Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

Schlussbericht 27. Februar 2016

Energy Elasticities and the Rebound Effect: A Comprehensive Empirical Analysis

UNI
BASEL

Auftraggeber:
Bundesamt für Energie BFE
Forschungsprogramm Energie-Wirtschaft-Gesellschaft
CH-3003 Bern
www.bfe.admin.ch

Auftragnehmer:
Wirtschaftswissenschaftliche Fakultät
Universität Basel
Peter Merian-Weg 6
Postfach
CH-4002 Basel
www.wwz.unibas.ch

Autoren:
Lukas Mohler, Wirtschaftswissenschaftliche Fakultät (WWZ) der Universität Basel,
Sebastian Deininger, Wirtschaftswissenschaftliche Fakultät (WWZ) der Universität Basel
Daniel Müller, Wirtschaftswissenschaftliche Fakultät (WWZ) der Universität Basel

BFE-Bereichs- und Programmleiterin: Anne-Kathrin Faust
BFE-Projektbetreuer: Boris Krey
BFE-Vertrags- und Projektnummer: SI/500616-02 / SI/500616

Abstrakt

In diesem Forschungsprojekt werden aktuelle Preis- und Einkommenselastizitäten für Energie und andere Produktionsfaktoren bzw. Konsumgütergruppen in der Schweiz geschätzt. Im Weiteren wird der Rebound-Effekt für den privaten Transport untersucht. Im ersten Teil werden auf Grundlage eines Schweizer Unternehmensdatensatzes Substitutionselastizitäten zwischen den Produktionsfaktoren Energie, Kapital, Arbeit und Material für Unternehmen mit tiefer, mittlerer und hoher Energieintensität berechnet. Unsere Resultate zeigen auf, dass energieextensive Unternehmen Energie nach einer Preiserhöhung durch alle anderen Produktionsfaktoren substituieren können. Jedoch zeigen unsere Schätzungen auf, dass bei energieintensiven Unternehmen die Produktionsfaktoren Energie und Kapital Komplemente und nicht Substitute darstellen. Dies ist ein Hinweis darauf, dass energieintensive Unternehmen grössere Anpassungsschwierigkeiten haben als energieextensive Unternehmen bei steigenden Energiepreisen. Im zweiten Kapitel werden Einkommens- und Kreuzpreiselastizitäten zwischen einzelnen Konsumgütergruppen von Schweizer Haushalten geschätzt. Die Eigenpreiselastizitäten zeigen beispielsweise auf, dass Transportleistungen unelastisch sind, der Energiekonsum hingegen einheitselastisch. Weiter decken wir verschiedene Muster der Substituierbarkeit zwischen den verschiedenen Konsumgütern auf. Die Einkommenselastizitäten weisen schliesslich Energie als Bedarfsgut aus, Transport hingegen besitzt eine Einkommenselastizität nahe eins. Die zudem berechneten Engel-Kurven sind für den Energiekonsum strikt fallend, hingegen sind sie für den privaten Transport S-förmig. Im dritten Teil werden Rebound-Effekte für den privaten Transport in der Schweiz berechnet. Dabei werden zwei Methoden verwendet, wobei die erste eher einen kurzfristigen und die zweite eher einen langfristigen Rebound-Effekt schätzt. Der Rebound-Effekt für den privaten Verkehr in der Schweiz, basierend auf der ersten Methode, liegt bei rund 20%. Die zweite Methode lieferte einen ungleich grösseren Effekt von rund 60%. Die Schätzung des Rebound-Effekts für verschiedene Haushaltsgruppen deckt grosse Unterschiede zwischen diesen Gruppen auf: Die Resultate zeigen beispielsweise, dass der Rebound-Effekt bei ärmeren und älteren Haushalten grösser ausfällt. Weiter ist der Rebound-Effekt kleiner, wenn der Freizeitverkehr betroffen ist und nicht die Fahrt zur Arbeit.

Zusammenfassung

Im Auftrag des Bundesamts für Energie (BFE) schätzen wir in diesem Projekt Preis- und Einkommenselastizitäten für Schweizer Haushalte und Unternehmen. Dieser Bericht besteht aus drei eigenständigen Kapiteln: In Kapitel 1 werden Substitutionselastizitäten zwischen Produktionsfaktoren von Schweizer Unternehmen geschätzt. In Kapitel 2 schätzen wir Preis- und Einkommenselastizitäten von verschiedenen Konsumgüterkategorien von Schweizer Haushalten. In Kapitel 3 werden Rebound-Effekte für den privaten Transport in der Schweiz berechnet.

Kapitel 1: Factor Substitution Elasticities in Swiss Manufacturing

Schätzungen von Substitutionselastizitäten zwischen den Produktionsfaktoren Kapital, Arbeit, Energie und Material basieren für die Schweiz auf aggregierten Branchendaten und sind zudem bereits älteren Datums. Ziel dieses Kapitels ist es, diese Lücke zu schliessen und mit einem aktuellen und detaillierten Unternehmensdatensatz Substitutionselastizitäten zwischen den vier Produktionsfaktoren Energie, Kapital, Arbeit und Materialeinsatz zu schätzen.

Die geschätzten ökonomischen Elastizitäten zeigen auf, wie sich die Mengen von Produktionsfaktoren aufgrund von Änderungen der Faktorpreise anpassen. So erhält man wichtige Informationen darüber, wie sich Unternehmen im Falle von Faktorpreisveränderungen verhalten. Das Hauptaugenmerk dieses Projektes liegt auf dem Faktor Energie. Insbesondere liegt das Interesse darin, wie Unternehmen auf eine Erhöhung der Energiepreise reagieren und wie sie den teurer gewordenen Faktor Energie durch die anderen Produktionsfaktoren ersetzen.

Aufgrund einer Linear Logit-Kostenfunktion und mittels Seemingly Unrelated Regression-Ansatz (SUR) werden Eigenpreiselastizitäten, Kreuzpreiselastizitäten und Morishima-Elastizitäten geschätzt. Die ersten beiden Elastizitätentypen geben an, wie sich die Menge eines Produktionsfaktors aufgrund einer Faktorpreisveränderung ändert. Morishima-Elastizitäten drücken hingegen aus, wie sich das Mengenverhältnis zweier Faktoren aufgrund der Preisänderung eines bestimmten Faktors verändert.

Bei der Schätzung unterscheiden wir zwischen Unternehmen mit tiefer, mittlerer und hoher Energieintensität und weisen Elastizitäten für diese drei Gruppen aus. Unsere Resultate zeigen einerseits auf, dass energieextensive Unternehmen sowie Unternehmen mit einer mittleren Energieintensität, Energie nach einer Energiepreiserhöhung durch alle anderen Produktionsfaktoren substituieren, um die Produktionsmenge konstant zu halten. So produzieren die Unternehmen dieser beiden Gruppen nach einer Erhöhung der Energiepreise beispielsweise kapitalintensiver als zuvor. Im Gegensatz dazu zeigen die Resultate bei den energieintensiven Firmen auf, dass die Produktionsfaktoren Energie und Kapital Komplemente und nicht

Substitute sind: In diesem Fall führt eine Preiserhöhung von Energie nicht nur zu einer Abnahme vom Energieverbrauch, sondern auch zu einer Abnahme des eingesetzten Kapitals. Diese Unternehmen produzieren nach einer Energiepreiserhöhung also weniger kapitalintensiv, dafür aber viel materialintensiver. Dies kann ein Hinweis darauf sein, dass die energieintensiven Unternehmen grössere Probleme bei der Substitution von Energie haben als weniger energieintensive Unternehmen. Eine Komplementarität zwischen den beiden Produktionsfaktoren Energie und Kapital führt so in der Regel und im Vergleich zur Substituierbarkeit zu höheren Kosten für die Unternehmen bei einer Energiepreiserhöhung.

Kapitel 2: Price and Income Elasticities of Swiss Households

Kapitel 2 beschäftigt sich mit dem Konsumverhalten von Schweizer Haushalten. Insbesondere sind wir daran interessiert, wie Preis- und Einkommenseffekte die Nachfrage nach einzelnen Konsumgütergruppen beeinflussen. Flexible Nachfragemodelle, die das Konsumverhalten von Schweizer Haushalten abbilden, wurden bisher nur für einzelne Teilbereiche wie zum Beispiel Nahrungsmittel und Getränke oder für einzelne Energiequellen geschätzt. Solche partiellen Schätzmodelle haben den Nachteil, dass sie Effekte auf den Konsum anderer Gütergruppen nicht berücksichtigten. Unser Vorgehen stellt aus dieser Sicht einen ganzheitlichen Ansatz dar.

Die theoretische Grundlage unserer Untersuchung bildet das Exact Affine Stone Index (EASI)-Nachfragemodell. Dieses Modell ist besonders flexibel und erlaubt es, beliebige, nichtlineare Engel-Kurven, welche die Nachfrage nach einem Gut in Abhängigkeit des Einkommens abbilden, zu schätzen. Neben den Engel-Kurven werden in diesem Kapitel Substitutions- und Einkommenselastizitäten der einzelnen Konsumgütergruppen berechnet. Die Schätzung basiert einerseits auf gepoolten Haushaltsdaten und andererseits als Kontrollspezifikation auf einem Pseudo Panel-Regressionsmodell auf Basis von Individualdaten.

Unser Interesse bei der Analyse der Resultate gilt besonders den Elastizitäten und Engel-Kurven vom Energieverbrauch und den privaten Transportausgaben der Haushalte: Der Konsum von Transportleistungen wird als inelastisch geschätzt, der Energiekonsum ist ungefähr einheitselastisch. Während die meisten anderen Konsumgruppen ebenfalls in der Nähe der Einheitselastizität stehen, finden sich auch preiselastische Kategorien, nämlich „Auswärts Essen“ und „Freizeit“. Die geschätzten Kreuzpreiselastizitäten zeigen ebenfalls einige interessante Muster auf, beispielsweise ist „Privater Transport“ ein Komplement zu „Wohnen“, „Bekleidung“ und „Zu Hause Essen“, jedoch ein Substitut für „Auswärts Essen“ und „Möbel“.

Die geschätzten Einkommenselastizitäten zeigen auf, dass „Zu Hause Essen“, „Bekleidung“, „Energie“, „Wohnen“ und „Kommunikation“ Bedarfsgüter sind mit Einkommenselastizitäten zwischen 0 und 1. Hingegen sind „Auswärts Essen“, „Freizeit“ und „Möbel“ Luxusgüter mit grösseren Einkommenselastizitäten. Privater Transport ist demgegenüber einheitselastisch.

Schliesslich zeigen wir anhand der Engel-Kurven, wie sich die Nachfrage nach einem Gut als Funktion des Einkommens ändert: Während die Engelkurve von „Energie“ streng monoton fallend ist, nimmt die Engel-Kurve vom „Privaten Transport“ eine S-Form an. Das Modell ermöglicht auch einen Vergleich der Engel-Kurven für verschiedene Haushaltstypen: Beispielsweise zeigen wir die unterschiedlichen Kurven für den Energiekonsum zwischen Hausbesitzern und Mietern auf. Insgesamt lässt sich zudem festhalten, dass die Schätzresultate aus dem gepoolten Regressionsmodell und dem Pseudo Panel zu ähnlichen Ergebnissen führen. Dies ist ein Hinweis auf die Robustheit unserer Schätzmodelle.

Kapitel 3: The Direct Rebound Effect of Private Transportation in Switzerland

In Kapitel 3 werden Rebound-Effekte für den privaten Verkehr in der Schweiz geschätzt. Ein Rebound-Effekt führt dazu, dass sich der Energieverbrauch nach der Steigerung der technischen Effizienz einer Leistung weniger stark senkt als aus technischer Sicht erwartet: Der Grund dafür ist, dass Effizienzsteigerungen erstens den relativen Preis von Produkten oder Dienstleistungen senken und zweitens die realen Einkommen erhöhen. Dies führt zu einer grösseren Nachfrage nach dem betreffenden Produkt oder der betreffenden Leistung und so zu einer Reduktion der Energieeinsparung.

