisture in their dwelling (in some or many places). These two fuel poverty measures were strongly correlated with income. Fuel poor for financial reasons was reported by 29% of our population in the lowest income quintiles, and mould/moisture by 26.3%. Young individuals seemed to be fuel poor more often, although they were more concerned by humidity problems than by unmet needs for financial reasons. Unskilled manual workers and inactive individuals suffered more from humidity/moisture problems than the rest of the population. Unskilled manual workers and individuals with no education were most affected by fuel poverty for financial reasons. Finally, regarding the type of household, single parents suffered more from fuel poverty for financial reasons and from mould/moisture than the rest of the population. Indeed, 17.1% of the single parents reported substantial mould/moisture problems, and 14.78% of those who were fuel poor for financial reasons were single-parent families. Regarding the health indicators, more than 19% had a long-term illness, 35% reported fair, poor or very poor health, and more than 25% had a poor mental health score. More precisely descriptive statistics are available in appendix 6.

### **3.5. Statistical method**

To estimate the associations between fuel poverty and poor health status after controlling for SES, our analysis was performed in two steps. First, we performed three simple probits corresponding to the three dichotomous health outcomes, ignoring the potential endogeneity between health indicators and fuel poverty. Then, we estimated three recursive bivariate probits for each health indicator respectively to address the potential endogeneity problem.

Each bivariate probit model simultaneously estimated two equations, one for fuel poverty and one for health status, under the assumption that the iid (independent and identically distributed) errors of each equation were correlated to account for common unobserved heterogeneity (Greene, 2003).

More specifically, the bivariate model could be written as follows:

$$Y_{1i}^* = \beta SES_i + \delta Z_i + v_{1i}, \quad (1)$$

$$Y_{2i}^* = \alpha SES_i + \eta Y_{1i} + v_{2i}, \quad (2)$$

$$\text{with } \begin{pmatrix} v_{1i} \\ v_{2i} \end{pmatrix} \rightarrow N \left[ \begin{pmatrix} 0 \\ 0 \end{pmatrix} \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix} \right]. \quad (3)$$

$Y_{1i}^*$  and  $Y_{2i}^*$  represented two latent variables.  $Y_{1i}$  (i.e., being fuel poor) and  $Y_{2i}$  (i.e., either having a long-term illness/poor self-assessed health/poor mental health) were dichotomous variables observed according to the following rule:

$$Y_{li} = 1 \text{ if } Y_{li}^* > 0, \quad (4)$$

$$Y_{li} = 0 \text{ if } Y_{li}^* \leq 0, \text{ where } l = 1, 2. \quad (5)$$

SES represents the vector of socioeconomic variables (e.g., level of income, level of education). Z represents the variable used for exclusion restriction, i.e., introduced in the fuel poverty equation but not in the equation of health indicators to ensure the identification of the model (Maddala, 1983). This exclusion restriction variable must be correlated with fuel poverty but not with the different health indicators. We decided to use the mean number of frost days per French department<sup>78</sup> as the exclusion restriction variable, which is related to the probability of being fuel poor based on thermal discomfort due to financial reasons but is independent from an individual's health. The average of the mean number of frost days for all departments was equal to 71; the lower mean number of frost days was equal to 12 (in Alpes-maritime), and the higher was 121 (in Lozère). As shown in table 1, the exclusion restriction was always significantly associated with the fuel poverty indicator and never significantly

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<sup>78</sup> Descriptive statistics are available in appendix 7.

associated with the three health indicators. Finally, the coefficient  $\eta$  estimates the causal impact of fuel poverty on health, and  $\beta_i$ ,  $\delta_i$  and  $x_i$  represent the conformable vectors of relevant coefficients.

Probit models	Long-term illness	Self-assessed health	Poor mental health score
	Marginal effect	Marginal effect	Marginal effect
<b>Exclusion restrictions</b>			
Mean number of frost days per French department	0.0001	-0.0014	0.0001
	<b>Humidity</b>	<b>Fuel poverty for financial reasons</b>	
	Marginal effect	Marginal effect	
<b>Exclusion restrictions</b>			
Mean number of frost days per French department	-0.0007***	-0.0003***	

Table 1: Descriptive statistics of energy expenditures per year (regressions adjusted by age, gender, level of education, level of income and type of household, \*\*\*:  $p \leq 1\%$ , \*\*:  $p \leq 5\%$ , \*:  $p < 10\%$ )

## 4. Results

### 4.1. Determinants of fuel poverty for financial reasons

	<b>Fuel poverty for financial reasons</b>
	Marginal effect
<b>AGE</b>	
[16-25]	REF
[26-35[	0,009
[35-45[	-0,003
[45-55[	0,008
[55-65[	-0,001
[65-75[	-0,021*
$\geq 75$	-0,026*
<b>GENDER</b>	
Male	REF
Female	0,011**
<b>Level of income</b>	
1st quintile	REF
2nd quintile	-0,011*
3rd quintile	-0,034***
4th quintile	-0,044***
5th quintile	-0,05***
NSP <sup>79</sup>	-0,032***
<b>Level of education</b>	
No education	REF
Primary school	-0,03*
College	-0,027*
Higher secondary	-0,032**
Post-secondary	-0,012
Education in progress	-0,092***
Other	0,029
<b>Occupational status</b>	

<sup>79</sup> Is not pronounced.

Farmer	REF
Self-employed	0,014
Skilled white collar occupation	0,0001
Intermediate profession	0,013
Clerical employee	0,014
Trade and craft employee	0,013
Skilled manual worker	0,014
Unskilled manual worker	0,028*
Inactive	0,005
<b>Household type</b>	
Single person	REF
Single parent family	-0,011
Couple without children	-0,027***
Couple with children	-0,026***
Other	-0,001
<b>Exclusion restriction</b>	
Mean number of frost days per French department	-0,0003***

Table 2: Probit estimation results for fuel poverty equation (regressions adjusted by age, gender, level of education, level of income and type of household, \*\*\*:  $p <= 1\%$ , \*\*:  $p <= 5\%$ , \*:  $p < 10\%$ )

Table 2 provides the results of the probit regression for the probability of being fuel poor and identifies the major determinants. As observed in the table, individuals older than 75 years had a lower probability of being fuel poor for financial reasons. The main reason for this result is likely that the older the individual, the higher the level of warmth in the dwelling (Meir and al., 2010). Therefore, the probability of thermal discomfort is reduced.

Additionally, unsurprisingly, the level of income was a main determinant of the probability of being fuel poor for financial reasons (Healy & Clinch, 2004a; Waddams & al., 2012; Scott & al., 2008). Furthermore, the level of education had an impact on the probability of being fuel poor; individuals with a primary, college or higher secondary level of education had a lower probability of being fuel poor compared to individuals without education. Additionally, individuals who were pursuing studies had a lower probability of being fuel poor than individuals without education. These results regarding the level of income and the level of education are consistent regarding the chapter 1 and 2 and despite the fact that the database is not the same and that fuel poverty indicators are different. So, it means that these two variables (i.e. level of income and the level of education) need to be considered as crucial determinants to characterize individuals who experiencing fuel poverty.

Regarding occupational status, we found that skilled and unskilled workers had a higher probability of being fuel poor for financial reasons compared to farmers. For household type, it appeared that couples with or without children had a reduced the probability of being fuel poor compared to single persons. This finding likely results from the fact that couples generally have more financial flexibility (due to cost sharing) than single persons. Again these results are similar to the results obtain in the chapter 2.

Finally, the marginal effect of our exclusion restriction variable (the mean number of frost days per French department) appeared to be negative and significant. Based on the findings, one additional frost day reduced the probability of being fuel poor for financial reasons by 0.03%. This unexpected result could indicate that individuals who live in colder departments have a higher body tolerance to cold temperatures (J. Leppäluoto et al. (2001)). Indeed, individuals exposed to cold temperatures have thermal sensations that are habituated to the cold.

## **4.2. Multivariate analysis without accounting for endogeneity**

	Health indicators		
	Long-term illness	Poor self-assessed health	Poor mental health score
	Marginal effect	Marginal effect	Marginal effect
<b>Fuel poverty for financial reasons</b>			
Yes	0,025	0,135***	0,192***
No	REF	REF	REF
<b>AGE</b>			
[16-25]	REF	REF	REF
[26-35[	0,08***	0,141***	0,039
[35-45[	0,131***	0,214***	0,070**
[45-55[	0,193***	0,30***	0,109***
[55-65[	0,294***	0,377***	0,061*
[65-75[	0,362***	0,418***	0,058*
>=75	0,415***	0,522***	0,025
<b>GENDER</b>			
Male	REF	REF	REF
Female	-0,043***	0,053	0,082***
<b>Level of income</b>			
1st quintile	REF	REF	REF
2nd quintile	0,002	-0,042**	-0,063***
3rd quintile	-0,031**	-0,108***	-0,094***
4th quintile	-0,03**	-0,091***	-0,101***
5th quintile	-0,06***	-0,169***	-0,116***
NSP	-0,021*	-0,077***	-0,075***
<b>Level of education</b>			
No education	REF	REF	REF
Primary school	-0,034	-0,064	0,085
College	-0,054*	-0,101*	0,071
Higher secondary	-0,069**	-0,1332**	0,079
Post-secondary	-0,114***	-0,194***	0,005
Education in progress	-0,056	-0,154*	0,032
Other	-0,072	-0,286***	-0,139
<b>Occupational status</b>			
Farmer	REF	REF	REF
Self-employed	-0,009	-0,041	0,446
Skilled white collar occupation	0,025	-0,009	0,089**
Intermediate profession	0,007	0,003	0,088**
Clerical employee	0,021	0,036	0,079**
Trade and craft employee	0,047**	0,044	0,07*
Skilled manual worker	0,012	0,014	0,08**
Unskilled manual worker	0,034	0,049	0,086**
Inactive	0,068**	0,079*	0,085*
<b>Household type</b>			
Single person	REF	REF	REF
Single parent family	0,013	0,027	0,026
Couple without children	0,001	0,018	-0,039***
Couple with children	-0,03**	-0,032*	-0,054***
Other	-0,024	-0,012	-0,000

Table 3: Probit estimation results for health equations (regressions adjusted by age, gender, level of education, level of income and type of household, \*\*\*:  $p \leq 1\%$ , \*\*:  $p \leq 5\%$ , \*:  $p \leq 10\%$ )

Table 3 reports the results of the multivariate analysis (probit estimations) for the three health

indicators (long-term illness, poor self-assessed health and poor mental health score). We found that fuel poverty was highly significantly and negatively associated with our health indicator specifications except for long-term illness (Table 3). The probability of reporting poor-assessed health was 0.1354 higher for individuals who were fuel poor for financial reasons. Additionally, those who were fuel poor had a 0.1926 higher probability of reporting a poor mental health score than those who were not fuel poor.

As expected, the probability of reporting a poor mental health score was higher for women than for men. Nevertheless, the probability of having a long-term illness was higher for men than for women, and the probability of reporting a poor-assessed health did not significantly differ between women and men. Compared to farmers, inactive individuals had a higher probability of having a long-term illness, reporting a poor self-assessed health and having a poor mental health score. Additionally, trade and craft employees had a 0.047 higher probability of having a long-term illness than farmers. In addition, farmers had a lower probability of reporting a poor mental health score than all other occupational categories (self-employed, skilled white collar occupations, intermediate profession, clerical employee, skilled and unskilled manual worker and inactive). Nevertheless, being inactive was positively correlated with poor health in terms of the three health indicators.

We observed a positive increasing effect of age on the first two health indicators (long-term illness and poor self-assessed health). Nevertheless, for poor mental health score, it appeared that the most positive effects of age were for those between [35-45[ and [45-55[. These intervals correspond to the period of activity in the labour force and the possibility of becoming promoted. These factors can cause some stress and anxiety (Melchior et al., 2007). Although we found that those who were [65-75[ years old had a higher probability of having a poor mental health score than individuals younger than 25 years, when we compared this marginal effect to that of the [45-55[ year age group, we found that people who were retired

(after 65 years) had a lower probability of having a poor mental health score than those who were active workers. This result is consistent with the literature, in which retirement is shown to reduce the probability of depression (Butterworth and al., 2006). For the three health indicators, the household variable indicated that living as a couple (with or without children) reduced the probability of long-term illness, poor self-assessed health and poor mental health score compared to individuals who were single. Individuals with a high level of education showed a decreasing probability of having or reporting health disorders, with the exception of a poor mental health score, which was not affected by the level of education. Finally, the higher the level of income, the lower the probability of long-term illness, poor self-assessed health and poor mental health score. The next section presents the estimation results of the recursive bivariate probit model.

### 4.3. Recursive bivariate probit analysis accounting for the endogeneity

	Long-term illness		Poor self-assessed health		Poor mental health score	
	Probit	Biprobit	Probit	Biprobit	Probit	Biprobit
	Marginal effect	Marginal effect	Marginal effect	Marginal effect	Marginal effect	Marginal effect
<b>Fuel poverty for financial reasons</b>						
Yes	0,025	0,355***	0,135***	0,399**	0,193***	0,576**
No	REF	REF	REF	REF	REF	REF
Rho (fuel poverty equation)		-0,734***		-0,419*		-0,706***

Table 4: Recursive bivariate probit estimation results (regressions adjusted by age, gender, level of education, level of income and type of household, \*\*\*:  $p \leq 1\%$ , \*\*:  $p \leq 5\%$ , \*:  $p \leq 10\%$ )

Table 4 reports the outcomes of the three recursive bivariate probit analyses of all health indicators accounting for the potential endogeneity problem between fuel poverty and health, as defined by the three health measures. A complete table of results is available in appendix 8. First, we note that the rho coefficient for these recursive bivariate probits were highly and

statistically significant. The rho coefficient was significant at 10.1% for the impact of fuel poverty on poor self-assessed health.