Diese Rebound-Effekte sind für die Energie- und Klimapolitik der Schweiz von Bedeutung, denn die Höhe dieser Effekte bestimmen beispielsweise die Bewertung von effizienzsteigernden politischen Massnahmen oder die Prognosen des zukünftigen Energieverbrauchs oder CO2-Ausstoss in der Schweiz.

Die exakte Grösse des Rebound-Effektes hängt von vielen Faktoren ab. Auch davon, welcher methodische Ansatz bei der Schätzung des Rebound-Effektes verwendet wird. In diesem Kapitel verwenden wir zwei verbreitete empirischer Ansätze, um die Grösse des Rebound-Effekts des privaten Verkehrs in der Schweiz zu bestimmen.

Unter dem ersten methodischen Ansatz werden die Rebound-Effekte aus den Eigenpreiselastizitäten aus Kapitel 2 berechnet. Der grosse Vorteil dieser Methode ist, dass nur Preis- und Mengenangaben benötigt werden und die Grösse direkt aus bestehenden Studien, die Preiselastizitäten von Produkten oder Dienstleistungen berechnet haben, abgeleitet werden kann. Der wichtigste Nachteil dieses Ansatzes ist, dass Preisveränderungen nicht immer die gleiche Wirkung haben, wie eine Effizienzsteigerung. Somit kann Grösse des Rebound-Effektes bei dieser Methode verzerrt geschätzt werden.

Unter dem zweiten methodischen Ansatz wird anhand von möglichst detaillierten Informationen über die tatsächlichen Effizienzsteigerungen die Nachfrageentwicklung aufgrund dieser Effizienzsteigerung gemessen. Diese Schätzmethode ist genauer, setzt aber eine entsprechende Datenbasis voraus.

Wir vergleichen die Resultate dieser beiden Ansätze und zeigen auch Ergebnisse für verschiedenen Haushaltstypen auf: Der Rebound-Effekt für den privaten Verkehr in der Schweiz, geschätzt mit der ersten Methode, liegt bei rund 20%. Die zweite Methode lieferte einen ungleich grösseren Effekt von rund 60%. Der grosse Unterschied zwischen diesen beiden Ergebnissen kann dadurch erklärt werden, dass der erste Ansatz eher einen kurz- bis mittelfristigen Rebound-Effekt misst, da er auf entsprechenden kurz- bis mittelfristigen Elastizitäten beruht. Hingegen basiert der zweite Ansatz auf einer Schätzung mit Querschnittsdaten und ist somit eher als langfristiger Rebound-Effekt zu interpretieren.

Die Schätzung des Rebound-Effekts für verschiedene Haushaltsgruppen deckt grosse Unterschiede zwischen diesen Gruppen auf: Die Resultate zeigen beispielsweise, dass der Rebound-Effekt bei Haushalten mit tieferen Einkommen und älteren Personen grösser ausfällt. Weiter ist der Rebound-Effekt kleiner, wenn der Freizeitverkehr betroffen ist und nicht die Fahrt zur Arbeit.

Contents

Chapter 1: Factor Substitution Elasticities in Swiss Manufacturing

Tables in Chapter 1

Figures in Chapter 1

Chapter 2: Price and Income Elasticities of Swiss Households

Tables in Chapter 2

Figures in Chapter 2

Chapter 3: The Direct Rebound Effect of Private Transportation in Switzerland

Tables in Chapter 3

Figures in Chapter 3

Chapter 1: Factor Substitution Elasticities in Swiss Manufacturing

1 Introduction

Over the last two decades, several national governments have revised their environmental and energy policy strategies. European countries such as Germany, the United Kingdom and Denmark have undertaken major environmental tax reforms to comply with their GHG emission reduction goals and to foster the transition from fossil fuels to renewable energy.[1] Standard policy measures are taxes on GHG emissions and energy use, accompanied by tighter environmental standards and efforts to improve energy efficiency in production, in buildings and in the transport sector. While such measures are effective in reducing emissions, they potentially increase energy prices and affect the production costs of firms and households' expenses. Policymakers are confronted with the challenge to achieve their environmental targets without negatively affecting the overall economy and the competitiveness of particular production sectors.

The Swiss government has decided to phase out nuclear power and to reduce GHG emissions by 20% compared with 1990 levels by 2020 (CO_2 Act). The government's Energy Strategy 2050 sets out the envisioned path of the energy transition in Switzerland. In 2008, a carbon tax was introduced at CHF 60 per metric tonne of CO_2. The tax was raised to CHF 84 in 2016 and a further increase is possible in 2018 if emissions are above target. Large emitters are exempted from the carbon tax and instead participate in a cap and trade system. Moreover, medium size companies can also be exempted from the tax provided they commit to legally binding CO_2 reduction goals. Similar exemptions or tax reductions for emitters such as energy-intensive companies exist in almost all countries. To evaluate the economic impact of such policies, a better understanding of substitution possibilities at the level of individual firms is needed. An important question is whether there are differences in the degree of substitutability between energy-intensive firms and energy-extensive firms, since a lower degree of factor substitution for energy-intensive firms might justify exemptions from carbon taxes.

In this study, we analyze the relationship between factor substitutability and the energy intensity of Swiss manufacturing firms.[2] Our panel dataset comprises about 7,400 observations on the firm-level from 1997 to 2008. It provides detailed information about output,

---

[1] For an in-depth analysis of environmental tax reforms in Europe, see Ekins and Speck (2011) and Patuelli et al. (2005).

[2] Elasticity estimates based on firm-level data do not exist for Swiss manufacturing firms. For Switzerland, substitution elasticities have been estimated on a sectoral level (Mohler and Mueller, 2012).

labor, energy and material, as well as firm-specific characteristics such as the number of employees and the stock of capital. This dataset, combined with price indices for the relevant factors, allows the estimation of firm-specific substitution elasticities by making use of the linear logit (LL) function. Additionally, we provide elasticity estimates based on the translog (TL) function.

Our work is related to existing studies estimating substitution elasticities using firm-level data. Woodland (1993) is the first study to use micro data to analyze substitution between capital, labor and four energy types in Australia. Nguyen and Streitwieser (1999) examine whether plant size in U.S. manufacturing has an impact on the degree of factor substitution. Arnberg and Bjorner (2007) apply cross-section and panel data techniques to a dataset of Danish firms. Finally, Tamminen and Tuomaala (2012) estimate substitution elasticities for 71 different sectors employing a large panel of service and manufacturing companies from Finland. Similar to the last two studies, we employ a panel of manufacturing firms and estimate substitution elasticities, controlling for time-invariant unobserved heterogeneity. However, our focus is on the relationship between factor substitutability and the energy intensity of manufacturing firms.

A descriptive analysis of our data reveals that the energy share of total production costs is typically low for Swiss manufacturing firms, with a median cost share of 1.4% and a mean cost share of 2.0%. However, there is substantial heterogeneity of the energy cost shares of different firms, even within the same industry.[3] Hence, to compare the degree of substitutability between different energy intensities, we classify firms into three categories: low, medium and high energy use. We measure substitutability of factors using both cross-price elasticities as well as Morishima elasticities of substitution.

Our first finding is that substantial differences exist in *firms' substitution possibilities* when we contrast the substitution elasticities of firms with different levels of energy intensity. We find evidence for substitutability between energy and all the other input factors for firms with low and medium energy use, implying that upon an energy price increase, factor shares of labor, capital and material increase to optimally compensate for the decreasing energy share in the production process. In contrast, capital and energy are estimated to be complements for the firms in the energy-intensive subset. As a consequence of this complementarity between energy and capital, these energy-intensive firms substitute the decreasing shares of energy and capital upon an energy price increase with higher shares of material and, to a lesser extent, labor in their production process. In conclusion and due to this complementarity, energy-intensive firms may have greater difficulty in adjusting to potential energy price increases.

Our second finding is that even small energy price changes affect the *energy intensity of firms' production*: If energy prices increase, firms of all three energy-intensity categories

---

[3] E.g. in Sector 1 (Food products, beverages and tobacco products), energy cost shares in the 5 and 95 percentile span from 2.8 to 11.3 percent (c.f. Table 5 in Appendix F), respectively.

produce less energy-intensively relative to every other input factor regarding the *factor quantities* of input factors. While this is a result that is also prevalent in similar analyses for other countries—it occurs when the own-price elasticity of energy is large enough—we also find some evidence that despite the price increase of energy, the *expenditure share* of energy is decreasing as well. Hence, the energy use of Swiss firms is generally responsive to price changes, and policy measures that increase the price of energy will lead to less energy intensive production processes.

The remainder of the paper is organized as follows: Section 2 gives a brief overview and discussion of previous micro data studies in the field of factor substitution. After introducing the modeling approach and the methodological procedure in Section 3 and Section 4, empirical evidence is provided in Section 5. The paper closes with the conclusions in Section 6.

2 Related Literature

Research on substitution possibilities between energy and other production factors emerged after the first oil crises in the 1970s. Earlier studies predominantly estimated substitution elasticities using time-series or cross-section data for specific industrial sectors or aggregate manufacturing. Enhanced data availability as well as more sophisticated estimation methods have increased the interest in micro data studies. The empirical literature has shown that elasticity estimates vary substantially and depend on the level of sector aggregation, the geographical region, the time period, and the applied model specification (Koetse et al., 2008).

The majority of studies find that production factors are substitutes in the production process. However, there is an ongoing controversy whether the factors energy and capital are substitutes or complements. Cross-section studies tend to predict substitutability, while time-series studies are more in favor of complementarity (Apostolakis, 1990). It is argued that the former measure long-run elasticities, whereas time series capture short-run effects. This would imply that capital and energy are complements in the short-run and substitutes in the long-run. More recently, similar patterns have been observed between cross-section studies and panel studies based on micro panel data (Arnberg and Bjorner, 2007). In contrast, Arnberg and Bjorner (2007) argue that endogeneity problems with labor and energy prices might cause the discrepancy. Thompson and Taylor (1995) show that this gap vanishes if one considers Morishima elasticities (MES) instead of cross-price elasticities. The factors capital and energy are usually MES-substitutes.

A general problem of studies using aggregated industry data is the difficulty to distinguish between factor substitution and concurrent effects. For instance, Solow (1987) demonstrates convincingly that compositional changes in output can lead to incorrect substitution estimates in aggregated studies. He concludes that "[f]actor substitution is a microeconomic phenomenon, and is best examined by looking at microeconomic data" (p.612). However, only a few micro data studies exist which estimate factor substitution between energy and non-energy factors. The main reason is that energy expenses are rarely available for individual firms. Below, we summarize the results of previous micro data studies in the field of factor substitution.

The first micro data study on substitution between energy and non-energy factors was conducted by Woodland (1993). He used repeated cross-sectional data of approximately 10,000 manufacturing firms in New South Wales, Australia covering the period from 1977 to 1985. Woodland focused on different types of fuels (coal, oil, gas and electricity) as well as labor and capital. He found that the demand for energy fuels is price-elastic (with the exception of coal), whereas the demand for capital and labor is price-inelastic. Moreover, he shows that substitution between fuels and the non-energy factors appears to be much stronger than substitution between different types of fuels.

Nguyen and Streitwieser (1999) investigate whether differences exist in factor substitution between small and large production firms. They use cross-sectional data comprising 10,412 U.S. industrial companies in 1991 to estimate the standard KLEM model using the translog specification. Nguyen and Streitwieser find that the demand of all four factors is price-elastic, with energy having the highest value and capital the lowest. Furthermore, when considering the Allen-Uzawa elasticity of substitution (AES) and the cross-price elasticity (CPE) as a measure of substitution, they find that the factors capital and energy are either substitutes or complements depending on the size of employment. When using the Morishima elasticity of substitution (MES), all factors become substitutes.