Finally, the rho coefficient indicates that unobserved individual characteristics had a simultaneous influence on the probability of fuel poverty, long-term illness, poor self-assessed health and poor mental health score. In these recursive bivariate probits, the  $\rho$  coefficient was consistently negative. Accordingly, these unobserved individual characteristics increased the probability of being fuel poor and decreased the probability of being free of a long-term illness, reporting a good self-assessed health and obtaining a good mental health score. As noted previously, the different levels of cold sensation as related to health status could be included in these unobserved individual characteristics. Additionally, the exclusion restriction variable (mean frost days per French department) was statistically significant in all biprobits, meaning that the mean number of frost days strongly predicted the probability of experiencing fuel poverty. Therefore, after controlling for endogeneity issues, fuel poverty based on thermal discomfort for financial reasons had an effect on health indicators; those who were fuel poor had a 0.355 higher probability of having a long-term illness. Additionally, those experiencing fuel poverty had a 0.399 higher probability of reporting a poor self-assessed health compared to those not in fuel poverty. Finally, compared to those without fuel poverty, individuals who were fuel poor had a 0.576 higher probability of a poor mental health score. It should be noted that the other variables such as age and level of income in particular had the same impact as in the probit regressions.

Comparing the probit and biprobit regressions, we can see that the impact of fuel poverty on the different health indicators was consistently higher in the biprobit regressions. This means that the impact of fuel poverty on health is under-estimated when endogeneity is not considered. Based on these results, we conclude that fuel poverty contributes to an increase in health inequalities and that individuals with a low income are more vulnerable to fuel poverty

and health disorders. The following section presents the several robustness checks performed.

**4.4. Robustness checks**

**4.4.1. Fuel poverty for financial reasons versus presence of humidity**

To confirm our results, we decided to perform our estimations with another indicator that was more objective and could be considered an indicator of dwelling conditions. This indicator was the presence of mould and/or moisture in the home. In the 2010 wave of the National Health, Health Care and Insurance Survey, this information was collected with the question, "Are the walls or ceilings degraded by moisture or mould?" with the response options of "No, Yes, in some areas or Yes, in several areas". We defined fuel poverty based on humidity presence if they reported that moisture or mould was present in some or several areas of their dwelling<sup>80</sup>. This fuel poverty indicator is currently used in studies (i.e., Alleviating Fuel poverty in the EU report, 2014) to estimate the prevalence of fuel poverty through surveys. Indeed, reports of moisture or mould are a sign of a home’s poor thermal efficiency.

Table 5 reports the marginal effects of this fuel poverty proxy on the health indicators.

Fuel poverty by mould/moisture presence in the dwelling	Long-term illness		Poor self-assessed health		Poor mental health score	
	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0.326***	-.801***	0.326***	-.488*	0.234	-.282
No	REF	REF	REF	REF	REF	REF

Table 5: Marginal effects of mould/moisture on health indicators (regressions adjusted by age, gender, level of education; level of income and type of household, \*\*\*: p<=1%, \*\*: p<=5%, \*: p<=10%)

We found that the presence of mould and/or moisture in the dwelling increased the probability of having a long-term illness (marginal effect: 0.326\*\*\*) and of reporting a poor self-assessed health (marginal effect: 0.326\*\*\*). The marginal effects of the fuel poverty proxy (i.e., moisture or mould) on long-term illness and on poor self-assessed health were quite similar to those obtained with the thermal discomfort for financial reasons indicator (0.326\*\*\* vs

<sup>80</sup> As said before, in the total sample 14% report moisture or mold in their dwelling.

0.355\*\*\*, respectively, for long-term illness and 0.326\*\*\* vs 0.399\*\*\*, respectively, for poor self-assessed health). However, the marginal effect of the fuel poverty indicator did not have a significant impact on the probability of obtaining a poor mental health score.

#### 4.4.2. Mean number of frost days per French department versus mean temperature per French department

We also decided to use another exclusion restriction variable, the mean temperature per French department<sup>81</sup>. Therefore, the average temperature of each French department was obtained.

Based on this exclusion restriction procedure, on average, the mean temperature of all departments was 11.25°C. Additionally, the lower average temperature was 7.4°C (Lozère), and the higher average temperature was 15.6°C (Alpes-maritime).

The following table reports the results of the exogeneity test for mould/moisture and the marginal effects of the outcome (mould and/or moisture presence) on the different health indicators.

	Health indicators			Fuel poverty indicator
	Long-term illness	Poor self-assessed health	Poor mental health score	Fuel poverty for financial reasons
	Marginal effect	Marginal effect	Marginal effect	Marginal effect
<b>Exclusion restriction</b>				
Mean temperature per French department	-0,002	-0,001	0.002	0,004***

Table 6: Exogeneity test for the exclusion restriction (Mean temperature per French department) (regressions adjusted by age, gender, level of education; level of income and type of household, \*\*\*: p<=1%, \*\*\*: p<=5%, \*: p<=10%)

Table 6 indicates that our exclusion restriction variable (i.e., Mean temperature per French department) was associated with the probability of being fuel poor for financial reasons. However, this exclusion restriction was not correlated with health indicators. Therefore, this exogeneity test revealed that this exclusion restriction could be used without concerns

<sup>81</sup> Descriptive statistics are available in appendix 9.

regarding endogeneity.

The following table (Table 7) reports the marginal effects of the impact of fuel poverty for financial reasons on the different health indicators.

<i>Exclusion restriction: Mean number of frost days per French department</i>						
	<b>Long-term illness</b>		<b>Poor self-assessed health</b>		<b>Poor mental health score</b>	
<b>Fuel poverty for financial reasons</b>	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0.335***	-0,734***	0.399***	-0.419*	0.576***	-0.701***
No	REF	REF	REF	REF	REF	REF
<i>Exclusion restriction: Mean temperature per French department</i>						
	<b>Long-term illness</b>		<b>Poor self-assessed health</b>		<b>Poor mental health score</b>	
<b>Fuel poverty for financial reasons</b>	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0,335***	-0,734***	0,399**	-0,419*	0,575***	-0,706***
No	REF	REF	REF	REF	REF	REF

Table 7: marginal effects with the mean temperature per French department and marginal effects comparison (regressions adjusted by age, gender, level of education; level of income and type of household, \*\*\*:  $p \leq 1\%$ , \*\*:  $p \leq 5\%$ , \*:  $p \leq 10\%$ )

We can conclude that our results are robust. Indeed, the marginal effects of the two exclusion restrictions were quite close. The last section presents a discussion and conclusion.

## 5. Conclusion

This article provides an analysis of the impact of fuel poverty, as measured by thermal discomfort for financial reasons, on three different health dimensions (long-term illness, self-assessed health and mental health), using French health data that were representative of the general population and controlling for unobserved heterogeneity. The results suggest that individuals who are fuel poor have a 0.3548 higher probability of having a long-term illness compared to those who are not fuel poor. Additionally, fuel poverty based on thermal

discomfort for financial reasons led to a 0.399 higher probability of reporting a poor self-assessed health. Finally, those who were fuel poor had a 0.575 higher probability of having a poor mental health score compared to those who were not fuel poor. A low income level, a low level of education, and being a trade & craft employee or unskilled manual worker significantly increased the probability of experiencing fuel poverty and having health disorders. Therefore, fuel poverty contributes to health inequalities.

Regarding the methodology, we used a fuel poverty measure that was consistent with the egalitarian principle of horizontal equity regarding access to basic commodities. Accordingly, we used a fuel poverty measure based on thermal discomfort due to financial reasons, which reflected unmet needs regarding energy consumption. We used three different health indicators to represent various dimensions of health. The recursive bivariate probit models exhibited marginal effects that were larger than the probit estimations for the three health indicators, suggesting an increased impact of fuel poverty after adjusting for unobserved heterogeneity. Regarding the exclusion restriction, several other potential candidates were available, including occupancy status and type of dwelling<sup>82</sup>. However, those variables were significantly correlated with the different health indicators. We used two variables exogenous to health status: the mean number of frost days per French department and the mean temperature per French department. In addition, we re-conducted the analyses using another fuel poverty measure (i.e., presence of mould and/or moisture in the dwelling) to verify the robustness of the findings.

This study highlights the deleterious consequences of fuel poverty on health. Consequently, fuel poverty could induce higher health expenditures for individuals who are fuel poor. This additional financial constraint could induce poverty and further self-restrictions regarding energy or health expenditures (i.e., a forced trade-off between two essential commodities).

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<sup>82</sup> Exogeneity test results are available in appendix 10.

Moreover, this vicious cycle could be worsened by an unequal distribution of fuel poverty. Based on our findings, fuel poverty is clearly an important factor related to vulnerability and poverty in general, as well as an important determinant of social health inequalities. Thus, specific actions, such as implementing social tariffs for energy or providing energy vouchers, in particular in favour of the poorest, are necessary to alleviate fuel poverty and to more broadly promote population health and achieve health equity.

## *Chapitre 4: Payment and self-control?*<sup>83</sup>

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# 1. Introduction

We explore how payment schedules for energy bills influence the energy consumption of a consumer with planning and budgeting problems. A consumer may know that he needs sufficient heating for his health, but yet he may tend to turn down radiators when they are most needed. The opposite behaviour also exists: exaggerate heating, which threatens the household's finance for a small benefit. These attitudes towards energy consumption are not directly caused by poverty, but their consequences are all the more serious that consumers have a tight budget. One could even argue that they are part of the economics difficulties that poor people encounter.

Prepayment spurs self-control, and it offers a budgeting tool for low-income households that complements other types of aid (energy voucher, renovation plan). Nevertheless, this benefit should be weighed against the cost of strict commitment in a situation of uncertainty. Rachlin (2009) reports that, in contrast to flexibility, commitment by consumers reduces the range of their future choices.

In this paper, we develop a model of realistic preferences, and we test the impact of payment method on a consumption plan where timing and budgeting across commodities are at stakes, in certainty and uncertainty context regarding climate consumers' predictions (i.e., What will the weather be like tomorrow?). Working solutions for households with difficulties paying their energy bills are part of any social programme. For example, the French "energy law for a green transition" (Royal, 2015) proposes establishing an "energy voucher" for poor households. In contrast to previous programmes ("social tariffs", i.e., subsidized prices distributed via utilities)<sup>86</sup> that were focused on electricity or natural gas, these vouchers could be used for any type of energy (electricity, gas, heating oil, wood). They could also be used to purchase more energy-efficient equipment. Such benefits would be means-tested (income and

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<sup>86</sup> "Tarif Première Nécessité" (TPN) for electricity and "Tarif Spécial Solidarité" (TSS) for gas consumers.

household composition). The programme's launch is expected in 2016. The fact that vouchers rather than simple financial assistance are provided clearly indicates a certain degree of paternalism.

Though these vouchers recognize that people need more heating for their health, they imply that giving them money would not solve the problem since they would use it for other purposes. If the intent is to take behavioural biases into account, then why not think of the best possible form of vouchers?

Budgeting problems in relation with difficulties to plan is commonly observed. To examine solutions (factual or counterfactual), one must have a theory. Lawrance (1991) indicates in an empirical study that households with low incomes have a higher time preference than high-income households. This time preference can be considered a symptom of serious planning and budgeting difficulties related to the vast subject of time inconsistency. In the literature, time inconsistency is largely limited to intertemporal choices regarding a single good per period. It has been recognized since Strotz (1955) that being rational and time inconsistent is not an oxymoron. A rational time inconsistent consumer prefers to use various strategies to help him commit, and thus generate self-control he couldn't sustain alone. Time inconsistent preferences introduce a conflict between "an impatient 'present self' and a patient "future self"" (Brutscher 2011). In other words, consumers' over-weigh the present compared to the future, but the present is constantly changing (O'Donoghue and Rabin 1999a).

In this paper, we claim that certain goods (energy being one of them) are specific in the sense that the budget share that people want dedicate to them varies inconsistently with time. Therefore, if we think that consumers could suffer of time inconsistency regarding a specific good, we should take into account the conditions under which and the moment at which they pay their delivery order or pay their bills. We test three payment methods: instant debit, postpayment, and prepayment.

**Instant debit.** Based on precise metering, an amount is automatically debited every so often (say each month) from the customer's bank account. Connected real-time meters could display the current account status and help people manage their expenditures. In practice, estimates of actual consumption are not perfect, and meters are not often checked. This payment method could be stylized as "pay as you consume". In any case, no predetermined upper limit is established for these tariffs.

**Postpayment.** Every so often, perhaps every quarter, the meter is checked and the consumer pays for the energy that has been consumed.

**Prepayment.** The household must be paid in advance for its energy consumption. For electricity or gas, prepayment metering is quite similar to the better known prepaid phone card system. A meter is set up in the dwelling and the household must insert a charge card in the block to obtain electricity. When the consumer's credit is close to zero, the customer receives a notification, and when the credit is exhausted, electricity is interrupted in the dwelling. There can be a short period during which even if the credit is zero, electricity is still delivered. This "safe zone" can be necessary "for consumers with health disorders requiring electricity utilization". Nevertheless, US companies have no obligation to send a notification or to provide a safe zone for their customers (Howat and McLaughlin, 2012).

Utilities currently offer the prepayment system to low-income customers<sup>87</sup>. Furthermore, prepayment metering is most often used by households living in energy poverty (O'Sullivan, Howden-Chapman, Stanley, et al., 2013). The literature indicates that prepayment can contribute to reducing electricity consumption and can offer a greater awareness and control of electricity use for households (O'Sullivan, Viggers, and Howden-Chapman, 2014; Coutard and Guy, 2007; Faruqui, Sergici, and Sharif, 2010; Sharam, 2003). Additionally, consumers who used the prepayment metering reported satisfaction most of the time O'Sullivan, Viggers,

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<sup>87</sup> Boardman and Fawcett (2002) (competition for the poor); Sharam (2003); Brutscher (2011), Colton (2001).

and Howden-Chapman (2014). The main reason invoked is that they see prepayment as a budgeting tool. Nevertheless, prepayment metering has been criticized. Indeed, several studies indicate that prepayment metering favours “self-disconnection”<sup>88</sup>. Consumers self-ration their energy consumption by restricting their prepayments.

Smart meters allow the latter two payment methods, since they display to the consumers and they send to the utilities the information on the energy consumed. As we can see, these different payment methods and the level of uncertainty regarding future consumer outcomes could have an influence on consumption behaviour for a consumer with time inconsistency. Prepayment and postpayment have the same incentive power with people who “only” have inconsistency problems, but who otherwise do not suffer from inattention, or oblivion.

We find that the prepayment method attenuates the undesirable effect of time inconsistency on energy consumption compared to other payment methods. In the absence of uncertainty, the prepayment is always preferred compared to other payments. We explain the (unlikely) exceptions to better illustrate the functioning of the model. With uncertainty, results regarding the prepayment methods are ambiguous.