Arnberg and Bjorner (2007) apply cross-section and panel data techniques, respectively, to a dataset of 903 Danish industrial firms for 1993 and the period from 1995 to 1997. They estimate substitution elasticities between the factors electricity, other energy, labor and machine capital using the translog and the linear logit specification. Their main finding is that, in the fixed-effects model, electricity and capital as well as other energy and capital are complements, whereas they are substitutes in the cross-section model. They point out that the results of the cross-section model might suffer from biased estimates due to endogeneity problems with the price of labor and energy. They argue that firm fixed-effects can control for unobservable quality differences of employees as well as for differences of energy fuels. Similar to other studies, Arnberg and Bjorner find lower values for interfuel substitution elasticities than for the elasticities between energy and non-energy factors.

Finally, Tamminen and Tuomaala (2012) employ panel data from 2000 to 2009 comprising 230,000 manufacturing and service companies operating in Finland. They estimate substitution elasticities for the factors labor, capital, outside services, electricity and other energy forms for 71 sectors. Their results show that the factors labor and capital are relatively price-inelastic. In contrast, material and energy inputs are price-sensitive. Due to the fact that energy expenses were only available for a subset of companies (the energy-intensive ones), energy elasticities could not be estimated for all sectors. As substitution elasticities significantly differ across the 71 sectors, they recommend using sector-specific estimates in computational general equilibrium models.

3 Modeling Approach

The translog (TL) function introduced by Christensen et al. (1973) is the preferred production function used in the literature because of its functional flexibility and the relatively low data requirements. While the majority of empirical studies make use of the TL function, more recent work also considers the linear logit (LL) function as developed in Considine and Mount (1984) as a functional specification. While the LL function is as flexible as the TL function, it has the advantage that it is well-behaved for a broader range of factor prices and shares. The LL model is especially suitable if some cost shares are very small (Considine, 1989) and if there is relatively large variation between firms in the cost shares (Arnberg and Bjorner, 2007). For these reasons, we rely on estimates gained from the LL model in our analysis of the substitution possibilities of Swiss manufacturing firms. The results from a TL specification can be found in Appendix A and will serve as a reference.[4]

3.1 The Linear Logit Function

We use the logistic production function with the factors capital (K), labor (L), energy (E) and material (M) to represent the production function of firms, developed in Considine and Mount (1984). In the linear logit model, the factor shares can be represented as

$$s_{in,t} = \frac{\exp(\beta_{in} + \sum_{j} \beta_{ijn} \cdot \ln(p_{jn,t}) + \beta_{iny} \cdot \ln y_{n,t})}{\sum_{i} \exp(\beta_{in} + \sum_{j} \beta_{ijn} \cdot \ln(p_{jn,t}) + \beta_{iny} \cdot \ln y_{n,t})}, \tag{1}$$

where i and j stand for the respective input factors (K,L,E,M), y denotes the output of firm n, and t is a time index. To estimate the linear logit model, we linearize it and directly impose the homogeneity and the symmetry restriction. We have to drop one share equation to obtain a non-singular system. This is done by dividing each share equation by the material share equation and by taking the logarithm. By dividing by the material share equation, the denominator in Equation 1 cancels out and the logarithm linearizes the functional form.

Following the procedure of Arnberg and Bjorner (2007), we transform the share equations in such a way that the restrictions can be imposed directly into our system of equa-

---

[4] Another possibility would be to employ the Generalized Leontief (GL) cost function, proposed by Diewert (1971). We refrain from doing so, because Tovar and Iglesias (2013) show in their study that the TL cost function has a better fit than the GL cost function.

tions. We define $\beta^*_{ijn} = \beta_{ijn}/m_{in}$, where m_{in} is the mean cost share of input factor i. Then the linearized form can be written as follows:

$$\begin{aligned}
\ln\left(\frac{s_{in,t}}{s_{\mathrm{M}n,t}}\right) &= \beta^*_{in} + \sum_j \alpha_{ijn} \cdot m_{jn} \cdot \ln\left(\frac{p_{jn,t}}{p_{\mathrm{M}n,t}}\right) + \beta^*_{iny} \cdot \ln y_{n,t}, \qquad (2)\\
\text{where } \beta^*_{in} &\equiv \beta_{in} - \beta_{\mathrm{M}n},\ \alpha_{ijn} \equiv \beta^*_{ijn} - \beta^*_{\mathrm{M}jn} \text{ and } \beta^*_{iny} \equiv \beta_{iny} - \beta_{\mathrm{M}ny},
\end{aligned}$$

for i and $j = \{\mathrm{K,L,E}\}$. To derive the elasticities, we first have to impose the symmetry and homogeneity restrictions and subsequently estimate the system of share equations (Equation 2). The symmetry restriction implies that $\beta^*_{ji} = \beta^*_{ij}$. The second important property of producer theory is that the production function is homogeneous of degree zero in prices. Therefore, the homogeneity restriction implies that $\beta^*_{ii} = -\sum_j^{j\neq i} s_j \cdot \beta^*_{ij}/s_i$. Applying the proposed normalization from Considine and Mount (1984) and adding an error term yields the system of share equations ready for estimation:

$$\begin{aligned}
\ln\left(\frac{s_{in,t}}{s_{\mathrm{M}n,t}}\right) &= \beta^*_{in} + \sum_{i\neq j} \beta^*_{ijn} \cdot m_{jn} \cdot \ln\left(\frac{p_{jn,t}}{p_{in,t}}\right) - \left[\textstyle\sum_{j\neq i} \beta^*_{j\mathrm{M}n} \cdot m_{jn} \cdot \ln\left(\frac{p_{jn,t}}{p_{\mathrm{M}n,t}}\right)\right]\\
&\quad - \beta^*_{i\mathrm{M}n} \cdot (m_{in} + m_{\mathrm{M}n}) \cdot \ln\left(\frac{p_{in,t}}{p_{\mathrm{M}n,t}}\right) + \beta^*_{iny} \cdot \ln y_{n,t} + \varepsilon_{in,t}, \qquad (3)\\
&\quad \text{for } i \text{ and } j = \mathrm{K,L,E}\ .
\end{aligned}$$

The remaining parameter values can be derived by using the imposed symmetry and homogeneity restrictions.

3.2 Concepts of Substitution Elasticities

In this section, two different concepts of substitution elasticities are introduced. First, we examine the cross-price elasticity (CPE) of demand as a standard measure for factor substitution. Second, the Morishima elasticity of substitution (MES) is presented as a different measure used for considering factor ratios rather than simple quantities.

3.2.1 Own- and Cross-price Elasticities

The CPE between factors i and j (η_{ij}) measures the relative change in the quantity of factor i (q_i) due to a relative change in the price of factor j (p_j). It is therefore called a *one-factor-one-price* elasticity. As can be seen from Equation (4), η_{ij} can be derived by the estimated factor share elasticity coefficient β^*_{ij} and the factor shares s_i and s_j, respectively.

$$\eta_{ij} \equiv s_j \cdot \hat{\beta}^*_{ij} + s_j, \quad \eta_{ii} \equiv -\sum_{j\neq i} s_j \cdot \hat{\beta}^*_{ij} + s_i - 1 \quad \text{for all } i, j, \qquad (4)$$

where the second term illustrates the special case of a own-price elasticity (OPE). If $\eta_{ij} > 0$, a price increase of input factor j leads to a higher quantity demand of factor i, with output and all other prices held constant. Firms compensate the price increase of factor j by using a higher amount of factor i instead. Consequently, the input factors are substitutes. However, if $\eta_{ij} < 0$, a price increase of j decreases the demand for factor i. Thus, firms reduce the amounts of factor i and j in the production process, for a constant output level. In this case, inputs are considered to be complements. Mundra and Russell (2004) further distinguish between whether or not the magnitude of the CPE is larger than unity. If the value of the CPE estimate is above 1, the factors are sufficiently substitutable. Analogously, if the CPE value is below –1, the factors will be sufficient complements.

3.2.2 Morishima Elasticity of Substitution

An alternative substitution elasticity concept was developed by Morishima (1967) and refined by Blackorby and Russell (1981, 1989). In contrast to the CPE, the MES (σ^m_{ij}) belongs to the group of *one-price-two-factor* elasticities.[5] Specifically, σ^m_{ij} measures the relative change in the quantity ratio of the factors i and j, (q_i/q_j), due to a relative price change of factor j (p_j). Note that the MES can be derived directly from the OPE and CPE. The effect of a change in p_j on q_i/q_j is the CPE of factor i and j (η_{ij}) minus the OPE of factor j (η_{jj}), formulated as

$$\sigma^m_{ij} = \eta_{ij} - \eta_{jj}, \quad \text{for all } i, j. \tag{5}$$

Since η_{jj} is generally negative (concavity constraint), one can conclude that $\sigma^m_{ij} > \eta_{ij}$. Hence, complementarity as implied by the CPE concept must not hold in the case of MES if the magnitude of η_{jj} is large enough.[6] The interpretation of the MES is as follows: If $\sigma^m_{ij} > 0$, a price shift for good j leads to an increase in the optimal quantity of factor i relative to the optimal quantity of factor j, holding the amount of output constant. In this case, factor i is considered to be a direct Morishima substitute for j (Mundra and Russell, 2004). If however $\sigma^m_{ij} < 0$, a factor price increase of j would lead to a reduction in the optimal quantity of factor i relative to the optimal quantity of factor j. In this case, j is called a direct Morishima complement to input i.

Similar to the CPE case, Mundra and Russell (2004) make a further distinction between whether or not the magnitude of the MES is larger than unity. If $\sigma^m_{ij} > 1$, an increase in the price of input i increases not just the quantity of input i relative to the quantity of factor j, but also the expenditure of i relative to j. According to Mundra and Russell (2004), this is true for factors which are sufficiently substitutable in the sense of Morishima.

---

[5] See Stern (2011) for an overview of different substitution elasticity concepts.

[6] The standard errors of the estimated elasticities can be calculated by using the Delta method (see e.g., Greene (2000)).

4 Methodological Procedure

The methodological approach is based on a pooled regression using seemingly unrelated regression (SUR) on transformed data with firm fixed effects. The general model is displayed below:

$$y_{nt} = \alpha_n + x'_{nt}\beta + \varepsilon_{nt}, \tag{6}$$

where y_{nt} is the endogenous variable, x_{nt} the exogenous variable of firm n at time t, while α_n is a random variable capturing the time-invariant unobserved heterogeneity across individuals (firms). Furthermore, β is the vector of coefficients, and ε_{nt} denotes the error term with elements being iid over n and t. Before the fixed effects model can be estimated, the data has to be transformed. According to Cameron and Trivedi (2009), this is done by calculating the variables' mean over time in the individual-specific effects model:

$$\begin{aligned} &\bar{y}_n = \alpha_n + \bar{x}'_n\beta + \bar{\varepsilon}_n, \text{ with} \\ &\bar{y}_n \equiv \frac{1}{T}\sum_{t=1}^{T} y_{nt},\ \bar{x}_n \equiv \frac{1}{T}\sum_{t=1}^{T} x_{nt} \qquad \text{and} \qquad \bar{\varepsilon}_n \equiv \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{nt}. \end{aligned} \tag{7}$$

Subsequently, the within transformation is performed by subtracting Equation (7) from (6), which yields the fixed effects model presented below.

$$\begin{aligned} y_{nt} - \bar{y}_n &= (x_{nt} - \bar{x}_n)'\beta + (\varepsilon_{nt} - \bar{\varepsilon}_n) \\ \ddot{y}_{nt} &= \ddot{x}'_{nt}\beta + \ddot{\varepsilon}_{nt}, \qquad n = 1, ..., N \text{ and } t = 1, ..., T. \end{aligned} \tag{8}$$

As the individual-specific effect α_n is time-invariant, it is canceled out. The variables $\ddot{y}_{nt}$ and $\ddot{x}_{nt}$ vary within the observations of an individual n. However, the correlation between individuals (firms) and over time is not considered. Consequently, the estimated standard errors are not valid and must be corrected. Applying cluster-robust standard errors, treating each individual as a cluster is the usual method of standard error correction. We employ an alternative possibility to estimate a cluster-robust covariance matrix, which consists in bootstrapping by randomly resampling the series k times. This procedure was first described in Efron (1979), while most extensions were performed in the last decade.