Indeed, in this context, a flexible solution (i.e., instant debit, postpayment) is attractive (Casari 2009; Halevy 2008; Rachlin 2009). In other words, if the level of uncertainty is high, the prepayment is inferior to other payment methods. The paper is organized as follows. Section 2 discusses the literature. Section 3 presents the model. Section 4 shows the optimal consumption plans according to the payment method. Section 5 analyses the determinant of the best payment method. Section 6 introduces uncertainty in the modelling. We conclude the paper in Section 7.

## **2. Literature review**

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<sup>88</sup> O’Sullivan et al. (2013b) examine people using prepayment, but seemingly do not compare prepayment with other payment methods. Other relevant studies include O’Sullivan et al. (2011, 2014), Doble (2000), and Howat et McLaughlin (2012).

Time inconsistency is generally the notion that the marginal rates of substitution between goods consumed on different dates change over time (Strotz, 1955; Laibson, 1997; Gul and Pesendorfer, 2001; Fudenberg and Levine, 2006; O'Donoghue and Rabin, 1999b). For example, the marginal rate of substitution between immediate consumption and some later consumption is different from the marginal rate of substitution when these two consumptions are observed from a remote prior date. In additively separable utility functions, the effects passes through changing discount rates. Pure preferences and how people act are different notions. Inconsistent preferences that can be hard-wired in the mind are not irrational per se. The rational decision maker who is conscious of his inconsistency searches for strategies in which the inconsistency is anticipated and embedded in his decision process. Strotz (1955) indicates that "if the inconsistency is recognized, the rational consumer will do one of two things. He may "precommit" his future behaviour by precluding future options so that it will conform to his present desire as to what it should be." Several studies have been realized to illustrate time inconsistency and precommit behaviours in different markets. Relevant classical papers include Dellavigna and Malmendier (2006) for health clubs; Lambrecht, Seim, and Skiera (2007) for telephone service; Fang and Silverman (2009) for the labour market; Thaler (1990) for saving behaviours and Carrillo and Mariotti (2000) for smoking consumption. Additionally, in the literature, it appears that the method of payment has influence on consumption behaviours (Hirschman, 1979; Prelec and Simister, 2001; Lambrecht and Skiera, 2006) as well as the period of time between two payments.

### **3. Model**

#### **3.1. The consumer**

The model considers a consumer who takes intertemporal consumption decisions about two goods: energy,  $E$ , and a composite good,  $X$ . Consumption periods are denoted by  $t = 0, \dots, T$ . We denote by  $x_t \geq 0$  and  $e_t \geq 0$  the consumptions at period  $t$ ; and we denote by  $X_t$  and  $E_t$

the consumption vectors  $(x_\tau)_{\tau=t,\dots,T}$  and  $(e_\tau)_{\tau=t,\dots,T}$ , respectively. The prices are  $p_x$  and  $p_e$ ; to simplify the analysis, they are assumed to be constant over time. We also assume that the interest rate is null. Overall,  $X_0$  and  $E_0$  satisfy a global intertemporal budget constraint

$$p_x \sum_{t=0}^T x_t + p_e \sum_{t=0}^T e_t = w_0, \quad (1)$$

where  $w_0$  is the total budget over the period. More generally, we denote by  $w_t$  the budget available from period  $t$  on. The different payment methods for energy (instant debit, post payment, and prepayment) impose dynamic constraints that we will expose in turn.

In all periods, the consumer maximizes an intertemporal utility with  $\beta$  as the subjective discount factor ( $0 < \beta < 1$ ). The logarithm is used for the calculability of the solutions, which enables us to use of flexible horizon  $T$ .

$$U_t(X_t, E_t) = \ln x_t + \alpha \delta \ln e_t + \sum_{\tau=t+1}^T \beta^\tau [\ln x_\tau + \alpha \ln e_\tau], \quad (2)$$

where  $\alpha$  ( $0 < \alpha < 1$ ) represents the “longview” elasticity of substitution between energy and the composite good, and  $\delta$  represents the “salience” effect: current consumption becomes more ( $\delta \geq 1$ ) or less ( $\delta \leq 1$ ) important than planned. O’Donoghue and Rabin (1999a) qualify this parameter  $\delta$  as a “short-term impatience” parameter. This  $\delta$  models time inconsistency since the consumer would like to revise former decisions. Note that in the case in which  $\delta = 1$ , we retrieve the classical time-consistent model.

We assume that the budget share of energy is lower than 50%, a weak assumption that is easily stated with a Cobb-Douglas utility function and which will be used later for the comparative statics.

**Assumption 1.**  $0 < \alpha \leq 1$ .

### 3.2. Payment methods

The payment for the composite goods is immediate. For energy, the consumer may prepay, pay as he consumes or postpay (i.e., pay all at the end), or prepay.

**Instant debit.**

At time  $t$ , the consumer pays  $p_t^e e_t$  when he consumes  $e_t$ . Consequently, he allocates his wealth available at time  $t$ , namely  $w_t$  between the  $X_t$  and  $E_t$ . If for the sake of convenience the prices are constant, then the budget constraint is:

$$\forall t, w_t = p_x x_t + p_e e_t + w_{t+1}, \quad (3)$$

where  $w_{T+1} = 0.$  (4)

**Postpayment.** There is no commitment involved in paying ex post. Because we assume that he consumer is aware of his debt, the mounting bill is paid in full. Consequently, he behaves exactly as with instant debit.

**Prepayment.** An image would be that of a consumer who prepays energy when he fills his domestic fuel tank (i.e., the consumer pays for all his energy before he actually consumes it). At the beginning of period 0, the consumer buys a stock of energy  $S_0$  that he has to manage over time, and the quantity  $x_0$  of the composite good that he consumes immediately.

The energy quantity available at the beginning of period  $t + 1$  is

$$S_{t+1} = S_t - e_t, \forall t. \quad (5)$$

All is consumed at the end,

$$e_T = S_T. \quad (6)$$

The following budget constraints are

$$p_x x_0 + p_e S_0 + w_1 = w_0, \quad (7)$$

$$p_x x_t + w_{t+1} = w_t, t \geq 1 \quad (8)$$

### 3.3. Programs and solutions

Time inconsistent decision programs are solved as dynamic games, more specifically as subgame-perfect equilibrium where each period has a different decision maker (the current self). The literature qualifies a “sophisticated” consumer as someone who knows that he

suffers from time inconsistency. In other words, these consumers have accurate expectations about their future behaviours. In our case, we hypothesize that these consumers anticipated their dynamic inconsistent behaviours.

**Instant debit.** At each period, the consumer determines his current consumption and the savings he leaves for the next period. Thus, the equation for the last period  $t$  is:

$$V_T(w_T) = \max_{x_T, e_T} \ln x_T + \alpha \delta \ln e_T, \quad (9)$$

subject to (3) and (4). The program for each  $t$  period is:

$$V_t(W_t) = \max_{x_t, e_t} \ln x_t + \alpha \delta \ln e_t + \beta V_{t+1}(w_{t+1}), \forall t < T, \quad (10)$$

subject to (3).

The program amounts to solving

$$\max_{x_0, e_0} \sum_{t=0}^T \beta^t [\ln x_t + \alpha \delta \ln e_t] \text{ s. t. (1)}. \quad (11)$$

Note that the objective is not  $U_0(X_0, E_0)$ .

With direct payment, we have the following choices:

$$x_{t,m}^* = \frac{1-\beta}{(1+\alpha\delta)(1-\beta^{T+1})} \frac{w_0}{p_x} \beta^t, \forall t. \quad (12)$$

$$e_{t,m}^* = \frac{(1-\beta)\alpha\delta}{(1+\alpha\delta)(1-\beta^{T+1})} \frac{w_0}{p_e} \beta^t, \forall t. \quad (13)$$

**Prepayment.** The program is following:

$$V_T(w_T, S_T) = \ln w_t + \alpha \ln S_t, \quad (14)$$

$$V_t(w_t, S_t) = \max_{x_t, e_t} [\ln x_t + \alpha \delta \ln e_t + \beta V_{t+1}(w_t - p_x x_t, S_t - p_e e_t)], \quad (15)$$

subject to (5)-(8). The program amounts to solving

$$\max_{x_0, e_0} \ln x_0 + \alpha \delta \ln e_0 + \sum_{t=0}^T \beta^t [\ln x_t + \alpha \delta \ln e_t] \text{ s. t. (1)., (16)}$$

Note that the objective here is not  $U_0(X_0, E_0)$  either.

We obtain the following choices:

$$x_{t,p}^* = \frac{1}{1+\alpha\delta+(1+\alpha)\sum_{j=1}^T \beta^j} \frac{w_0}{p_x} \beta^t, \forall t; \quad (17)$$

$$e_{0,p}^* = \frac{\alpha \delta}{1+\alpha\delta+(1+\alpha)\sum_{j=1}^T \beta^j} \frac{w_0}{p_e} \text{ for } t = 0, \quad (18)$$

$$e_{t,p}^* = \frac{\alpha}{1+\alpha\delta+(1+\alpha)\sum_{j=1}^T \beta^j} \frac{w_0}{p_e} \beta^t, \forall t \neq 0. \quad (19)$$

## 4. Consumption plans

### 4.1. Consumption

We compare optimal consumption levels according to payment methods. We call the case  $\delta < 1$  compulsive frugality, and  $\delta > 1$  compulsive consumption.

These traits concern the attitude towards energy.

**Proposition 1.** *1. If the agent is a compulsive frugal, then*

- a. *consumption of the composite good is lower in all periods.*
- b. *energy consumption is lower in period 0, and*
- c. *energy consumption is higher in subsequent periods.*

*2. If the agent is a compulsive consumer, then, with the prepayment,*

- a. *consumption of the composite good is higher in all periods,*
- b. *energy consumption is higher in period , and*
- c. *energy consumption is lower in subsequent periods.*

*Proof.* See appendix 11.

So, we find that the prepayment mitigates the time inconsistency of the consumer in all cases.

If he is a compulsive consumer, though the prepayment cannot prevent a high consumption in period 0, the subsequent consumptions are moderated (i.e. the effect is against the direct impact of  $\delta$ ); this benefits the consumption of the composite good. If this moderation

beneficial to the consumer from his own viewpoint? In the following subsection, we compare the level of inter temporal utility between the different payment methods.

**Proposition 1.** *Consumption of the composite good is higher in all periods with the prepayment method if and only if  $\delta > 1$ .*

*Energy consumption is higher in period 0 and lower in the subsequent period with the prepayment method if and only if  $\delta > 1$ .*

Thus, we find that prepayment method seems to mitigate the time inconsistency of the consumer; although it cannot prevent high consumption in the first period, the subsequent consumptions are moderated (i.e., the effect is against the direct impact of delta); this benefits the consumption of the composite good.

In the following sub-section, we compare the level of intertemporal utility among the different payment methods. Indeed, we know that the prepayment method reduces the impact of time inconsistency because it is a type of commitment for the consumer. Nevertheless, if the prepayment system is too constrained for a consumer, the level of intertemporal utility might be inferior compared to the level of intertemporal utility obtained through other payment methods, despite the fact that the prepayment method reduces the level of time inconsistency.

## 5. Best payment method

We know that the prepayment method reduces the impact of time inconsistency because it is a kind of physical commitment for the consumer. He is committed to consume enough if he is compulsively frugal, and to restrict himself if he is a compulsive consumer. Nevertheless, if the prepayment system is too constraining for the consumer, the level of inter temporal utility might be inferior compared to the level of intertemporal utility obtain with the other payment methods.

We denote by  $(U_{-1})$  the level of “cold” intertemporal utility of a given consumption plan:

$$U_{-1}(X_0, E_0) := \sum_{t=0}^T \beta^t [\ln x_t + \alpha \ln e_t]. \quad (20)$$

On the one hand, we must compare the level of intertemporal utility obtained with the prepayment system ( $U_{-1,p} := U_{-1}(X_{0,p}, E_{0,p})$ ) and the intertemporal utility the instant debit ( $U_{-1,m} := U_{-1}(X_{0,m}, E_{0,m})$ ). Thus, we have

$$\Delta U_{-1}(\delta) := U_{-1,p} - U_{-1,m} = \sum_{t=0}^T \beta^t [\ln x_{t,p}^* + \alpha \ln e_{t,p}^*] - \sum_{t=0}^T \beta^t [\ln x_{t,m}^* + \alpha \ln e_{t,m}^*]. \quad (21)$$

We can replace this expression with the optimal value for each good and simplifying the expression; thus, and we have

$$\Delta U_{-1}(\delta) = U_{-1,p} - U_{-1,m} = \frac{(1+\alpha)(1-\beta^{1+T})}{1-\beta} \ln \left( \frac{(1+\alpha)\delta(1-\beta^{1+T})}{1-\beta^{1+T} + \alpha(\delta + \beta(1-\beta^T - \delta))} \right) - \frac{\alpha\beta(1-\beta^T)\ln\delta}{1-\beta}. \quad (22)$$

Let us study the sign of  $\Delta U_{-1}(\delta)$ . We know that  $\Delta U_{-1}(1) = 0$ . Let us calculate the first derivative of  $\Delta U_{-1}(\delta)$ . We obtain

$$\Delta'_{U_{-1}}(\delta) = \frac{-\alpha\beta(1-\beta^T)(1-\delta)(1-(1+\alpha)\beta^{1+T} + \alpha(\beta - \alpha(1-\beta)\delta))}{(1-\beta)\delta(1+\alpha\beta)((1-\beta^{1+T} + \alpha(\delta + \beta(1-\beta^T - \delta)))}, \quad (23)$$

It is worth noting that the denominator of  $\Delta'_{U_{-1}}(\delta)$  is positive, since  $1 - \beta^{1+T} \geq 0$  and  $1 - \beta \geq 0$ .

Consequently, the sign of  $\Delta'_{U_{-1}}(\delta)$  is the sign of its numerator. The numerator is a factor quadratic function of  $\delta$ ; therefore, we have directly two roots:

$$\delta_1 = 1, \quad (24)$$

$$\delta_2 = \frac{1-\beta^{1+T} + \alpha\beta(1-\beta^T)}{\alpha^2(1-\beta)} > 0. \quad (25)$$

The sign of  $\Delta'_{U_{-1}}(\delta)$  is positive between the roots, and negative outside the roots.