Considering the symmetry conditions, the system of equations in (9) can be estimated by pooled OLS, or, as in this paper, by the SUR approach which accounts for error correlations across the system of equations. The simultaneous estimation of the model, which is also applied in Arnberg and Bjorner (2007), is more efficient compared to the equation-by-equation OLS estimation and allows for a straightforward implementation of the various parameter restrictions.[7]

---

[7] Furthermore, SUR accounts for cross-equation contemporaneous correlations but assumes cross-time independence of the residual vectors ($\ddot{\varepsilon}^j_{n,t}$, with $j \in$ {K,L,E}). In other words, we assume $E[\ddot{\varepsilon}^j_{n,r}\ddot{\varepsilon}^j_{n,s}|X] = 0$ if $r \neq s$ and $E[\ddot{\varepsilon}^i_{n,s}\ddot{\varepsilon}^j_{n,s}|X] = \sigma_{ij}$.

$$\begin{bmatrix} \ddot{s}^{\mathrm{K}}_{nt} \\ \ddot{s}^{\mathrm{L}}_{nt} \\ \ddot{s}^{\mathrm{E}}_{nt} \end{bmatrix} = \begin{bmatrix} \beta^{\mathrm{K}}_{\mathrm{K},n} & \beta^{\mathrm{K}}_{\mathrm{L},n} & \beta^{\mathrm{K}}_{\mathrm{E},n} \\ \beta^{\mathrm{L}}_{\mathrm{K},n} & \beta^{\mathrm{L}}_{\mathrm{L},n} & \beta^{\mathrm{L}}_{\mathrm{E},n} \\ \beta^{\mathrm{E}}_{\mathrm{K},n} & \beta^{\mathrm{E}}_{\mathrm{L},n} & \beta^{\mathrm{E}}_{\mathrm{E},n} \end{bmatrix} \cdot \begin{bmatrix} \ddot{p}_{\mathrm{K},nt} \\ \ddot{p}_{\mathrm{L},nt} \\ \ddot{p}_{\mathrm{E},nt} \end{bmatrix} + \begin{bmatrix} \ddot{\varepsilon}^{\mathrm{K}}_{n,t} \\ \ddot{\varepsilon}^{\mathrm{L}}_{n,t} \\ \ddot{\varepsilon}^{\mathrm{E}}_{n,t} \end{bmatrix} \qquad s.t. \qquad \begin{aligned} \beta^{\mathrm{K}}_{\mathrm{L},n} &= \beta^{\mathrm{L}}_{\mathrm{K},n} \\ \beta^{\mathrm{K}}_{\mathrm{E},n} &= \beta^{\mathrm{E}}_{\mathrm{K},n}. \\ \beta^{\mathrm{L}}_{\mathrm{E},n} &= \beta^{\mathrm{E}}_{\mathrm{L},n} \end{aligned} \qquad (9)$$

5 Empirical Evidence

5.1 Data

5.1.1 Data Description

We use firm-level panel data comprising capital, labor, energy and material expenditures as input factors for the period from 1997 to 2008. These data as well as the number of employees and the firm's output are collected in the context of the survey "Production and value added statistics" (WS), conducted by the Swiss Federal Statistical Office (SFSO). The survey levies detailed information on the balance sheets and the income statements of Swiss firms in manufacturing, retail and services. A total of 10,400 companies were interviewed in 1997/1998, and this number increased to about 20,000 companies in 2008/2009. The response rate is about 90% for large firms, 70% for medium firms, and 60% for small firms.[8] The WS survey has been published since 1997 on an annual basis. The sample used in this study, comprises 1,965 manufacturing firms (7,396 observations) from 22 industry divisions.[9]

Factor cost shares of an input are obtained by dividing the firm's cost of an input by the total costs of all considered factors consumed or used in production. While this approach is suitable for labor, energy and material, obtaining the annual real consumption of capital is a challenging task. While Arnberg and Bjorner (2007) calculate factor cost shares by using total costs as the denominator and correcting the model by the building capital stock, Woodland (1993) calculate the share of capital as a residual value. This is done by using the value of firm's output as the denominator. After subtracting the cost of labor, energy and material, capital is obtained as the residual. In this paper, we follow the second approach.

Furthermore, deflators on these input factors are needed as we want to identify the adjustment in consumption within the set of input factors after prices have altered. We use a weighted industry-wide capital deflator and sector-specific series for material and output that are taken from the OECD. Also, sector-specific energy price indices are calculated on the basis of price surveys from the IEA and the SFOE, as well as the survey "Energy consumption statistics in the industry and services sectors" (EVID) published by the SFOE.[10]

---

[8] Data are made available for specific industries, corresponding to the 2-digit ISIC 3.1 classification.

[9] Only observations of firms stating their energy consumption have been considered. The sample is an unbalanced panel due to firms' entry, exit and non-response of the survey.

[10] More precisely, we calculate a chain Laspeyres index where the weights are updated annually by using the expenditure shares of the different energy sources as weights. Sector-specific expenditure shares were computed by using energy prices and physical quantities (measured in TJ) of the major energy sources (elec-

In accordance with Arnberg and Bjorner (2007), the price index for labor is obtained by dividing the annual wage bill of company n by the number of employees (full-time equivalents). As they mention, the price of labor tends to depend on the quality of labor chosen, therefore, endogeneity might be an issue. However, they argue that if labor quality is firm-specific and does not vary over time (time-constant), using fixed effects mitigates the endogeneity problem. This line of reasoning applies analogously to the remaining input factors, because the energy mix of demand, and capital good requirements, as well as materials are likely to be firm-specific rather than time-dependent.[11]

After the within transformation introduced in Section 4, we are left with 7,396 observations covering 1,965 companies in 22 manufacturing divisions. Because energy price indices are only available for 12 aggregate sectors, we aggregate the 22 divisions into 12 manufacturing sectors as displayed in Table 13 in Appendix E.

5.1.2 Descriptive Statistics

In the production process of Swiss manufacturing firms, the factor with the largest mean cost share is material (41.0%), followed by labor (35.5%), capital (21.4%) and energy (2.0%). The mean cost share of energy in Switzerland is only half the size of the U.S. manufacturing firms in the dataset of Nguyen and Streitwieser (1999). The energy cost share (electricity and other energy) of the Danish firm sample is roughly 4.5% (Arnberg and Bjorner, 2007).[12] As can be seen from Figure 1, the firms' mean cost shares of capital, labor and material exhibit a smooth distribution over the observations. In contrast, mean energy cost shares are far from being equally distributed over the observations.

Higher energy prices resulting from new policy measures will, as a matter of course, hit the companies with high energy shares hardest. However, firms that can easily substitute energy using other production factors are able to mitigate the negative effects of rising energy prices to a greater extent. In this paper, we are interested in finding differences in the substitution possibilities between energy-intensive firms and energy-extensive firms. Consequently, the dataset is subdivided into three subsets of similar sizes according to the firms' mean energy cost share. Subset 1 (S1) comprises the set of firms with a mean energy cost share below 1.1% (c.f. Figure 1). Firms within S1, will be called low energy-use firms. On the other hand, subset 3 (S3) includes the most energy-intensive firms, with mean energy cost shares above 2.0%. Subset 2 (S2) contains the remaining firms with medium energy use. Every subset represents one third of total observations. While the differences of firms' energy intensity are negligible in S1 and S2, there exist substantial differences

---

tricity, natural gas, light fuel oil, heavy fuel oil and coal). The same method to compute sector-specific price indices for energy has been used in Mohler and Mueller (2012).

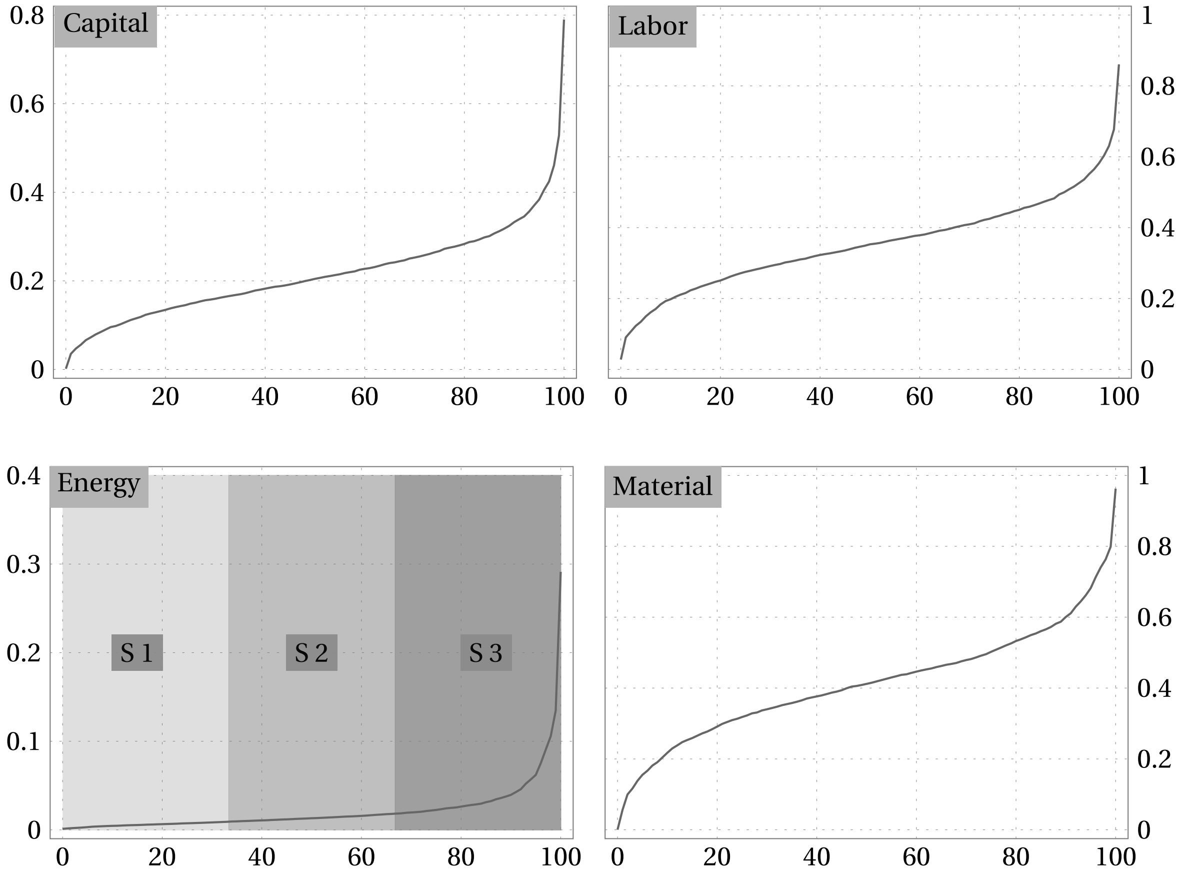
[11] We checked for possible endogeneity issues by applying 3SLS estimations on data from 1998 to 2008, using the one period lagged price series. The results were very similar to those of the SUR approach.

[12] Note that (Arnberg and Bjorner, 2007) exclude material, which leads to a higher energy share. Excluding material in our sample, would result in an mean energy cost share of 3.5%, which is still lower than in Denmark.

between firms in S3. For this reason, we will also consider other subdivisions of S3 in Appendix D.

The cost shares in the three subsets are generally stable over time with the exception of S1, where we observe a slight decline in the mean cost share of material, while the labor share increases. In all subsets, material is the major cost share and accounts for about 40% of total cost, while labor and capital contribute about 35% and 20%.

Figure 1: Percentiles of the Factor Cost Shares



5.2 Results

In the LL model (and the TL model), the concavity condition is not globally satisfied, and it has to be checked whether the cost function is concave at the sample means and at each observation. Concavity violations may indicate a misspecification of the underlying production model and result in biased elasticity estimates (Diewert and Wales, 1987). We use likelihood ratio (LR) tests and the concavity condition as criteria to choose the best specification for the LL model and the TL model.

Table 10 in Appendix B displays the Eigenvalues of the Hessian matrix at the sample means and the percentage of observations that satisfy concavity for the LL model and the TL model. The cost function is concave if the Hessian matrix of second partial derivatives is negative semi-definite (Considine, 1989). The table first shows that all Eigenvalues are negative semi-definite in the LL model and in the majority of cases in the TL model, when considering the sample means of the three subsets. If we check concavity at each observation, the rate of observations that satisfy concavity can be very low as the last row implies. The gray-shaded areas indicate the specification that performs best subject to our two criteria and we use these specifications in our analysis.

The estimated parameter values from the systems of equations for the three subsets and the two production models are displayed in Table 11 in Appendix C. Below, we discuss the results of the model estimations: We present the OPEs, CPEs and MES for the three different subsets. In our description of the results, we focus on the firms' reaction upon an energy price change. Remember that, by definition, the estimated elasticities describe firms' optimal adjustment of the production process under the assumption of constant output quantity. For example, if increased energy prices lead to a decrease of energy use in the production process (own-price elasticities are typically negative), one or more of the other factors have to increase to hold output of firms at a constant level. In other words, there will always be at least one of the other factors that is substitutable with energy by construction and consequently increases upon an energy price increase. The other two factors can, in principle, increase or decrease, thus being substitutes or complements vis-a-vis the factor energy.

5.2.1 Low Energy-Use Firms

Table 1 displays the estimated OPEs and CPEs for S1 containing firms with energy shares below 1.1%. Each Table is supplemented by a graphical representation of the 95% confidence intervals.[13] In S1, all OPEs are negative. The OPE of energy is about –1, indicating that energy is unit elastic in demand. The OPEs of the other factors are between –1 and 0, indicating that the factors capital, labor and material are less price-sensitive than the factor energy. All four OPEs are significantly smaller than zero at least at the 5% level.

The CPEs describe the reaction of the quantity of the remaining factors upon a price change of a factor and they are presented next in the table. For example, μ_{KE} denotes the percentage change of the capital input upon an energy price increase of one percent. The mostly positive estimates of the CPEs indicate substitution possibilities among the considered input factors, though there are considerable differences in the ease of substitution indicated by the magnitude of the estimates. Regarding changes in the energy prices, we observe that the factors material (CPE of 0.00), capital (0.02) and labor (0.00) are weak substitutes, however, not estimated as being significantly different from zero. Since the energy share is generally low for these firms, naturally an energy price increase of one percent is not having a large impact on the employed quantity of the other factors in percentage terms. Hence, the small CPEs associated with energy price increases do not come as a surprise.

---

[13] LCL, UCL denote the lower and the upper confidence limit of the elasticity estimates, respectively.

Table 1: Own- and Cross-price Elasticities for Low Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
η_{KK}	-0.865	-1.318	-0.411	0.231	-3.736	0.000
η_{LL}	-0.715	-0.900	-0.530	0.094	-7.586	0.000
η_{EE}	-1.031	-1.942	-0.121	0.464	-2.220	0.027
η_{MM}	-0.710	-0.971	-0.449	0.133	-5.332	0.000
Negative 4 (4)						
η_{LK}	0.172	0.085	0.259	0.045	3.855	0.000
η_{EK}	0.740	0.225	1.254	0.263	2.817	0.005
η_{MK}	0.251	0.039	0.464	0.108	2.317	0.021
η_{KL}	0.267	0.131	0.403	0.069	3.855	0.000
η_{EL}	0.212	0.000	0.424	0.108	1.962	0.050
η_{ML}	0.360	0.261	0.458	0.050	7.177	0.000
η_{KE}	0.020	0.006	0.034	0.007	2.817	0.005
η_{LE}	0.004	0.000	0.007	0.002	1.962	0.050
η_{ME}	0.000	-0.007	0.006	0.003	-0.082	0.935
η_{KM}	0.478	0.074	0.882	0.206	2.317	0.021
η_{LM}	0.440	0.320	0.560	0.061	7.177	0.000
η_{EM}	-0.020	-0.495	0.455	0.242	-0.082	0.935
Substitutes 10 (8) | Complements 2 (0)						$N = 2,462$

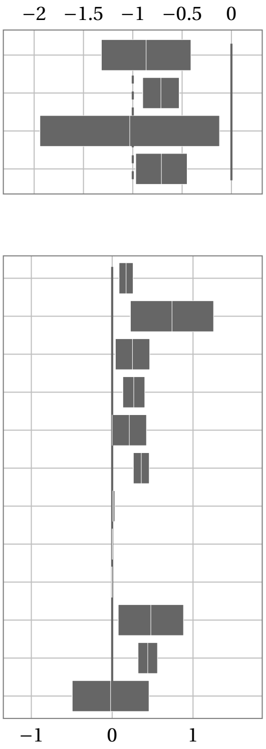


Table 2: Morishima Elasticities for Low Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
σ^m_{LK}	1.037	0.575	1.499	0.236	4.398	0.000
σ^m_{EK}	1.604	0.918	2.290	0.350	4.583	0.000
σ^m_{MK}	1.116	0.615	1.617	0.256	4.366	0.000
σ^m_{KL}	0.982	0.753	1.212	0.117	8.395	0.000
σ^m_{EL}	0.927	0.646	1.208	0.143	6.467	0.000
σ^m_{ML}	1.075	0.866	1.284	0.107	10.068	0.000
σ^m_{KE}	1.051	0.141	1.962	0.465	2.263	0.024
σ^m_{LE}	1.035	0.124	1.945	0.464	2.228	0.026
σ^m_{ME}	1.031	0.121	1.941	0.464	2.219	0.027
σ^m_{KM}	1.188	0.707	1.669	0.246	4.839	0.000
σ^m_{LM}	1.150	0.863	1.438	0.147	7.845	0.000
σ^m_{EM}	0.690	0.148	1.232	0.276	2.497	0.013
Substitutes 12 (12) | Complements 0 (0)						$N = 2,462$

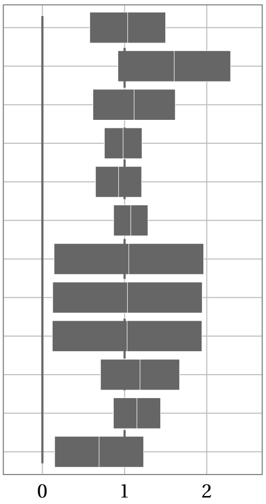


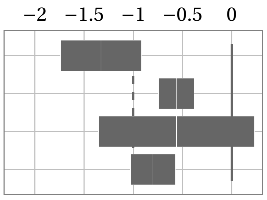
Table 2 displays the Morishima elasticities (MES) of S1. As mentioned in Section 3.2.2, MES belong to the class of *two-factor-one-price* elasticities. They measure how the ratio of the two factors alters if there is a price increase of one percent for one of these factors. All MES are positive implying that the share in production of a factor that experiences a price increase relative to each other factor is decreasing due to the price increase. The MES that describe the reaction to an energy price change are all close to one. Hence, an energy price increase of one percent leads to an increase of the other factor's share relative to energy use of roughly one percent.

5.2.2 Medium Energy-Use Firms

Table 3 displays the estimated OPEs and CPEs for S2, containing the firms with medium energy use. The factor energy is less price-elastic than in S1, with an OPE of -0.56, note however the relatively large standard errors of both estimates. Similar to S1, energy price increases have a small effect on capital (0.02) and almost no effect on labor and material for medium energy-use firms.

Table 3: Own- and Cross-price Elasticities for Medium Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
η_{KK}	-1.328	-1.738	-0.918	0.209	-6.347	0.000
η_{LL}	-0.563	-0.743	-0.383	0.092	-6.130	0.000
η_{EE}	-0.561	-1.353	0.230	0.404	-1.390	0.165
η_{MM}	-0.800	-1.028	-0.573	0.116	-6.903	0.000
Negative 4 (3)						
η_{LK}	0.159	0.073	0.245	0.044	3.638	0.000
η_{EK}	0.308	-0.137	0.752	0.227	1.356	0.175
η_{MK}	0.435	0.268	0.603	0.085	5.096	0.000
η_{KL}	0.289	0.133	0.444	0.079	3.638	0.000
η_{EL}	0.063	-0.163	0.289	0.115	0.547	0.585
η_{ML}	0.257	0.153	0.361	0.053	4.840	0.000
η_{KE}	0.022	-0.010	0.053	0.016	1.356	0.175
η_{LE}	0.002	-0.006	0.011	0.004	0.547	0.585
η_{ME}	0.003	-0.011	0.016	0.007	0.422	0.673
η_{KM}	0.913	0.562	1.264	0.179	5.096	0.000
η_{LM}	0.297	0.176	0.417	0.061	4.840	0.000
η_{EM}	0.086	-0.313	0.484	0.203	0.422	0.673
Substitutes 12 (6) | Complements 0 (0)						$N = 2,461$



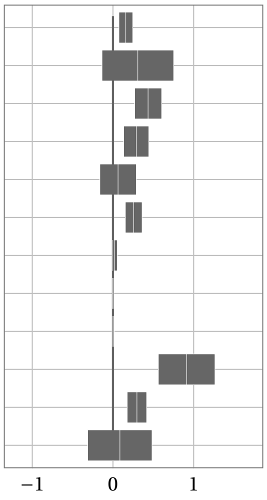
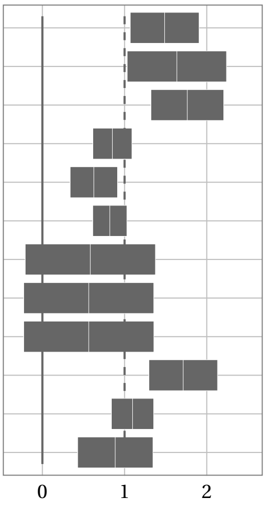


Table 4: Morishima Elasticities for Medium Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
σ^m_{LK}	1.487	1.068	1.906	0.214	6.956	0.000
σ^m_{EK}	1.636	1.031	2.240	0.309	5.299	0.000
σ^m_{MK}	1.763	1.320	2.206	0.226	7.802	0.000
σ^m_{KL}	0.852	0.614	1.089	0.121	7.017	0.000
σ^m_{EL}	0.626	0.337	0.914	0.147	4.250	0.000
σ^m_{ML}	0.820	0.612	1.028	0.106	7.730	0.000
σ^m_{KE}	0.583	-0.209	1.375	0.404	1.442	0.149
σ^m_{LE}	0.564	-0.228	1.355	0.404	1.396	0.163
σ^m_{ME}	0.564	-0.228	1.356	0.404	1.397	0.163
σ^m_{KM}	1.713	1.295	2.131	0.213	8.029	0.000
σ^m_{LM}	1.097	0.840	1.354	0.131	8.364	0.000
σ^m_{EM}	0.886	0.428	1.345	0.234	3.787	0.000
Substitutes 12 (9) | Complements 0 (0)						$N = 2,461$



The MES estimates of S2 are displayed in Table 4. As a consequence of the lower OPE of energy, MES describing the behavior of the firms after an energy price change are smaller than in S1, roughly 0.60. Still, energy price increases lead to less energy-intensive production.