We need to know where  $\delta_2$  is compared to 1.

$$\delta_2 < 1 \Leftrightarrow \frac{1-\beta^{1+T} + \alpha\beta(1-\beta^T)}{\alpha^2(1-\beta)} < 1 \Leftrightarrow \alpha > \frac{1-\beta^{1+T}}{1-\beta}. \quad (26)$$

Clearly, we have  $\frac{1-\beta^{1+T}}{1-\beta} \geq 1$ . Under Assumption 1,  $\delta_2 > 1$  in our domain of definition. Since

$\Delta U_{-1}(1) = 0$ , we have  $\Delta U_{-1}(\delta) > 0$  for all  $0 < \delta < \delta_2$ .

Note  $\lim_{\delta \rightarrow +\infty} \Delta_{U_{-1}}(\delta) \rightarrow -\infty$ ; so there is  $\delta_3 > \delta_2$  such that  $\Delta_{U_{-1}}(\delta_3) = 0$ . Consequently, for all  $\delta > \delta_3$ , we have  $\Delta_{U_{-1}}(\delta) < 0$ .

The properties are summarized in the following table of variations.

$\delta \in$	$[0, 1]$	$[1, \delta_2]$	$[\delta_2, \delta_3]$	$[\delta_3, +\infty[$
$\Delta U'_{-1}(\delta)$	-	+	-	-
$\Delta U_{-1}(\delta)$	$\searrow$ $\geq 0$	$\nearrow$ $\geq 0$	$\searrow$ $\geq 0$	$\searrow$ $\leq 0$

**Proposition 2.**

1. *There is a threshold  $\delta_3$  with*

$$\delta_3 > \delta_2 = \frac{1 - \beta^{1+T} + \alpha\beta(1 - \beta^{1+T})}{\alpha^2(1 - \beta)} > 1$$

*such that the prepayment method is preferred to the other payment methods if and only if  $\delta < \delta_3$ .*

2.  $\delta_3$  *has a simple lower bound:  $\delta_3 > \frac{1}{\alpha^2}$ .*

**Corollary 1.** *If  $\delta < \frac{1}{\alpha^2}$ , then the prepayment method is preferred to the other payment methods.*

So, if  $0 < \alpha < 0.5$  (see Assumption 1 and Merceron and Theulière (2010), we find that the condition on  $\delta$  to have a preference for the prepayment method is  $\delta \leq 4$ . In practice, this condition seems lax.

Yet it is worth considering why the instant debit may be preferred. If  $\delta$  is large, the utility from the prepayment method is inferior to the utility from the other payment methods.

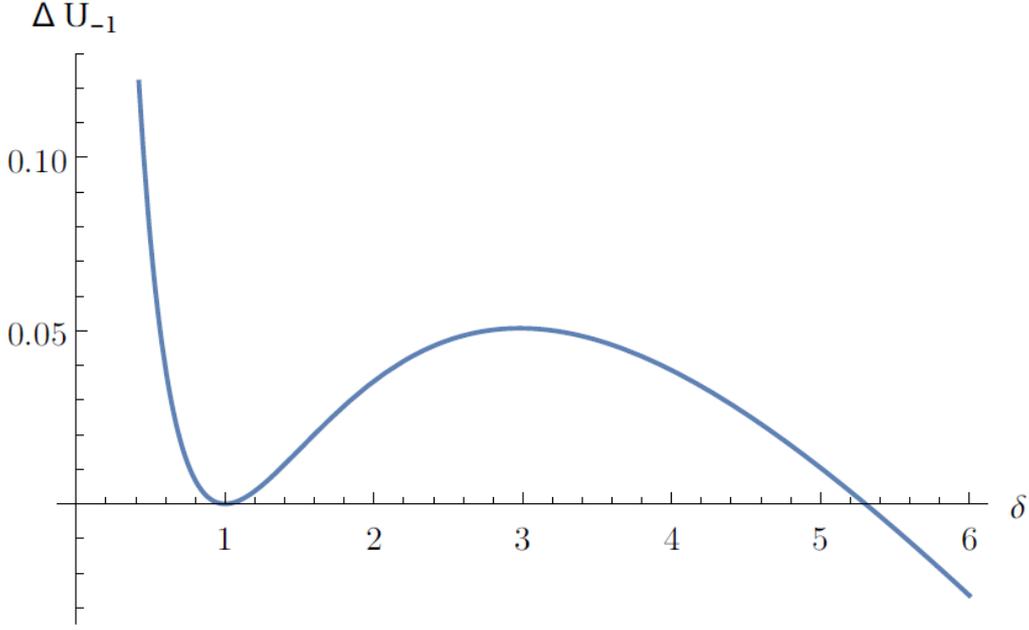


Figure 1: Difference in utility between prepayment and instant debit with  $\alpha = 1$ ,  $\beta = 1$  and  $T = 1$ . To illustrate the intuition, we set  $\alpha = 1$ ,  $\beta = 1$  and  $T = 1$ . With these parameters,

$\Delta'_{U_{-1}}(\delta) = -\ln\delta + 4\ln\frac{2(1+\delta)}{3+\delta}$  (the expression converges when  $\beta \rightarrow 1$ ).  $\delta_3$  can be calculated:

$$\delta_3 = \frac{1}{3}(2 + (359 - 12\sqrt{78})^{1/3}) + (359 + 12\sqrt{78})^{1/3} \simeq 5.357. \quad (27)$$

Consider  $\delta$  larger than 5.357. The utility is determined by  $x_0$ ,  $e_0$ ,  $x_1$  and  $e_1$ . With the prepayment method,  $e_0$  captures the lion's share of the budget; the use of money is very distorted. In contrast, with cash payments,  $e_0$  and  $e_1$  share equally the largest chunk of the budget.

The distortion is limited primarily to the balance between energy and the composite good, but at least energy consumption on one hand and the composite good's consumption on the other hand are smooth. From the standpoint of period  $-1$ , cash payment is a better choice.

For smaller values of  $\delta$  (and more realistic), this logic does not quite work, since prepayment in general (and especially for  $T > 1$ ) allows a good smoothing of energy consumption (except at period 0) and above all an excellent balance between energy and the composite good. The figure 1 illustrates the previous commentary.

## 6. Modelling uncertainty of “demand”

Prepayment is efficient against impulsive consumption or impulsive privation. By construction, it rigidifies the consumption plan of the consumer. In the case of energy consumption, especially heating, future needs are partially unknown since they will depend on the weather. The external temperature is not only random on a day to day basis, but its average is also random from one year to the other. We reconsider our model with demand shocks: the value of energy will be affected in the future by a random upward or downward shock, modelled as  $\bar{\gamma}$  and  $\underline{\gamma}$ . The consumer anticipates these shocks when he chooses the payment method and the consumption plan.

For simplicity, suppose that there are only two periods ( $t = 0$  and  $1$ ): the non-heating season and the heating season, respectively. Nevertheless, consumers believe with probability  $\eta$  that the winter will be cold and with probability  $1 - \eta$  that the winter will be mild. Then, if  $(\underline{x}_1, \underline{e}_1)$  represents consumption during a mild winter and  $(\bar{x}_1, \bar{e}_1)$  is consumption during a cold winter, the intertemporal utility becomes the following:

$$EU(X_0, E_0) = \ln x_0 + \alpha \delta \ln e_0 + \eta \beta (\ln \bar{x}_1 + \alpha \bar{\gamma} \ln \bar{e}_1) + (1 - \eta) \beta (\ln \underline{x}_1 + \alpha \underline{\gamma} \ln \underline{e}_1). \quad (28)$$

The state dependent utility at date 1 are now:

$$\bar{U}_1(\bar{x}_1, \bar{e}_1) = \ln \bar{x}_1 + \alpha \delta \bar{\gamma} \ln \bar{e}_1 \quad (29)$$

$$\underline{U}_1(\underline{x}_1, \underline{e}_1) = \ln \underline{x}_1 + \alpha \delta \underline{\gamma} \ln \underline{e}_1 \quad (30)$$

### 6.1. Prepayment

All that can be consumed in period 1 is what is left from period 0. In the case of prepayment,  $\underline{e}_1 = \bar{e}_1$  and  $\underline{x}_1 = \bar{x}_1$ . The consumer's choices are:

$$x_{Pre,0} = \frac{1}{D} * \frac{w_0}{p_x}, \quad x_{Pre,0} = \frac{1}{D} * \frac{w_0}{p_x} \beta, \quad (31)$$

$$e_{Pre,0} = \frac{\alpha \delta}{D} * \frac{w_0}{p_e}, \quad e_{Pre,1} = \frac{\alpha E_\gamma}{D} * \frac{w_0}{p_e} \beta, \quad (32)$$

where

$$E_\gamma = \eta \bar{\gamma} + (1 - \eta) \underline{\gamma}, \quad (33)$$

and

$$D = 1 + \alpha \delta + \beta(1 + E_\gamma). \quad (34)$$

Consequently, the level of intertemporal utility obtained with the prepayment system is

$$EU_{Pre,-1}(\delta) = \ln\left(\frac{w_0}{p_x D}\right) + \beta \ln\left(\frac{\beta w_0}{p_x D}\right) + \alpha \left( \ln\left(\frac{\alpha \delta w_0}{p_e D}\right) + \beta E_\gamma \ln\left(\frac{\alpha \delta \beta w_0}{p_e D}\right) \right). \quad (35)$$

## 6.2. Instant debit

In this case, the negotiation between energy and the other goods is adapted to the temperature.

The consumer choices are:

$$x_{Cash,0} = \frac{1}{D_\delta} * \frac{w_0}{p_x}, \quad \bar{x}_{Cash,0} = \frac{(1 + \alpha \delta E_\gamma)}{(1 + \alpha \delta \bar{\gamma}) D_\delta} * \frac{w_0}{p_x}, \quad \underline{x}_{Cash,0} = \frac{(1 + \alpha \delta E_\gamma)}{(1 + \alpha \delta \underline{\gamma}) D_\delta} * \frac{w_0}{p_x}, \quad (36)$$

$$e_{Cash,0} = \frac{\alpha \delta}{D_\delta} * \frac{w_0}{p_x}, \quad \bar{e}_{Cash,0} = \frac{\alpha \delta \bar{\gamma} (1 + \alpha \delta E_\gamma)}{(1 + \alpha \delta \bar{\gamma}) D_\delta} * \frac{w_0}{p_x}, \quad \underline{e}_{Cash,0} = \frac{\alpha \delta \underline{\gamma} (1 + \alpha \delta E_\gamma)}{(1 + \alpha \delta \underline{\gamma}) D_\delta} * \frac{w_0}{p_x}, \quad (37)$$

where

$$D_\delta = 1 + \alpha \delta + \beta(1 + \alpha \delta E_\gamma). \quad (38)$$

Consequently, the level of intertemporal utility obtained with the cash payment method is

$$EU_{Pre,-1}(\delta) = \ln\left(\frac{w_0}{p_x D}\right) + \beta \ln\left(\frac{\beta w_0}{p_x D}\right) + \alpha \left( \ln\left(\frac{\alpha \delta w_0}{p_e D}\right) + \beta E_\gamma \ln\left(\frac{\alpha \delta \beta w_0}{p_e D}\right) \right). \quad (39)$$

## 6.3. Comparison of intertemporal utility levels

$$\begin{aligned} \Delta EU_{-1}(\delta) = & \left(1 + \beta + \alpha \delta (1 + E_\gamma)\right) \ln\left(\frac{D_\delta}{D}\right) + \alpha \beta E_\gamma (\ln E_\gamma - \ln \delta) - \beta (1 + \alpha E_\gamma) \ln(1 + \\ & \alpha \delta E_\gamma) + \beta \eta \left( (1 + \alpha \bar{\gamma}) \ln(1 + \alpha \delta \bar{\gamma}) - \alpha \bar{\gamma} \ln \bar{\gamma} \right) + \beta (1 - \eta) \left( (1 + \alpha \underline{\gamma}) \ln(1 + \alpha \delta \underline{\gamma}) - \right. \\ & \left. \alpha \underline{\gamma} \ln \underline{\gamma} \right). \end{aligned} \quad (40)$$

We have

$$\frac{\Delta EU_{-1}(1)}{\alpha \beta} = E_\gamma \ln E_\gamma - \left( \eta \bar{\gamma} \ln \bar{\gamma} + (1 - \eta) \underline{\gamma} \ln \underline{\gamma} \right) - (1 + \alpha E_\gamma) \ln(1 + \alpha E_\gamma) + \eta(1 + \alpha \bar{\gamma}) \ln(1 + \alpha \bar{\gamma}) + (1 - \eta)(1 + \alpha \underline{\gamma}) \ln(1 + \alpha \underline{\gamma}). \quad (41)$$

Of course, for  $\underline{\gamma} = \bar{\gamma}$ , we have  $\Delta EU_{-1}(1) = 0$ . In addition,  $\Delta EU_{-1}(1) < 0$  if  $\underline{\gamma} \neq \bar{\gamma}$ .

Since  $\lim_{\delta \rightarrow 0} \Delta EU_{-1} = \infty$ , then  $\exists \delta_1 \in ]0, 1]$ , such that  $\Delta EU_{-1}(\delta_1) = 0$ . For all  $\delta \in ]0, \delta_1]$ ,  $\Delta EU_{-1} \geq 0$ .