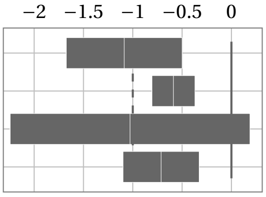
5.2.3 High Energy-Use Firms

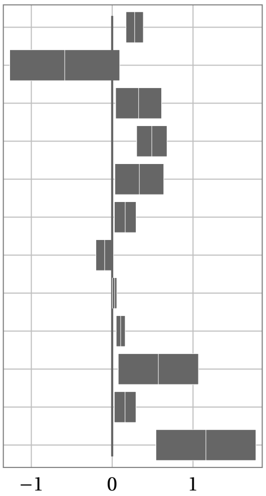
Table 5 displays the OPEs and the CPEs for the high energy intensity subsample (S3). Again, all estimated OPEs are negative and significantly different from zero at the 1% level, except for the factor energy which is significant at the 10% level. The factor energy is unit-elastic in demand ($\eta_{\mathrm{EE}} = -1.03$). The factors labor and material are both inelastic in S3, while the OPE of capital is marginally more elastic than the one of energy with a value of -1.09.

The substitution possibilities for firms with low and medium energy use, as shown by the CPE estimates for S1 and S2, persists for the majority of elasticity estimates in S3, with the exception of energy and capital, which are complements instead of substitutes in the production process of energy-intensive firms ($\eta_{\mathrm{KE}} = -0.09$, $\eta_{\mathrm{EK}} = -0.59$). These CPEs between energy and capital are significantly different from zero at the 10% level. The observed complementarity between these factors implies that an energy price increase of one percent leads to a decrease in the amount of capital of 0.09%, holding the firm's output constant. If the price of capital increases by one percent, firms reduce the amount of energy by approximately 0.59% when holding output constant.

Table 5: Own- and Cross-price Elasticities for High Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
η_{KK}	-1.087	-1.675	-0.500	0.300	-3.629	0.000
η_{LL}	-0.588	-0.806	-0.370	0.111	-5.289	0.000
η_{EE}	-1.028	-2.244	0.188	0.620	-1.657	0.098
η_{MM}	-0.713	-1.099	-0.327	0.197	-3.619	0.000
Negative 4 (3)						
η_{LK}	0.278	0.171	0.385	0.055	5.102	0.000
η_{EK}	-0.587	-1.267	0.093	0.347	-1.691	0.091
η_{MK}	0.327	0.042	0.611	0.145	2.251	0.024
η_{KL}	0.490	0.302	0.678	0.096	5.102	0.000
η_{EL}	0.336	0.034	0.638	0.154	2.179	0.029
η_{ML}	0.161	0.026	0.296	0.069	2.330	0.020
η_{KE}	-0.093	-0.201	0.015	0.055	-1.691	0.091
η_{LE}	0.030	0.003	0.057	0.014	2.179	0.029
η_{ME}	0.105	0.049	0.161	0.029	3.667	0.000
η_{KM}	0.571	0.074	1.067	0.254	2.251	0.024
η_{LM}	0.159	0.025	0.294	0.068	2.330	0.020
η_{EM}	1.159	0.540	1.778	0.316	3.667	0.000
Substitutes 10 (10) | Complements 2 (0)						$N = 2,473$





As a consequence of this complementarity, how does an energy-intensive firm react to a price increase? First and due to the negative OPE of energy, an energy price increase of one percent leads to a reduction of energy use by 1.02%. Since capital is a complement of energy, capital use will also decrease, namely by 0.09%. To hold output constant, the firm must therefore increase material and labor use by 0.11% and 0.03%. One possible story that may fit these facts is that these firms are not able to absorb an energy price increase by increasing their capital stock (e.g. using more energy-efficient technologies). Since capital use is falling, a substantial increase in material use and to a lesser extent, labor use, is needed to hold output constant.[14]

In Appendix D, we test whether our finding of complementarity depends on our definition of S3, by excluding gradually the least energy-intensive firms and re-estimating the CPEs. Moreover, we control for a possible misspecification of the production model with respect to the concavity condition. We show that complementarity becomes even stronger when we exclude the least energy-intensive firms of S3. Hence, the adaption costs for very energy-intensive firms tend to be higher. However, the reliability of the estimation results falls as we decrease the number of firms in S3 to only include the firms with the highest energy shares. Notice, that it does not suffice to simply check that the concavity condition

---

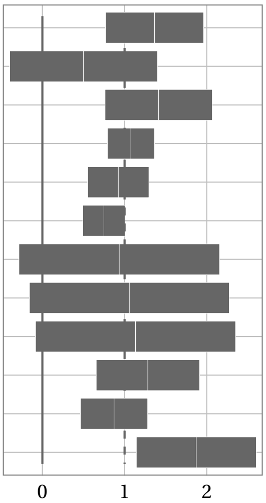
[14] For instance, by outsourcing some production steps and replacing them by using more intermediate goods instead. This is just one of many possible interpretations and is presented here to illustrate how energy-intensive firms adjust their production process after an energy price increase.

is satisfied at the sample means. Our exercise shows that in the 15% subset, for example, concavity is still satisfied at the sample means, but only 9.6% of the observations satisfy concavity.

Regarding the MES in S3, displayed in Table 6, we observe that these CPEs translate into similar MES as in S1 and S2: energy price increases of one percent lower the energy share compared to all the other factors by roughly one percent.

Table 6: Morishima Elasticities for High Energy-Use Firms

	Estimate	**LCL**	**UCL**	**SE**	**t-values**	**p-values**
σ^m_{LK}	1.365	0.769	1.962	0.305	4.484	0.000
σ^m_{EK}	0.500	-0.398	1.399	0.458	1.091	0.275
σ^m_{MK}	1.414	0.762	2.067	0.333	4.248	0.000
σ^m_{KL}	1.077	0.790	1.365	0.147	7.337	0.000
σ^m_{EL}	0.924	0.551	1.296	0.190	4.862	0.000
σ^m_{ML}	0.749	0.492	1.005	0.131	5.722	0.000
σ^m_{KE}	0.935	-0.286	2.155	0.623	1.501	0.133
σ^m_{LE}	1.058	-0.158	2.274	0.620	1.706	0.088
σ^m_{ME}	1.133	-0.084	2.350	0.621	1.825	0.068
σ^m_{KM}	1.283	0.654	1.913	0.321	3.998	0.000
σ^m_{LM}	0.872	0.463	1.281	0.209	4.183	0.000
σ^m_{EM}	1.872	1.142	2.602	0.372	5.026	0.000
Substitutes 12 (8) | Complements 0 (0)						$N = 2,473$



5.2.4 Comparison of the Elasticity Estimates

A summary of substitution elasticities of Swiss manufacturing firms reveals that there exists a link between firms' energy intensity and the way firms substitute towards other production factors. Table 7 displays the price elasticities (OPEs and CPEs) related to an energy price increase of low, medium and high energy-use firms. Moreover, the last three rows show how the firms' energy shares adjust after a price increase of one of the remaining production factors.

The table shows that the OPEs of energy are unit elastic for low and high energy-use firms. The factor energy is slightly less price-elastic for medium energy-use firms, but not significantly different from the other two subsets. At the same time, cross-substitution possibilities seem to play an important role in Swiss manufacturing. First, the majority of cross-price elasticities are significantly different from zero. Moreover, the specification test for Cobb-Douglas, displayed in in Appendix A.1, is rejected in S2 and S3 at the 1% level and in S1 at the 10% level, confirming the result.

While capital and energy are cross-price substitutes for firms in the low and medium energy intensity subset, complementarity was detected for firms in the high energy in-

Table 7: Comparison of the Elasticity Estimates Related to Energy

	Low Energy-Use		**Med. Energy-Use**		**High Energy-Use**	
	Estimate	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
η_{EE}	-1.031	0.464	-0.561	0.404	-1.028	0.620
η_{KE}	0.020	0.007	0.022	0.016	-0.093	0.055
η_{LE}	0.004	0.002	0.002	0.004	0.030	0.014
η_{ME}	0.000	0.003	0.003	0.007	0.105	0.029
η_{EK}	0.740	0.263	0.308	0.227	-0.587	0.347
η_{EL}	0.212	0.108	0.063	0.115	0.336	0.154
η_{EM}	-0.020	0.242	0.086	0.203	1.159	0.316

tensity subset ($\eta_{\mathrm{KE}} = -0.09$, $\eta_{\mathrm{EK}} = -0.59$). Low substitutability or complementarity between these factors implies that the firms' adjustment to higher energy prices will be more difficult, and unit costs may rise substantially (Berndt and Wood, 1975). Remember that the exclusion of less energy-intensive firms from the sample and the re-estimation of the production models results in even stronger complementarity. We find that very energy-intensive manufacturing firms would have to reduce their capital stock more than less energy-intensive firms in S3, after energy price increases. Hence, the adaption costs for very energy-intensive firms tend to be even higher.

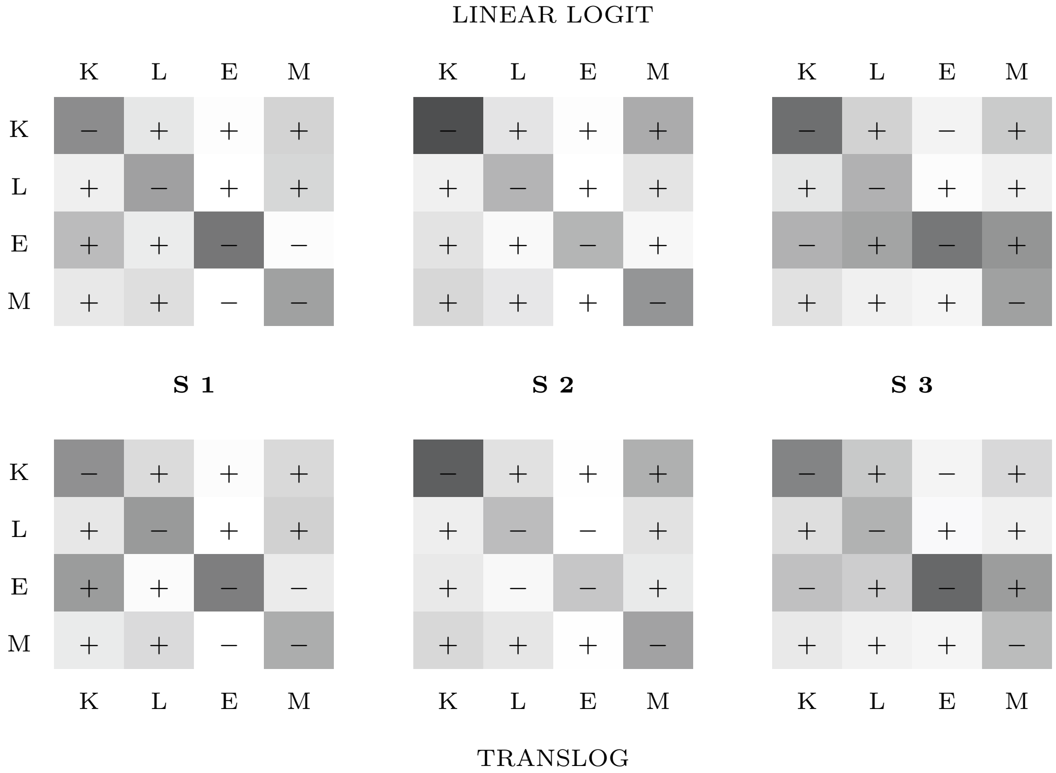
Another interesting result is that there exists a link between firms' energy intensity and the way firms substitute towards other production factors. For example, low and medium energy-use firms only marginally substitute material or labor for energy ($\eta_{\mathrm{ME}} = 0.00$, $\eta_{\mathrm{LE}} = 0.00$), while energy-intensive firms substitute material for energy more extensively after an energy price increase ($\eta_{\mathrm{ME}} = 0.11$, $\eta_{\mathrm{LE}} = 0.03$).

5.3 Comparison of Linear Logit and Translog Elasticity Estimates

Considine and Mount (1984) and Arnberg and Bjorner (2007) favor the linear logit model for the estimation of substitution elasticities when using firm-level data, because the model can handle high heterogeneity in the size of factor shares as well as factor shares that are close to zero in a more appropriate manner than other function forms. Yet, the translog cost function has been the standard approach used in the literature since the 1970s to estimate substitution elasticities between production factors of individual industries, or, more generally, the whole industry. As a benchmark and to show that our results do not depend on the choice of the underlying cost function, we also display the elasticity estimates from the translog model in Table 9 in Appendix A.2. Instead of discussing the TL elasticity estimates, we use a graphical representation to compare the results.

Figure 2 displays the elasticity estimates of the LL model (upper panel) and the estimates of the TL model (lower panel) in form of heatmaps for low, medium and high energy use firms. The heatmaps show the relative magnitude of own-price elasticities on the diagonal and the degree of substitutability (+) and complementarity (−) on the off-diagonal elements, among the production factors capital, labor, energy and material. The substitutability patterns are very similar for the two models. Notice the low magnitude of substitution after an energy price change in S1 and S2, represented by the white off-diagonal elements of the third columns. In contrast, the magnitude of substitution (complementarity) is higher for material (capital) in S3. Complementarity between energy and capital in the high energy intensity subset is detected by both the LL as well as the TL model. To summarize, the elasticity estimates generally correspond in both sign and magnitude over the two models.

Figure 2: Graphical Representation of the LL and TL Elasticity Estimates



LINEAR LOGIT

S 1

	K	L	E	M
K	−	+	+	+
L	+	−	+	+
E	+	+	−	−
M	+	+	−	−

S 2

	K	L	E	M
K	−	+	+	+
L	+	−	+	+
E	+	+	−	+
M	+	+	+	−

S 3

	K	L	E	M
K	−	+	−	+
L	+	−	+	+
E	−	+	−	+
M	+	+	+	−

TRANSLOG

S 1

	K	L	E	M
K	−	+	+	+
L	+	−	+	+
E	+	+	−	−
M	+	+	−	−

S 2

	K	L	E	M
K	−	+	+	+
L	+	−	−	+
E	+	−	−	+
M	+	+	+	−

S 3

	K	L	E	M
K	−	+	−	+
L	+	−	+	+
E	−	+	−	+
M	+	+	+	−

Notes: The diagonal cells display the magnitude of the own-price elasticities. All OPE estimates are negative (−). The off-diagonal cells display the magnitude of the cross-price elasticities, where + (−) indicates substitutability (complementarity). The cell-specific opacity provides information about the magnitude.

6 Conclusions

This paper provides an analysis of factor substitution among capital, labor, energy and material in Swiss manufacturing using micro panel data from 1997 to 2008. The focus lies on examining the relationship between factor substitutability and the energy intensity of manufacturing firms in Switzerland. Consequently, the firms are subdivided into three groups, namely low, medium and high energy-use firms. The findings from the elasticity estimates in Swiss manufacturing bear strong implications for policy makers.

Substitution possibilities between capital, labor, energy and material help to mitigate the negative effects of increasing factor prices: Firms adjust their production process by substituting towards other production factors after relative factor price increases. One interesting result of our study is that there exists a link between firms' energy intensity and the way firms substitute towards other production factors: While capital and energy are cross-price substitutes for firms in the low and medium energy intensity subset, complementarity was detected for firms in the high energy intensity subset. These results imply that the high energy-use firms' adjustment to higher energy prices will be more difficult, and, as a consequence, unit costs may rise more than in the case of substitutability. A possible explanation for the complementarity result is that these firms have to considerably adjust their production process by producing more material-intensively; possibly by importing more intermediate products or shifting parts of their production to other countries. However, further research is needed to explain the adjustment process thoroughly.

The complementarity result for energy-intensive firms is in line with the results of Tovar and Iglesias (2013) and Arnberg and Bjorner (2007). The former analyze the relationship between capital and energy for the eight industries with the highest energy consumption in the United Kingdom. Using industry-level data, the authors find complementarity between capital and energy in all eight industries. Applying firm fixed-effects, Arnberg and Bjorner also find complementarity between capital and energy in their Danish industrial dataset. Energy-intensive firms in Switzerland and in other countries seem to have greater difficulty in adjusting to energy price increases.

Another finding of the study of Arnberg and Bjorner (2007) is of interest: The complementarity result is reversed if the time dimension of the panel data is ignored. Pooling the data, the elasticities between capital and energy are positive, implying substitutability between capital and energy, as is the case with the other factors of production. This result might indicate that firm-specific factors such as the firm's production technology and the goods produced are fixed in the short run. In the longer term, however, substitution possibilities might increase as firms are able to undertake more substantial adjustments in their production (e.g. underlying technology). Hence, the considered time horizon of the adjustment process to relative price changes in a production factor is crucial and might be a reasonable explanation for the differing results between panel and cross-section estimates.

While we are interested in the relationship between substitutability and the energy intensity of firms, Nguyen and Streitwieser (1999) examine the question of whether plant size, as indicated by the number of employees, has an impact on factor substitutability. Our elasticity estimates are smaller in magnitude than the elasticities of U.S. firms. Interestingly, considering cross-price elasticities, they also find complementarity between capital and energy and to a smaller extent between capital and labor for some of the plant size classes. Yet, in the overall sample, all production factors are substitutes; and if Morishima elasticities are considered, all production factors are substitutes in all plant-size classes. They find no structural differences in the ease of substitution between small and large manufacturing plants and therefore conclude that policies which result in raising energy prices will not affect plants differently depending on their size. Testing for differences between small and large firms with our sample revealed no significant differences in the ease of factor substitution, confirming the findings of Nguyen and Streitwieser (1999).

The policy implications to be drawn from this analysis are that both the low and medium energy-use firms are unlikely to face severe problems in dealing with rising energy prices. These firms are able to reduce their energy use by producing slightly more capital-intensively and by adopting energy-saving measures without making major changes in their production processes. In contrast, energy-intensive firms have substantially higher energy cost shares: In our sample, these firms have a mean energy cost share of 4.0%, compared to 0.5% (1.4%) for low (medium) energy-use firms. More importantly, energy intensive firms face further problems in coping with energy price increases, as there is evidence for complementarity between energy and capital, at least in the short and medium run.

References

Apostolakis, B. E. (1990). Energy–capital substitutability/ complementarity: The dichotomy. *Energy Economics 12*(1), 48–58.

Arnberg, S. and T. B. Bjorner (2007). Substitution between energy, capital and labour within industrial companies: A micro panel data analysis. *Resource and Energy Economics 29*(2), 122–136.

Berndt, E. R. and L. R. Christensen (1973). The translog function and the substitution of equipment, structures, and labor in U.S. manufacturing 1929-68. *Journal of Econometrics 1*(1), 81–113.

Berndt, E. R. and D. O. Wood (1975). Technology, prices, and the derived demand for energy. *The Review of Economics and Statistics 57*(3), 259–268.

Blackorby, C. and R. R. Russell (1981). The Morishima elasticity of substitution; Symmetry, constancy, separability, and its relationship to the Hicks and Allen elasticities. *Review of Economic Studies 48*(1), 147–158.

Blackorby, C. and R. R. Russell (1989). Will the real elasticity of substitution please stand up? (A comparison of the Allen/Uzawa and Morishima elasticities). *American Economic Review 79*(4), 882–888.

Cameron, A. C. and P. K. Trivedi (2009). *Microeconometrics: Methods and Applications*. Cambridge University Press.

Christensen, L. R., D. W. Jorgenson, and L. J. Lau (1973). Transcendental logarithmic production frontiers. *The Review of Economics and Statistics 55*(1), 28–45.

Considine, T. J. (1989). Separability, functional form and regulatory policy in models of interfuel substitution. *Energy Economics 11*(2), 82–94.

Considine, T. J. and T. D. Mount (1984). The use of linear logit models for dynamic input demand systems. *The Review of Economics and Statistics 66*(3), 434–443.

Diewert, W. E. (1971). An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function. *Journal of Political Economy 79*(3), 481–507.

Diewert, W. E. and T. J. Wales (1987). Flexible Functional Forms and Global Curvature Conditions. *Econometrica, Econometric Society 55*(1), 43–68.

Efron, B. (1979). Bootstrap Methods: Another Look at the Jackknife. *The Annals of Statistics 7*(1), 1–26.

Ekins, P. and S. Speck (Eds.) (2011). *Environmental Tax Reform (ETR) – A Policy for Green Growth*. Oxford University Press.

Greene, W. H. (2000). *Econometric Analysis*. Prentice Hall.

Koetse, M. J., H. L. de Groot, and R. J. Florax (2008). Capital-energy substitution and shifts in factor demand: A meta-analysis. *Energy Economics 30*(5), 2236–2251.

Mohler, L. and D. Mueller (2012). Substitution elasticities in Swiss manufacturing. Technical report, Swiss Federal Office of Energy (SFOE).

Morishima, M. (1967). A few suggestions on the theory of elasticity. *Keizai Hyoron 16*, 144–150.

Mundra, K. and R. R. Russell (2004). Dual elasticities of substitution. Technical report, San Diego State University and University of California, Riverside.

Nguyen, S. V. and M. L. Streitwieser (1999). Factor substitution in U.S. manufacturing: Does plant size matter? *Small Business Economics 12*(1), 41–57.

Patuelli, R., P. Nijkamp, and E. Pels (2005). Environmental tax reform and the double dividend: A meta-analytical performance assessment. *Ecological Economics 55*(4), 564–583.

Solow, J. L. (1987). The capital-energy complementarity debate revisited. *American Economic Review 77*(4), 605–614.

Stern, D. (2011). Elasticities of substitution and complementarity. *Journal of Productivity Analysis 36*(1), 79–89.

Tamminen, S. and E. Tuomaala (2012). Variation in price and substitution elasticities between sectors? A microdata analysis. Working Papers 34, Government Institute for Economic Research Finland (VATT).

Thompson, P. and T. G. Taylor (1995). The capital-energy substitutability debate: A new look. *The Review of Economics and Statistics 77*(3), 565–569.

Tovar, M. A. and E. M. Iglesias (2013). Capital-Energy Relationships: An Analysis when Disaggregating by Industry and Different Types of Capital. *The Energy Journal 34*(4), 129–150.

Woodland, A. D. (1993). A micro-econometric analysis of the industrial demand for energy in NSW. *The Energy Journal 14*(2), 57–90.

A Translog Function

The translog (TL) function was proposed in Christensen et al. (1973) and has become a very popular modeling approach in factor demand models over the last decades. The main reason for the success of the TL is its flexible functional form which does not impose any prior constraints on the elasticities. Typically, the elasticities of substitution are derived from cost functions. An exception is Berndt and Christensen (1973) which estimate the elasticities directly from the production function. The TL function requires two model restrictions to be fulfilled. First, the factor shares $s_{in,t}$ have to sum up to 1 at each point in time and for each individual firm n. Furthermore, symmetry has to be satisfied, such that $\beta_{ij} = \beta_{ji}$. The factor share equations of the TL cost function can be stated as follows:

$$s_{in,t} = \beta_{in} + \sum_{j=1}^{4} \beta_{ijn} \ln\left(p_{jn,t}\right) + \beta_{iny} \ln\left(y_{n,t}\right) + \varepsilon_{in,t}, \tag{10}$$

where i and j denote the four considered factor inputs capital, labor, energy and material, while n and t stand for the firm and the time index, respectively. In the right-hand side of the equation, β_{in} captures input and firm-specific effects which are considered to be constant over time when using panel data. Furthermore, the log of output (y) of firm n at time t is included to control for different production levels. Finally, an error term denoted by $\varepsilon_{in,t}$ is added.