We demonstrate that the sign of  $\frac{\partial \Delta EU_{-1}}{\partial \delta}$  is the sign of the function

$$S(\delta) = \varphi_4 \delta^4 + \varphi_3 \delta^3 + \varphi_2 \delta^2 + \varphi_1 \delta^1 + \varphi_0. \quad (42)$$

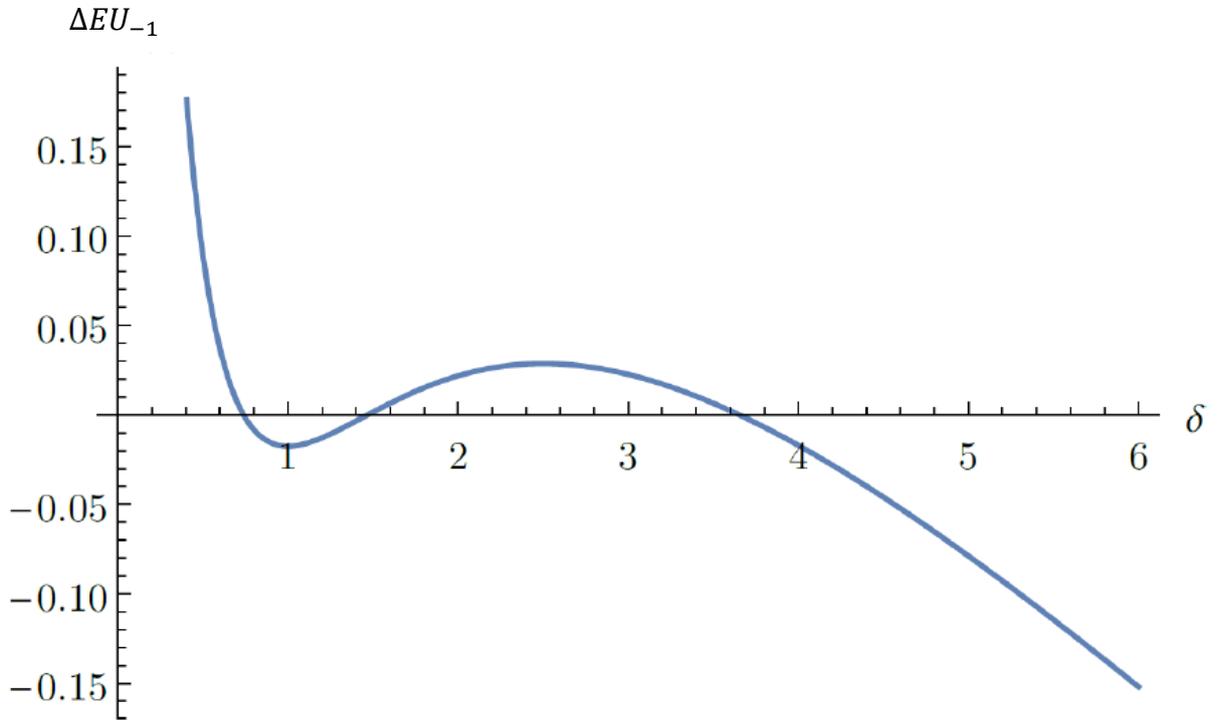


Figure 2: Difference in utility level between prepayment and instant debit with  $\alpha = 1$ ,  $\beta = 0.9$ ,  $T = 1$ ,  $\eta = 0.9$ ,  $\bar{\gamma} = 2$  and  $\underline{\gamma} = 0.75$ .

There still exists a  $\delta_2 > 1$  such that  $\Delta EU_{-1}(\delta_2) = 0$ . In this case, for all  $\delta > \delta_1$ , we have  $\Delta EU_{-1} < 0$ . However, if  $\delta_2$  exists, and if  $S(\delta_2) \neq 0$ , then  $\delta_3$  exists such that  $\Delta EU_{-1}(\delta_3) = 0$  (i.e.,  $\lim_{\delta \rightarrow \infty} \Delta EU_{-1} = -\infty$ ). It does not exist more than three delta superior to zero (i.e.,  $\frac{\partial \Delta EU_{-1}}{\partial \delta}$  is a power function of degree four). The next figure represents

the intertemporal utility comparison between the prepayment and instant debit methods with uncertainty.

As we can see, under uncertainty, the flexible solution (i.e., instant debit) can be preferred compared to the prepayment system. So, as said before, without uncertainty, the prepayment is always preferred compared to the instant debit. Nevertheless, the prepayment method is a kind of “commitment” without flexibility. So, with the introduction of the uncertainty, the more “flexible” payment method (i.e., instant debit) can be preferred compared to the prepayment method even if there still exists time inconsistency. See Figure 2 when  $\delta > 3.5$ .

## **7. Conclusion**

In this article we explore how the payment schedule for energy bills influences the level of energy consumption for a consumer with time inconsistency. The theoretical framework of Strotz (1955) and Laibson (1997) is reconsidered to exhibit a specific time inconsistency with a specific good: energy. So the model we propose can explain realistic issues with consumption timing and budgeting between commodities. It also explains the impact of the payment method on the consumption plan. We compare three common payment methods: prepayment, instant debit and postpayment. We find that the prepayment method mitigates the time inconsistency of the consumer: though it cannot prevent a high consumption in the first period, the subsequent consumptions are moderated (i.e., the effect is against the direct impact of delta); these benefits the consumption of the composite good. Also the intertemporal level of utility between the prepayment and the cash payment method is compared. Without uncertainty on the energy needs, the prepayment method is always preferred compared to other methods under mild conditions on the preferences. With uncertainty on the energy needs, results are less clear-cut. Indeed, flexible payment methods (i.e., instant debit or postpayment) could be preferred when the level of uncertainty on climate consumer predictions is important. This result highlight the fact that the preference for the prepayment

method is a trade-off between commitment with oneself and flexibility towards adverse conditions. Adding flexible options to the prepayment system will be interesting to release this constraint. So, introduce a « virtual wallet » based on voluntary money transfers could be considered. Indeed, it would allow consumers to make voluntary saving to withstand with uncertain or unanticipated variations of their energy consumptions (i.e., particularly during the winter unless for example). So the establishment of the virtual wallet system would introduce more flexibility to this payment method that it reduce time inconsistency.

Finally, our theoretical model can be a relevant tool to understand a different kind of budget arbitrations for individuals who experiencing fuel poverty.

# Conclusion générale

La loi sur la Transition Énergétique pour une Croissance Verte (LTECV- août 2015) qui doit « permettre à la France de contribuer plus efficacement à la lutte contre le dérèglement climatique et de renforcer son indépendance énergétique en équilibrant mieux ses différentes sources d’approvisionnement » relance des questionnements autour des implications sociales en lien avec la question énergétique. En parallèle, la thématique de la précarité énergétique suscite un intérêt grandissant dans la sphère économique et sociale. Une connaissance et la bonne définition des éléments de mesure de ce phénomène est nécessaire pour la bonne poursuite des objectifs de réduction des inégalités.

En effet, le phénomène de la précarité énergétique n’est pas aisé à délimiter, dans la mesure où une multitude d’éléments la définisse (e.g., éléments financiers, logement, prix énergie etc...). La multiplicité de ces facteurs et leurs interactions font de la précarité énergétique un objet d’étude complexe, engendrant une absence de consensus quant aux outils de mesure à retenir pour évaluer ce phénomène. Ainsi, l’étude de la précarité énergétique via le concept d’équité (i.e. horizontale et verticale) induit que chaque indicateur de mesure de la précarité énergétique peut être un instrument d’évaluation du degré d’équité et donc permettrait de réconcilier les avis divergents sur les outils de mesure de la précarité énergétique.

Cette thèse qui a été structurée en quatre chapitres illustre notre désir de répondre à cette problématique : une discussion de ce phénomène en termes d’équité a permis de mettre en exergue l’existence d’inégalités (i.e., chapitre 1), justifiant ainsi la mise en place de mesures complémentaires, voire nouvelles, en faveur d’une plus grande équité entre individus concernant le bien énergie. La caractérisation de la dynamique de ce phénomène (i.e., chapitre 2) a dispensé de précieuses informations sur le type de mesures (i.e., aides au paiement de factures, modes de paiement de facture innovants, aides à la rénovation du logement) pouvant être mises en place pour contrecarrer ce phénomène, et ainsi participer à la poursuite des

objectifs d'équité sous-jacents. L'analyse des conséquences de la précarité énergétique sur d'autres dimensions que celle faisant référence à l'énergie (i.e., santé) permet d'interpeller les décideurs politiques sur son aspect multidimensionnel et poreux avec d'autres dimensions de la précarité sociale (i.e., chapitre 3). Ce phénomène est un vecteur concourant à l'aggravation d'autres inégalités (i.e., inégalités de santé), pouvant ainsi compromettre la poursuite de l'objectif d'équité des décideurs publics. Enfin, l'étude de moyens de paiement innovants du bien énergie, à moindre coût, a permis d'identifier le prépaiement comme un outil pouvant contribuer à l'atteinte des objectifs respectivement d'équité horizontale et verticale (i.e., chapitre 4).

Le chapitre 1 a identifié l'amplitude, la concentration et les déterminants des inégalités ayant trait aux dépenses énergétiques (hors dépenses de mobilité) et au poids qu'elles constituent pour le budget des individus. Nous identifions un fort niveau d'inégalités quant aux niveaux de dépenses énergétiques des individus en absolu. De plus le même constat est effectué lorsque l'on considère la part du budget alloué à celles-ci (i.e., niveau de consommation d'énergie relatif au revenu).

Entre autres, la contribution des dépenses énergétiques pour motif de chauffage (ou eau chaude sanitaire), non incluses dans les dépenses d'électricité ou de gaz, aux inégalités globales de dépenses énergétiques est la plus forte. Par ailleurs, une plus forte concentration des niveaux élevés de dépenses énergétiques chez les individus les plus aisés est identifiée. A contrario, les individus à faibles revenus concentrent des taux d'efforts énergétiques plus élevés par rapport aux individus à fort niveau de revenu et ceci en dépit de dépenses énergétiques inférieures en valeur absolue (pour les individus à faibles revenus). De plus, la majeure partie des inégalités des dépenses énergétiques sont expliquées par l'effet direct du revenu (i.e., décomposition de l'indice de concentration). Les variables sociodémographiques

ayant un faible impact explicatif. Le manque de pouvoir d'achat est le déterminant majeur expliquant les différences de niveau moyen de dépenses énergétiques entre les pauvres<sup>89</sup> et les non pauvres (i.e., décomposition de Blinder-Oaxaca). Les différences de comportements dans l'usage du bien énergie ne détiennent en effet qu'un très faible pouvoir explicatif de cet écart. L'existence d'inégalités brutes et relatives au revenu des ménages ainsi que l'identification des leurs, illustre le non-respect du principe d'équité à la fois horizontale (i.e., utilisation du bien énergie) et verticale (i.e., financement du bien énergie). Ainsi, concentrer l'analyse de la précarité énergétique au travers du concept d'équité (i.e., horizontale et verticale) participerait à la bonne évaluation des objectifs fixés par la loi sur la Transition Énergétique pour une Croissance Verte (LTECV- août 2015).

Le chapitre 2 fournit une compréhension de la dynamique du phénomène de la précarité énergétique et de ses déterminants. Le phénomène de précarité énergétique y est défini par la caractérisation de deux états distincts. D'une part, l'état de précarité énergétique « simple » rapportant les difficultés de chauffage rencontrées par les individus mais les moyens financiers pour faire face à ces dépenses sont suffisants. Cet état rend compte de la non satisfaction du principe d'équité horizontale appliquée à la précarité énergétique. D'autre part, l'état de précarité énergétique « sévère » quant à lui rapporte les difficultés de chauffage rencontrées par les individus et qui en plus ne détiennent pas les moyens financiers de faire face à ces dépenses de chauffage. Cet état bafoue le principe d'équité horizontale quant à l'utilisation du bien énergie ainsi que le principe d'équité verticale de son financement. Cette étude conclut que majoritairement transitoire plutôt que chronique, même si les proportions estimées d'individus enclavés dans ces états de précarité énergétique ne sont pas négligeables. Nous avons identifié les déterminants de stabilité et de transition en situation de précarité énergétique enrichissant par ailleurs la caractérisation de la dynamique du phénomène. Ainsi,

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<sup>89</sup> Notons que les seuils de 50% et 60% du revenu médian sont utilisés dans les estimations.

le niveau revenu, le niveau d'éducation et la qualité du logement apparaissent comme étant des déterminants majeurs de transition et d'enclavement dans la précarité énergétique. Par conséquent, l'augmentation des revenus, l'investissement dans l'éducation, les transferts de revenus, et l'amélioration de la qualité thermique du logement contribueraient à faire sortir les individus de la précarité énergétique, voire de situation de pauvreté. Enfin, le caractère plus transitoire que chronique de ce phénomène de précarité énergétique encourage le maintien et le renforcement des mesures d'aide de « court terme » (i.e., aide au paiement de facture (e.g., chèque énergie)).

Le chapitre 3 identifie et quantifie l'impact délétère de la précarité énergétique sur la probabilité de déclarer une Affection de Longue Durée, de déclarer un mauvais état de santé et d'obtenir un mauvais score de santé mentale. La conséquence directe de ce résultat est un besoin plus important de consommation de soins pour les individus en situation de précarité énergétique. Ainsi, une contrainte financière additionnelle est subie par les individus en situation de précarité énergétique pouvant conduire à des arbitrages forcés (rendus difficiles) entre deux facilités essentielles (i.e., énergie et santé). La précarité énergétique est caractérisée dans ce chapitre par la sensation de froid ressenti dans le logement dû à limitation de la quantité d'énergie consommée en raison de son coût, cette mesure rendant compte de la non satisfaction du principe d'équité horizontale. De plus, la mobilisation de l'outil économétrique permet une prise en compte des facteurs inobservés dans l'estimation (i.e., différence de frilosité entre individus par exemple) pouvant entraîner un biais dans l'estimation.

De plus, nous identifions que les déterminants délétères pour la santé (faible niveau de revenu, d'éducation par exemple) sont similaires aux déterminants de transition et d'enclavement dans la précarité énergétique (i.e., chapitre 2). Cette similarité des déterminants met en lumière l'effet cumulatif négatif de ces déterminants concourant à

l'accroissement, voire au renforcement, de la vulnérabilité et de la précarisation des individus y étant exposés.

La précarité énergétique devrait donc être considérée comme un déterminant des inégalités sociales de santé. Ainsi, des mesures d'aides innovantes en faveur des catégories socioéconomiques les plus vulnérables doivent être mise en place pour réduire la précarité énergétique et plus généralement pour promouvoir la santé des individus et l'équité entre individus que ce soit sur le bien énergie ou santé.

Enfin, le chapitre 4 identifie le prépaiement comme un outil d'aide budgétaire pour les individus souffrant d'incohérence temporelle (i.e., ménages à faibles revenus, précaires énergétiques). Ce moyen de paiement innovant aidera, à la poursuite des objectifs d'équité et contribuera à l'instauration de solutions et mesures efficaces à moindres coûts pour les décideurs publics. En effet, les résultats de notre modélisation théorique indiquent que le système de prépaiement atténue l'incohérence temporelle des individus qui en souffrent. De plus, la comparaison des niveaux d'utilité inter temporelle entre les différents moyens de paiement révèle que malgré le caractère contraignant du prépaiement, celui-ci sera préféré par les individus incohérents temporellement dans notre modélisation sous certaines conditions identifiées. En revanche, l'introduction de l'incertitude sur la demande du bien énergie (i.e., prévision du temps qu'il fera demain) rend les résultats de supériorité du prépaiement plus ambiguë. En effet, en présence d'un fort niveau d'incertitude, la solution plus flexible que le prépaiement (i.e., paiement mensuel) peut être préférée. Pour finir, la modélisation réalisée dans ce chapitre participe à une meilleure compréhension des différents types d'arbitrage que la précarité énergétique peut entraîner via un modèle dit comportemental permettant une reproduction des comportements pouvant s'éloigner des standards normatifs stricts de la théorie de la décision, tels que la cohérence inter temporelle. De surcroît, ce chapitre permet de tester différentes formules d'aide à la consommation d'énergie (nous avons ici traité du

prépaiement) mais la fréquence des aides et leur forme (divisible ou non, très spécialisée ou non) pourraient également être évaluées.

Cette thèse a donc montrée qu'une dichotomie de la précarité énergétique via le concept d'équité à la fois horizontale et horizontale permet d'appréhender le sujet de la précarité énergétique dans sa globalité et de façon multidimensionnelle. En effet, l'équité horizontale permet de discuter de la dimension relative à la non satisfaction des besoins quant à l'utilisation du bien énergie alors que celui-ci est considéré comme un bien de première nécessité (i.e., chapitre 1,2 et 3). D'autre part, l'équité verticale relative au moyen de financement permet de discuter des conséquences financières et du fardeau financier pouvant être occasionné par celles-ci (i.e., chapitre 1 et 2). Tout ceci contribuant à une meilleure discussion des mesures à mettre en place pour contrecarrer ce phénomène et permet de prioriser les mesures pour soit poursuivre le critère horizontale ou le critère d'équité verticale.

Cette thèse rend donc compte qu'une approche de la précarité énergétique par la poursuite d'un objectif d'équité horizontale et verticale, rend possible l'utilisation d'une large variété d'indicateurs de mesure de la précarité énergétique. Un consensus pourrait donc émerger sur les indicateurs pouvant être mobilisés pour mesurer la précarité énergétique.



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# Appendix

## a) Appendix 1:

	If there is no answer to energy expenditures questions. (205 observations)	If head of household declared that their electricity or gas expenditures were included in condominium fees or rental charges (177 observations)	If head household declared that their electricity or gas expenditures are not included in condominium fees or rental charges but they did not answer to these questions. (MIELEC, MIGAZ) (764 observations)	Rest of the population
<b>Net income</b>				
1 <sup>st</sup> quintile	33.66%	32.98%	34.73%	20.03%
2 <sup>nd</sup> quintile	17.07%	23.94%	23.63%	20.23%
3 <sup>rd</sup> quintile	11.22%	14.36%	14.56%	19.36%
4 <sup>th</sup> quintile	11.71%	14.36%	16.11%	20.72%
5 <sup>th</sup> quintile	26.34%	14.36%	10.98%	19.66%
<b>Level of education</b>				
No education	24.88%	27.13%	23.75%	24.76%
Lower secondary	15.12%	21.81%	15.87%	16.31%
Higher secondary	29.51%	41.49%	43.32%	48.20%
Post-secondary	20.49%	9.57%	17.06%	10.73%
<b>Status on the labour market</b>				
Employed	50.24%	55.32%	49.16%	49.57%
Student	7.32%	11.63%	10.74%	9.56%
Unemployed	5.85%	9.04%	11.46%	9.15%

Retired	25.37%	18.62%	18.62%	5.63%
Homemaker	5.85%	3.19%	6.56%	28.36%
Inactive	3.41%	0.53%	2.74%	4.64%
Others	1.95%	1.60%	0.72%	2.25%
<b>Type of household</b>				
Single person	20.98%	39.89%	15.99%	14.45%
Single parent family	10.24%	5.85%	14.20%	7.50%
Couple without children	30.24%	25.53%	25.54%	31.37%
Couple with children	32.20%	25.53%	39.7%	43.69%
Others	6.34%	3.19%	44.53%	2.98%
<b>Occupancy status</b>				
Owner	49.27%	5.85%	19.57%	70.42%
Tenant	46.83%	76.06%	79.39%	27.58%
Free of charge	3.90%	18.09%	1.07%	2%%
<b>Type of dwelling</b>				
Farm, house	35.32%	15.73%	7.64%	51.20%
Town, adjacent house	20.90%	16.29%	22.55%	21.63%
Apartment	43.78%	67.98%	69.81%	27.17%

This table reports descriptive statistics regarding dropped observations. We observe that individuals who never answer to energy expenditures questions are more present in the first quintile of the income distribution. Also, they are more often retired individuals and

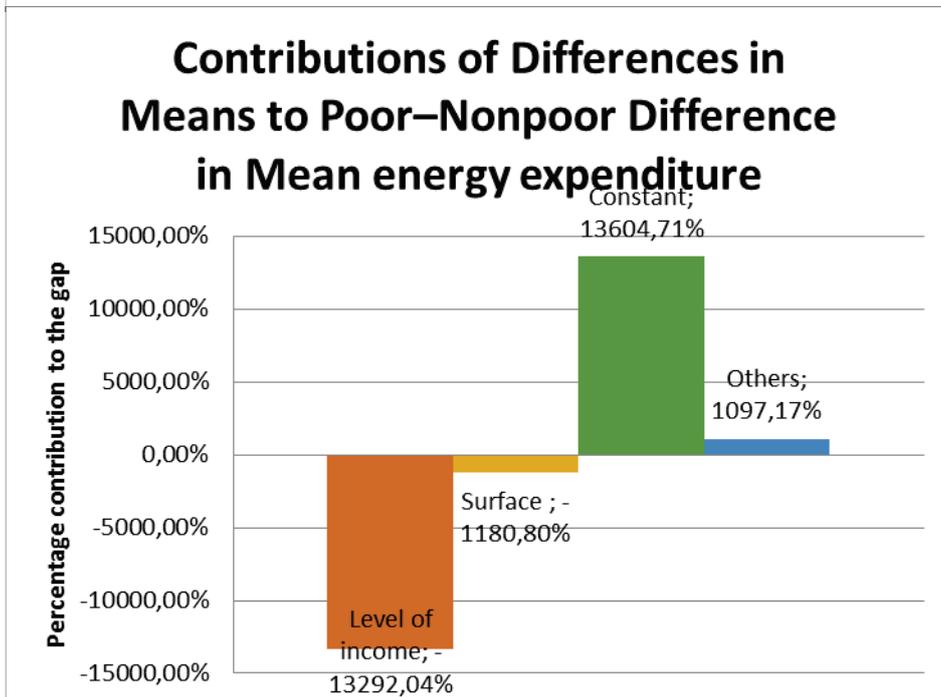
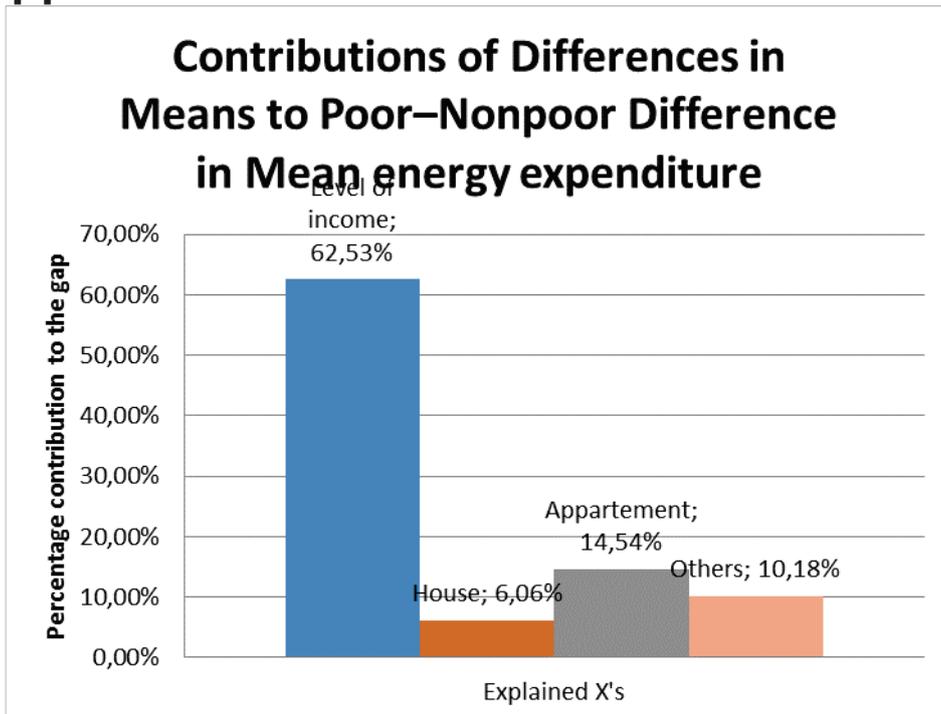
individuals with Post-secondary level of education. Regarding the occupancy status and the type of dwelling, there are more tenant and more individuals who live in an apartment.

For the two other types dropped observations (i.e., if head of household declared that their electricity or gas expenditures were included in condominium fees or rental charges and if household declared that their electricity or gas expenditures are not included in condominium fees or rental charges but they did not answer to these questions) the results are quite similar for the occupancy status, the type of dwelling and the level of income. Nevertheless there are more single persons for individuals who declared that their electricity or gas expenditures were included in condominium fees or rental charges compared to the rest of the population. Finally, others types of couple (i.e., complex households<sup>90</sup>) are more present in the category where head household who declared that their electricity or gas expenditures are not included in condominium fees or rental charges but they did not answer to these questions.

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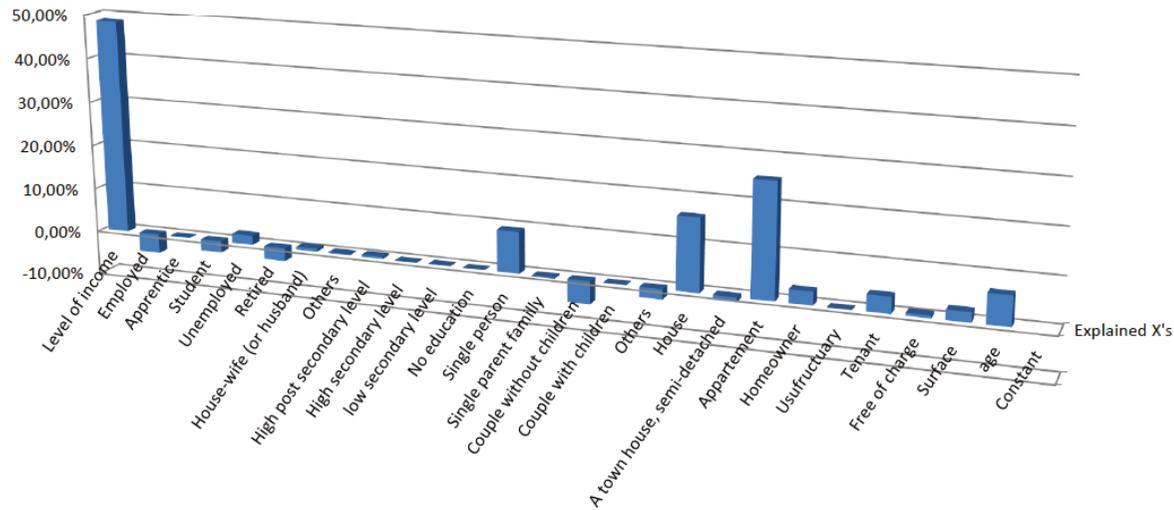
<sup>90</sup> Complex households are those with more than one family or more isolated person, or any other combination of individual families and persons. (INSEE définition)

**b) Appendix 2:**

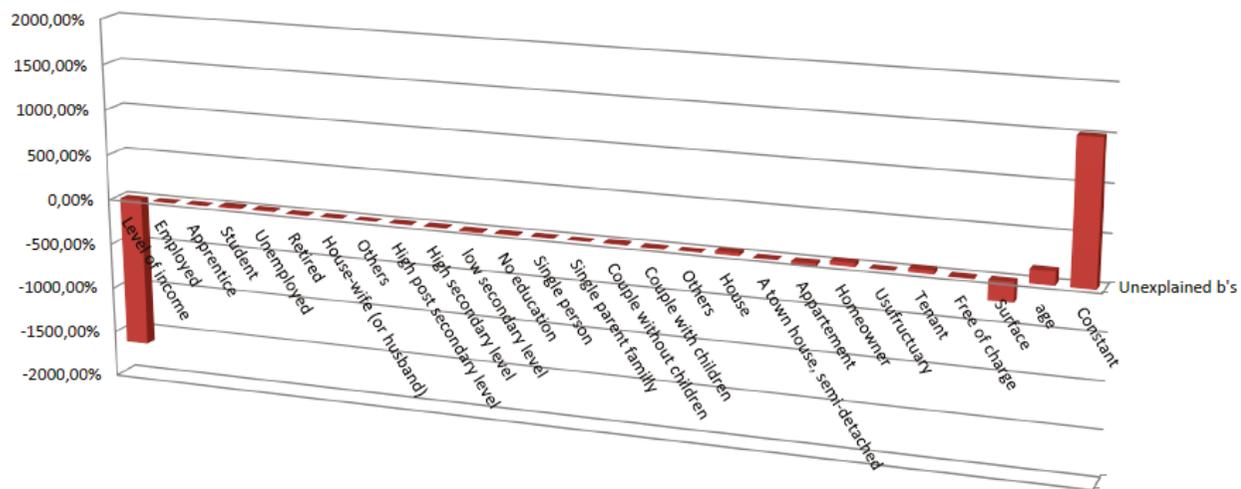


### c) Appendix 3:

Percentage contributions of differences in means to poor-nonpoor difference in mean energy expenditures for explained X's

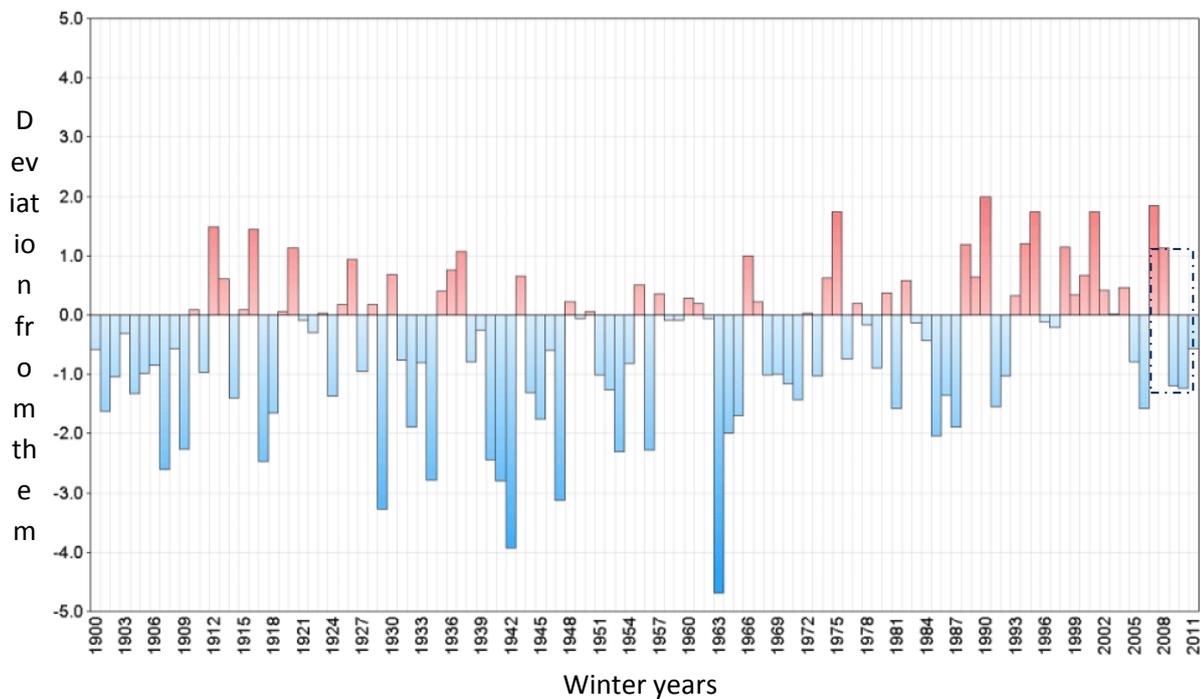


Percentage contributions of differences in means to poor-nonpoor difference in mean energy expenditures for unexplained b's



## d) Appendix 4:

As we can see, the winter temperature for 2008 is quietly different compared to 2009-2010-2011 years. Indeed, the deviation from the mean is equal to  $+1^{\circ}\text{C}$  in 2008 but approximately  $-1^{\circ}\text{C}$  for 2009, 2010 and 2011. So, for a better consistency regarding mean winter temperatures across years, we decided to suppress the 2008 year.



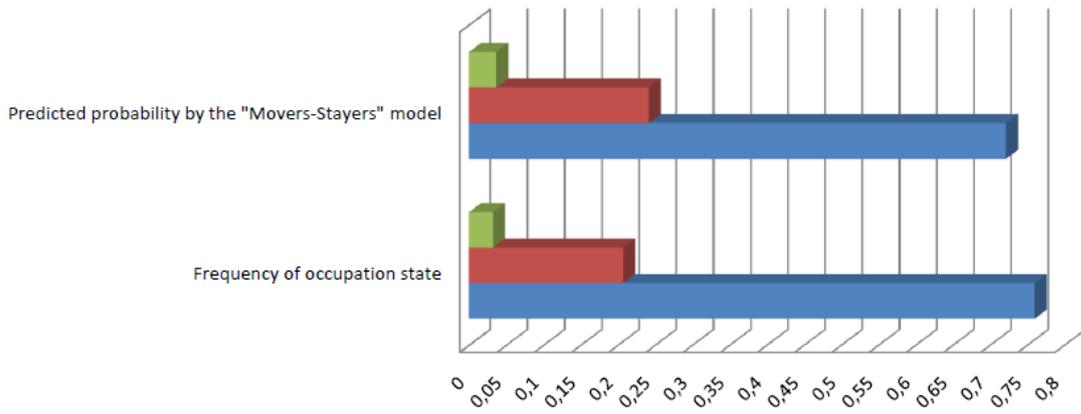
French temperature during winter season since 1900

(i.e., <http://www.meteofrance.fr/documents/10192/35608/25066-43.gif/>)

## e) Appendix 5:

The following figure represents the goodness-of-fit of the “mover-stayer” model on our data. It represents the probability of frequency of each state estimated by the “mover-stayer” model and the real frequency of each state in our data. As we can see, the “mover-stayer model” slightly underestimates the proportion of non-fuel poor and respectively slightly overestimates the proportion of fuel poor. Nevertheless, it appears that the frequency of severe fuel poor is correctly estimated. Finally, this model seems to be a good adequacy for our data.

### Goodness-of-fit of the Mover-Stayer model



	Frequency of occupation state	Predicted probability by the "Movers-Stayers" model
■ Severe Fuel Poor	0,0324	0,0364946
■ Fuel Poor	0,2074	0,241603
■ Non Fuel poor	0,7602	0,721903

## f) Appendix 6:

	Long-term illness			Poor self-assessed health			Bad mental health			Humidity			Fuel poverty for financial reasons		
	No	Yes	Total	No	Yes	Total	No	Yes	Total	No	Yes	Total	No	Yes	Total
	80.67%	19.3%	100%	64.49%	35.51%	100%	72.86%	27.14%	100%	85.18%	14.82%	100%	95.84%	4.16%	100%
<b>AGE</b>															
<=25	9.29%	1.37%	7.76%	8.82%	1.98%	6.39%	7.05%	5.76%	6.70%	7.83%	10.83%	7.76%	7.79%	6.96%	7.76%
]25-35[	16.69%	3.87%	14.22%	17.80%	6.66%	13.84%	15.33%	13.15%	14.74%	13.56%	18%	14.22%	14.02%	18.84%	14.22%
[35-45[	23.20%	8.30%	20.32%	23.59%	12.83%	19.77%	20.38%	20.14%	20.32%	19.55%	24.76%	20.32%	20.32%	20.29%	20.32%
[45-55[	21.72%	14.61%	20.35%	20.51%	18.52%	19.80%	18.82%	23.73%	20.15%	20.43%	19.79%	20.34%	20.14%	24.93%	20.34%
[55-65[	15.51%	24.28%	17.21%	15.04%	21.71%	17.41%	17.13%	16.88%	17.06%	18.01%	12.62%	17.21%	17.24%	16.52%	17.21%
[65-75[	7.36%	20.47%	9.90%	8.24%	15.77%	10.91%	10.23%	10.03%	10.18%	10.56%	6.11%	9.90%	10.06%	6.09%	9.90%
>=75	6.22%	27.09%	10.26%	6%	22.53%	11.87%	11.06%	10.31%	10.86%	10.67%	7.90%	10.26%	10.43%	6.38%	10.26%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>
<b>GENDER</b>															
Male	40.64%	45.44%	41.57%	41.98%	39.03%	40.93%	43.75%	31.93%	40.54%	42.58%	35.75%	41.56%	41.90%	33.91%	41.56%
Female	59.36%	54.56%	58.43%	58.02%	60.97%	59.07%	56.25%	68.07%	59.46%	57.42%	64.25%	58.44%	58.10%	66.09%	58.44%
<b>Total</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>	<b>100%</b>
<b>Level of income</b>															

1st quintile	14.97%	17.48%	15.55%	15.52%	24.07%	18.55%	15.84%	26.17%	18.64%	13.69%	26.30%	15.56%	14.96%	29.28%	15.56%
2nd quintile	13.10%	17.48%	13.95%	14.88%	19.87%	16.65%	16.12%	17.49%	16.49%	13.43%	16.94%	13.95%	13.75%	18.55%	13.95%
3rd quintile	15.09%	13.90%	14.88%	18.73%	16.02%	17.77%	18.54%	16.54%	18%	15.32%	12.38%	14.88%	15%	12.17%	14.88%
4th quintile	13.43%	10.74%	12.91%	16.98%	13.51%	15.74%	17.13%	13.63%	16.18%	13.76%	8.06%	12.91%	13.05%	9.86%	12.91%
5th quintile	13.43%	9.18%	12.91%	18.60%	9.70%	15.44%	17.40%	12%	15.94%	13.39%	8.14%	12.61%	12.90%	6.09%	12.61%
NSP	29.96%	30.95%	12.61%	15.30%	16.84%	15.85%	14.98%	14.17%	14.76%	30.42%	28.18%	30.09%	30.35%	24.06%	30.09%
<b>Total</b>	<b>100%</b>														
<b>Level of education</b>															
No education	0.96%	2.12%	1.18%	0.58%	1.74%	0.99%	0.93%	0.88%	0.92%	1.08%	1.79%	1.18%	1.12%	2.61%	1.18%
Primary school	12.51%	37.08%	17.26%	11%	31.89%	18.42%	16.60%	19.32%	17.34%	17.75%	14.41%	17.26%	17.37%	14.78%	17.26%
College	39.58%	38.08%	39.29%	37.75%	40.42%	38.70%	37.36%	41.76%	38.55%	38.50%	43.89%	39.30%	39.18%	42.03%	39.30%
Higher secondary	18.74%	11.36%	17.32%	18.97%	13.22%	16.93%	16.87%	18.78%	17.39%	17.26%	17.67%	17.32%	17.40%	15.36%	17.32%
Post-secondary	25.45%	10.36%	22.53%	29.04%	11.92%	16.93%	26.07%	17.76%	23.81%	23.07%	19.38%	22.52%	22.48%	23.48%	22.52%
Education in progress	2.27%	0.50%	1.93%	2.02%	0.53%	1.49%	1.67%	1.29%	1.56%	1.87%	2.28%	1.93%	2%	0.29%	1.93%
Other	0.49%	0.50%	0.49%	0.64%	0.29%	0.51%	0.51%	0.20%	0.42%	0.48%	0.57	0.49%	0.45%	1.45%	0.49%
<b>Total</b>	<b>100%</b>														
<b>Occupational status</b>															
Farmers	3.07%	6.55%	3.74%	2.90%	6.13%	4.04%	3.94%	2.85%	3.64%	3.75%	3.66%	3.74%	3.80%	2.32%	3.74%
Self-employed	5.55%	6.68%	5.77%	5.71%	5.89%	5.77%	5.81%	4.61%	5.49%	5.96%	4.64%	5.77%	5.81%	4.93%	5.77%

Skilled white collar occupations	12.13%	9.99%	11.72%	14.35%	8.25%	12.18%	13.56%	9.22%	12.38%	12.30%	8.31%	11.71%	11.91%	6.96%	11.71%
Intermediate profession	18.67%	12.92%	17.56%	20.46%	13.89%	18.13%	18.69%	16.61%	18.13%	18.43%	12.54%	17.56%	17.58%	17.10%	17.56%
Clerical employees	14.97%	12.55%	14.50%	14.67%	15%	14.78%	14.62%	16.88%	15.24%	14.64%	13.76%	14.51%	14.48%	15.07%	14.51%
Trade and craft employees	15.30%	16.10%	15.46%	13.89%	16.98%	14.99%	13.92	17.90%	15%	14.76%	19.46%	15.46	15.31%	18.84%	15.46%
Skilled manual workers	15.05%	17.92%	15.60%	14.72%	16.59%	15.38%	15.61%	14.98%	15.44%	15.77%	14.66%	15.60	15.65%	14.49%	15.60%
Unskilled manual workers	9.51%	12.05%	10%	8.34%	12.01%	9.65%	8.97%	11.19%	9.57%	9.37%	13.68%	10%	9.75%	15.94%	10%
Inactive	5.74%	5.24%	5.65%	4.97%	5.26%	5.07%	4.87%	5.76%	5.12%	5.02%	9.28%	5.65%	5.70%	4.35%	5.65%
<b>Total</b>	<b>100%</b>														
<b>Household type</b>															
Single person	15.87%	25.09%	17.65%	17.03%	24.55%	19.70%	18.64%	22.44%	19.67%	17.61%	17.92	17.66%	17.29%	26.09%	17.66%
Single parent family	9.62%	7.43%	9.20	8.87%	9.36%	9.05%	7.65%	13.29%	9.18%	7.82%	17.10%	9.20%	8.95%	14.78%	9.20%
Couple without children	26%	44.26%	29.53%	26.41%	38.40%	30.67%	30.82%	26.37%	29.61%	31.28%	19.46%	29.53%	30.02%	18.26%	29.53%
Couple with children	45.56%	20.29%	40.68%	45.11%	24.70%	37.86%	40.44%	34.78%	38.90%	40.49%	41.69%	40.67%	40.84%	36.81%	40.67%
Other	2.95	2.93%	2.94%	2.58%	2.99%	2.72%	2.45%	3.12%	2.63%	2.79%	3.83%	2.94%	2.90%	4.06%	2.94%
<b>Total</b>	<b>100%</b>														
<b>Humidity</b>															
Yes	14.89%	14.54%	14.82%	12.97%	16.45%	14.20%	12.38%	19.59%	14.34%	.	.	.	.	.	.
No	85.11%	85.46%	85.18%	87.03%	83.55%	85.80%	87.62%	80.41%	85.66%	.	.	.	.	.	.
<b>Total</b>	<b>100%</b>	.	.	.	.	.	.								

Fuel poverty for financial reasons															
Yes	4.13%	4.31%	4.16%	3.06%	5.55%	4.04%	2.53%	7.46%	3.87%	.	.	.	.	.	.
No	95.87%	95.69%	95.84%	96.94%	94.45%	96.06%	97.47%	92.54	96.13%	.	.	.	.	.	.
<b>N</b>	6685	1601	8286	3764	2073	5837	3959	1475	5434	7058	1228	8286	7941	345	8286
<b>Total</b>	<b>100%</b>	.	.	.	.	.	.								

### g) Appendix 7:

Min	Max	Average	Median
1	121	67.5	70

## h) Appendix 8:

	Long-standing disease				Poor self-assessed health				Poor mental health score			
	Probit	biprobit	Probit	biprobit	Probit	biprobit	Probit	biprobit	Probit	biprobit	Probit	biprobit
	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect	Marg effect
<b>Fuel poverty for budgetary reasons</b>												
Yes	.	.	<b>0,0249</b>	<b>0,335***</b>	.	.	<b>0,135***</b>	<b>0,399**</b>	.	.	<b>0,193***</b>	<b>0,576***</b>
No	.	.	REF		.	.	REF	REF	.	.	REF	REF
<b>Rho</b>	.	.	.	<b>-0,734***</b>	.	.	.	<b>-0,419</b>	.	.	.	<b>-0,706***</b>
<b>Fuel poverty for mould/moisture presence in the dwelling</b>												
Yes	<b>0,0247**</b>	<b>0,326***</b>	.	.	<b>0,073**</b>	<b>0,326***</b>	.	.	<b>0,079***</b>	<b>0,234</b>	.	.
No	REF	REF	.	.	REF	REF	.	.	REF	REF	.	.
<b>Rho</b>	.	<b>-0,801***</b>	.	.	.	<b>-0,488*</b>	.	.	.	<b>-0,282</b>	.	.
<b>AGE</b>												
[16-25]	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF
[26-35[	0,081***	0,036***	0,08***	0,033***	0,138***	0,08***	0,141***	0,091***	0,038	0,028	0,039	0,031
[35-45[	0,132***	0,0693***	0,131***	0,066***	0,214***	0,148***	0,214***	0,155***	0,071**	0,063**	0,071**	0,061**
[45-55[	0,195***	0,129***	0,194***	0,116***	0,30***	0,235***	0,30***	0,235***	0,113***	0,111***	0,109***	0,098***

[55-65[	0,296***	0,243***	0,294***	0,233***	0,382***	0,33***	0,377***	0,327***	0,066**	0,069**	0,061*	0,053**
[65-75[	0,364***	0,338***	0,362***	0,337***	0,422***	0,374***	0,419***	0,379***	0,060*	0,063**	0,058*	0,054*
>=75	0,416***	0,409***	0,415***	0,423***	0,523***	0,485***	0,523***	0,501***	0,025	0,03	0,026	0,027
<b>GENDER</b>												
Male	REF											
Female	-0,044***	-0,047***	-0,043***	-0,045***	0,052	0,004	0,053	0,003	0,084***	0,078***	0,083***	0,074***
<b>Level of income</b>												
1st quintile	REF											
2nd quintile	0,003	0,014	0,003	0,0081	-0,04**	-0,231	-0,042**	-0,039*	-0,062***	-0,054**	-0,063***	-0,056***
3rd quintile	-0,03**	-0,005	-0,031**	-0,02	0,107***	-0,074***	-0,108***	-0,01***	-0,095***	-0,076**	-0,094***	-0,076***
4th quintile	-0,031*	-0,002	-0,03**	-0,021	-0,088***	-0,051*	-0,091***	-0,081***	-0,099***	-0,077*	-0,101***	-0,082***
5th quintile	-0,06***	-0,034**	-0,06***	-0,047***	-0,169***	-0,129***	-0,169***	-0,153***	-0,118***	-0,098***	-0,116***	-0,094***
NSP	-0,021*	0,0001	-0,0215*	-0,01	-0,075***	-0,042	-0,077***	-0,066***	-0,076***	-0,068	-0,075***	-0,058***
<b>Level of education</b>												
No education	REF											
Primary school	-0,034	-0,016	-0,034	-0,022	-0,064	-0,04	-0,064	-0,054	0,087	0,096*	0,085	0,089*
College	-0,054*	-0,04	-0,054*	-0,043	-0,102*	-0,081	-0,101*	-0,093	0,071	0,078	0,071	0,076
Higher secondary	-0,0691**	-0,053	-0,069**	-0,058	-0,133**	-0,108*	-0,133**	-0,128**	0,082	0,09*	0,079	0,081

Post-secondary	-0,114***	-0,096***	-0,114***	-0,103***	-0,192***	-0,165**	-0,195***	-0,19***	0,01	0,022	0,005	0,01
Education in progress	-0,054	-0,005	-0,056	-0,045	-0,149*	-0,098	-0,154*	-0,145*	0,038	0,068	0,032	0,043
Others	-0,072	-0,067	-0,072	0,084	-0,274**	-0,238**	-0,286***	-0,281***	-0,122	-0,822	-0,139	-0,107
<b>Occupational status</b>												
Farmers	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF
Self-employed	-0,008	-0,001	-0,01	-0,012	-0,038	-0,031	-0,041	-0,044	0,05	0,044	0,446	0,032
Skilled white collar occupations	0,026	0,032	0,025	0,022	-0,007	0,001	-0,009	-0,01	0,092**	0,086**	0,089**	0,078**
Intermediate profession	0,009	0,0198	0,007	0,003	0,007	0,018	0,003	-0,002	0,096***	0,093***	0,089**	0,072**
Clerical employees	0,022	0,028	0,021	0,016	0,0403	0,043	0,036	0,03	0,086**	0,078**	0,079**	0,062*
Trade and craft employees	0,047**	0,047 **	0,047**	0,042**	0,045	0,039	0,044	0,038	0,074**	0,063**	0,07*	0,054*
Skilled manual workers	0,014	0,019	0,012	0,008	0,014	0,021	0,014	0,001	0,089**	0,083**	0,08**	0,061**
Unskilled manual workers	0,0348	0,028	0,034	0,025	0,053	0,043	0,049	0,382	0,092**	0,079**	0,086**	0,064**
Inactive	0,067**	0,044*	0,068**	0,069**	0,072*	0,046	0,079*	0,077*	0,078*	0,053	0,085*	0,075*
<b>Household type</b>												
Single person	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF	REF
Single parent family	0,012	-0,007	0,014	0,018	0,019	0,001	0,027	0,033	0,016	0,004	0,026	0,033
Couple without children	0,001	0,001	0,001	0,01	0,015	0,02	0,018	0,026	-0,044***	-0,042**	-0,039***	-0,027

Couple with children	-0,03**	-0,023*	-0,03**	-0,021*	-0,035**	-0,029*	-0,032*	0,022	-0,061***	-0,057**	-0,054***	-0,038**
Other	-0,025	-0,026	-0,024	-0,021	-0,014	-0,017	-0,012	-0,007	-0,074	-0,011	-0,0001	0,001

\*\*\*:  $p \leq 1\%$ , \*\*:  $p \leq 5\%$ , \*:  $p \leq 10\%$

Exclusion restriction: Mean temperature per French department						
	Long-standing disease		Poor self-assessed health		Poor mental health score	
Fuel poverty for mould/moisture presence in the dwelling	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0,326***	-0,80***	0,335***	-0,511*	0,024	-0,304
No	REF	REF	REF	REF	REF	REF
Fuel poverty for budgetary reasons	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0,335***	-0,68***	0,379**	-0,368	0,572***	-0,695***
No	REF	REF	REF	REF	REF	REF

Exclusion restriction: Mean number of frost days per French department						
	Long-standing disease		Poor self-assessed health		Poor mental health score	
Fuel poverty for mould/moisture presence in the dwelling	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0,327***	-0,665***	0,3257***	-0,4878*	0,234	-0,282
No	REF	REF	REF	REF	REF	REF
Fuel poverty for budgetary reasons	Marginal effect	Rho	Marginal effect	Rho	Marginal effect	Rho
Yes	0,355***	-0,734***	0,399***	-0,419*	0,567***	-0,705***
No	REF	REF	REF	REF	REF	REF

### i) Appendix 9:

Min	Max	Average	Median
7.4°C	15.6°C	11.25°C	10.8°C

### j) Appendix 10:

	Exclusion restriction Owner/tenant (REF)	Exclusion restriction Dwelling type: house/apartment (REF)
	Marginal Effect	Marginal Effect
<b>Fuel poverty for budgetary reasons</b>	0.005	-0.013**
<b>Fuel poverty for mould/moisture presence in the dwelling</b>	0.1***	0.05***
<b>Long-standing disease</b>	0.045***	0.023**
<b>Poor self-assessed health</b>	0.042**	0.038**
<b>Poor mental health score</b>	0.032**	0.022

### k) Appendix 11: Proof of proposition 1

For the composite good:

$$\Delta x_t(\delta) := x_{0,p}^* - x_{0,m}^* = \left( \frac{1}{1 + \alpha\delta + (1 + \alpha) \sum_{s=1}^T \beta^s} - \frac{1}{(1 + \alpha\delta) \sum_{s=0}^T \beta^s} \right) \frac{\alpha\delta w_0}{p_x} \beta^t.$$

For energy, the difference between the two optimal values in the first period is:

$$\Delta e_0(\delta) := e_{0,p}^* - e_{0,m}^* = \left( \frac{1}{1 + \alpha\delta + (1 + \alpha) \sum_{s=1}^T \beta^s} - \frac{1}{(1 + \alpha\delta) \sum_{s=0}^T \beta^s} \right) \frac{w_0}{p_e} \alpha\delta.$$

For the other periods, the difference is:

$$\Delta e_t(\delta) := e_{t,p}^* - e_{t,m}^* = \left( \frac{1}{1 + \alpha\delta + (1 + \alpha) \sum_{s=1}^T \beta^s} - \frac{\delta}{(1 + \alpha\delta) \sum_{s=0}^T \beta^s} \right) \frac{w_0}{p_e} \alpha \beta^t.$$

Let's study the sign of  $\Delta x_t(\delta)$  and  $\Delta e_0(\delta)$  (they have the same sign). After reduction to the same denominator, we find that

$$\Delta x_t(\delta) > 0 \Leftrightarrow \Delta e_0(\delta) > 0 \Leftrightarrow$$

$$(1 + \alpha\delta) \left( \sum_{s=0}^T \beta^s \right) - \left( (1 + \alpha\delta + (1 + \alpha) \sum_{s=1}^T \beta^s) \right) > 0 \Leftrightarrow (\delta - 1) \alpha \sum_{s=1}^T \beta^s > 0$$

We have  $\Delta e_0(\delta) > 0$  iff  $\delta > 1$ . Note that this is the same condition as for  $\Delta x_t(\delta)$ .

Let study the sign of  $\Delta e_t(\delta)$ .

$$\Delta e_t(\delta) > 0 \Leftrightarrow (1 + \alpha\delta) \left( \sum_{s=0}^T \beta^s \right) - \delta \left( (1 + \alpha\delta + (1 + \alpha) \sum_{s=0}^T \beta^s) \right) > 0$$

The left-hand side has two roots:  $\delta > 1$  and  $\delta = -\frac{1-\beta^{T+1}}{\alpha(1-\beta)} < 0$ . This implies that  $\Delta e_t(\delta) > 0$  iff  $\delta < 1$ .

## I) Appendix 12: Proof of proposition 3

We have  $\delta_3 > \delta_2$ . In addition,  $\delta_2$  increases with respect to  $T$  since

$$\frac{\partial \delta_2}{\partial T} = -\frac{(1+\alpha)\beta^{T+1}\ln(\beta)}{\alpha^2(1-\beta)} > 0$$

Hence, by taking the value for  $T = 1$ , we find that  $\delta_2 \geq \frac{1+\beta+\alpha\beta}{\alpha^2}$ . We can find a simple lower bound by taking  $\beta = 0$ :

$$\delta_2 \geq \frac{1}{\alpha^2}$$

## Résumé

La thématique de la précarité énergétique suscite un intérêt grandissant de la sphère économique, politique et sociale. Cette thèse en sciences économiques porte sur la représentation et l'analyse des interactions de trois postes fondamentaux dans les dépenses contraintes des ménages à savoir la santé, le logement, et l'énergie afin de faire apparaître des leviers pertinents pour la mise en place d'action de lutte contre la précarité énergétique. Celle-ci propose une analyse théorique et analytique originale, en abordant d'une part ce phénomène en termes d'équité permettant de mettre en exergue l'existence d'inégalités, justifiant ainsi la mise en place de mesures complémentaires, voire nouvelles, en faveur d'une plus grande équité entre individus concernant le bien énergie. D'autre part, la caractérisation de la dynamique de ce phénomène dispense de précieuses informations sur le type de mesures (i.e., aides au paiement de factures, modes de paiement de facture innovants, aides à la rénovation du logement) pouvant être mises en place pour contrecarrer ce phénomène, et ainsi participer à la poursuite des objectifs d'équité sous-jacents. Ensuite, l'analyse des conséquences de la précarité énergétique sur d'autres dimensions que celles faisant référence à l'énergie (i.e., santé) permet d'interpeller les décideurs politiques sur son aspect multidimensionnel et poreux avec d'autres dimensions de la précarité sociale. Ce phénomène est être un vecteur concourant à l'aggravation d'autres inégalités (i.e., inégalités de santé), pouvant ainsi compromettre la poursuite de l'objectif d'équité des décideurs publics. Enfin, l'étude de nouveaux moyens de paiement innovants du bien énergie (i.e., prépaiement), à moindres coûts, permet d'identifier le prépaiement comme un outil pouvant contribuer à l'atteinte des objectifs respectivement d'équité horizontale et verticale.

## Mots Clés

Précarité énergétique  
Energie  
Équité  
Inégalité  
Dynamique  
Santé  
Prépaiement

## Abstract

The topic of fuel poverty has generated an increasing interest in the economic, political and social spheres. This economics thesis examines the measurement and analysis of the interactions between three fundamental indicators of forced household expenses in terms of health, housing, and energy to identify the relevant factors needed for the implementation of actions that address and prevent fuel poverty. This paper presents an original theoretical and analytical study that investigates this phenomenon first in terms of equity, highlighting the existence of disparities and justifying the implementation of additional potentially new measures that promote greater equity in the allocation of energy among individuals. Furthermore, the study characterizes the dynamics of this phenomenon, providing invaluable information on the types of measures (e.g., social tariffs for energy, innovative models of payment for energy, housing renovation assistance) that could be implemented to prevent fuel poverty and thus address the underlying objectives of equity. The thesis then presents an analysis of the consequences of energy vulnerability on dimensions other than those directly referring to energy (i.e., health), raising political decision-makers' awareness of the multidimensional and broad effects of fuel poverty on other dimensions of social vulnerability. Fuel poverty is a factor that contributes to the worsening of other disparities (i.e., health disparities), compromising public decision-makers' pursuit of the objective of equity. Finally, the analysis of new innovative methods of payment that provide energy (i.e., prepayment) with fewer costs indicated that prepayment is a tool that could contribute to the respective goals of horizontal and vertical equity.

## Keywords

Fuel poverty  
Energy  
Equity  
Inequality  
Dynamic  
Health  
Prepayment