The adding up restriction of the factor shares leads to singularity, because the sum of error terms is zero for each firm. To obtain a non-singular system of equations, we omit the factor share equation of material and normalize the remaining factor share equations by the price of material. The reformulated factor share equation is

$$s_{in,t} = \beta_{in} + \sum_{j=1}^{3} \beta_{ijn} \ln\left(\frac{p_{jn,t}}{p_{4n,t}}\right) + \beta_{iny} \ln\left(y_{n,t}\right) + \varepsilon_{in,t}. \tag{11}$$

The factor shares in Equation (11) can be estimated by a system of equations approach. The elasticities of the factor material can be calculated subsequently by using the adding-up and homogeneity conditions.

As can be seen from Equation (12), the cross-price elasticity η_{ij} can be derived by the estimated factor share elasticity coefficient β_{ij} and the factor shares s_i and s_j, respectively:

$$\eta_{ij} \equiv \frac{\hat{\beta}_{ij} + s_i s_j}{s_i}, \quad \eta_{jj} \equiv \frac{\hat{\beta}_{jj} + s_j s_j - s_j}{s_j}, \quad \text{for all } i, j, \tag{12}$$

where the second term illustrates the special case of an own-price elasticity (OPE). The Morishima elasticity, σ_{ij}^{m} is stated in Equation (13). As one aims to isolate the effect of a change in p_j on q_i/q_j, the OPE of factor j (η_{jj}) must be subtracted from the CPE of factor j and i (η_{ij}).[15]

$$\sigma_{ij}^{m} = \eta_{ij} - \eta_{jj}, \quad \text{for all } i, j. \tag{13}$$

A.1 Cobb-Douglas Specification Test

The Cobb-Douglas function is a nested function of the translog function (Christensen et al., 1973). With a likelihood ratio (LR) test, we check whether the Cobb-Douglas form is sufficient to fit the production process of Swiss manufacturing firms. Table 8 displays the LR test results for the three subsets. In S2 and S3, Cobb-Douglas is rejected at the 1% level and in S1 at the 10% level. Hence, cross-substitution possibilities seems to play an important role and assuming Cobb-Douglas production functions might lead to biased results.

Table 8: Cobb-Douglas Specification Tests

Subset	N	df	F	p-value
1	2,462	3	2.1844	0.08768
2	2,461	3	5.3912	0.00105
3	2,473	3	4.4149	0.00416

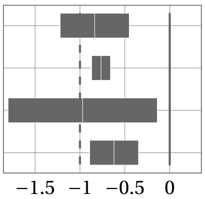
---

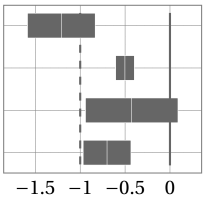
[15] The standard errors of the estimated elasticities can be calculated by using the Delta method (see e.g., Greene (2000)).

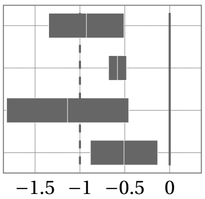
A.2 Translog Elasticity Estimates

Table 9: Own-, Cross-price and Morishima Elasticities in the Translog Case

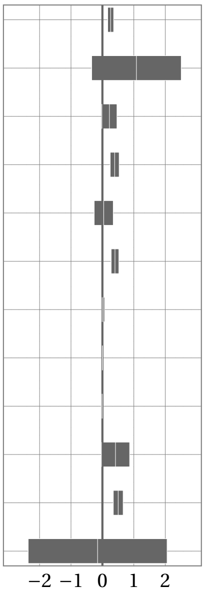
	Subset 1	**Subset 2**	**Subset 3**
OPE			
η_{KK}	-0.836^{***} (0.197)	-1.21^{***} (0.193)	-0.928^{***} (0.214)
η_{LL}	-0.765^{***} (0.054)	-0.502^{***} (0.053)	-0.582^{***} (0.051)
η_{EE}	-0.971^{**} (0.424)	-0.427 (0.263)	-1.138^{***} (0.347)
η_{MM}	-0.621^{***} (0.139)	-0.701^{***} (0.136)	-0.509^{***} (0.191)

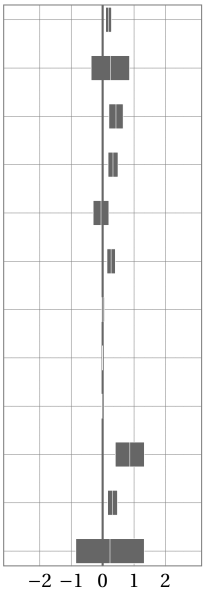


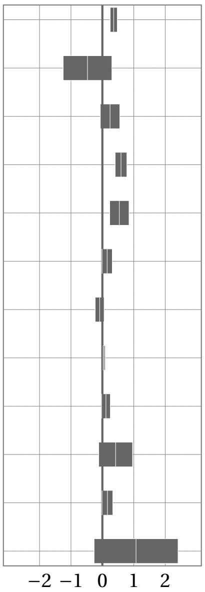




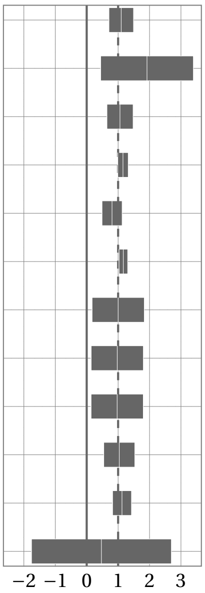
	Subset 1	**Subset 2**	**Subset 3**
CPE			
η_{LK}	0.262^{***} (0.049)	0.189^{***} (0.046)	0.361^{***} (0.058)
η_{EK}	1.082 (0.728)	0.244 (0.311)	-0.474 (0.396)
η_{MK}	0.223^{*} (0.123)	0.424^{***} (0.116)	0.244 (0.159)
η_{KL}	0.390^{***} (0.072)	0.329^{***} (0.081)	0.593^{***} (0.096)
η_{EL}	0.041 (0.155)	-0.052 (0.127)	0.540^{***} (0.157)
η_{ML}	0.400^{***} (0.063)	0.269^{***} (0.068)	0.152^{*} (0.083)
η_{KE}	0.030 (0.020)	0.016 (0.021)	-0.086 (0.072)
η_{LE}	0.001 (0.049)	-0.002 (0.005)	0.060^{***} (0.017)
η_{ME}	-0.002 (0.017)	0.008 (0.018)	0.113 (0.072)
η_{KM}	0.416^{*} (0.229)	0.865^{***} (0.236)	0.422 (0.275)
η_{LM}	0.502^{***} (0.080)	0.315^{***} (0.079)	0.161^{*} (0.088)
η_{EM}	-0.153 (1.128)	0.234 (0.555)	1.071 (0.682)

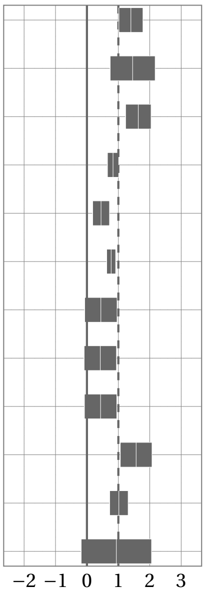


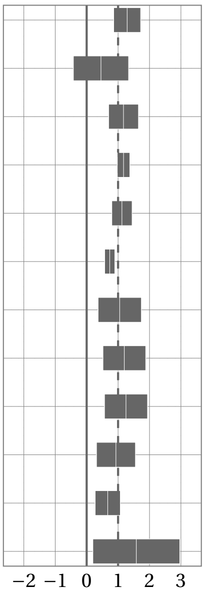




	Subset 1	**Subset 2**	**Subset 3**
MES			
σ^{m}_{LK}	1.098^{***} (0.200	1.399^{***} (0.196)	1.289^{***} (0.218)
σ^{m}_{EK}	1.919^{**} (0.754)	1.455^{***} (0.366)	0.455 (0.448)
σ^{m}_{MK}	1.059^{***} (0.213)	1.634^{***} (0.207)	1.172^{***} (0.243)
σ^{m}_{KL}	1.155^{***} (0.085)	0.831^{***} (0.092)	1.174^{***} (0.101)
σ^{m}_{EL}	0.806^{***} (0.164)	0.449^{***} (0.137)	1.122^{***} (0.165)
σ^{m}_{ML}	1.165^{***} (0.071)	0.771^{***} (0.073)	0.734^{***} (0.083)
σ^{m}_{KE}	1.001^{**} (0.425)	0.443^{*} (0.264)	1.051^{***} (0.352)
σ^{m}_{LE}	0.972^{**} (0.424)	0.425 (0.263)	1.198^{***} (0.347)
σ^{m}_{ME}	0.969^{**} (0.424)	0.434^{*} (0.263)	1.251^{***} (0.350)
σ^{m}_{KM}	1.037^{***} (0.252)	1.566^{***} (0.258)	0.931^{***} (0.316)
σ^{m}_{LM}	1.123^{***} (0.154)	1.016^{***} (0.151)	0.670^{***} (0.204)
σ^{m}_{EM}	0.468 (1.136)	0.936 (0.572)	1.580^{**} (0.706)







Notes: The symbols *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively. Asymptotic standard errors in parentheses.

B Concavity and Specification Tests

Table 10: Concavity in the Translog and the Linear Logit Model

Eigenvalues	none			linear trend			quadratic trend			quadratic and linear trend		
	Subset 1	Subset 2	Subset 3	Subset 1	Subset 2	Subset 3	Subset 1	Subset 2	Subset 3	Subset 1	Subset 2	Subset 3
Linear Logit												
λ_1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
λ_2	-0.009	-0.011	-0.039	-0.009	-0.009	-0.043	-0.009	-0.009	-0.042	-0.009	-0.009	-0.042
λ_3	-0.270	-0.282	-0.312	-0.268	-0.270	-0.285	-0.268	-0.273	-0.297	-0.268	-0.270	-0.277
λ_4	-0.443	-0.473	-0.335	-0.442	-0.519	-0.405	-0.441	-0.526	-0.386	-0.441	-0.521	-0.383
Pct. of sample concavity	100	100	87.2	100	100	90.0	100	100	88.8	100	100	89.9
Translog												
λ_1	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.005	0.000	0.000	0.006	0.000
λ_2	-0.004	-0.008	-0.050	-0.040	0.000	-0.006	-0.008	0.000	-0.011	-0.008	0.000	-0.010
λ_3	-0.282	-0.264	-0.256	-0.282	-0.258	-0.253	-0.279	-0.259	-0.261	-0.280	-0.258	-0.249
λ_4	-0.438	-0.459	-0.347	-0.438	-0.480	-0.425	-0.436	-0.479	-0.413	-0.433	-0.479	-0.416
Pct. of sample concavity	82.6	89.7	96.5	84.7	10.9	30.9	100	15.5	39.0	100	12.6	37.0

Notes: The gray-shaded areas indicate our specification choice based on LR-tests for the linear logit model and the translog model.

C Estimated Parameters

Table 11: Estimated Parameter Values from the Systems of Equations

	Linear Logit			Translog		
	Subset 1	Subset 2	Subset 3	Subset 1	Subset 2	Subset 3
β_{KK}	-0.3261 (1.40383)	-2.8252^{**} (1.37144)	-1.4632 (1.89095)	-0.0146 (0.04405)	-0.0859^{**} (0.03973)	-0.0325 (0.04697)
β_{KL}	-0.1439 (0.22205)	-0.1153 (0.24317)	0.4746^{*} (0.28905)	0.0115 (0.01667)	-0.0062 (0.01671)	0.0510^{**} (0.02104)
β_{KE}	2.6823^{**} (1.30739)	0.7123 (1.26284)	-4.1125^{**} (1.8406)	0.0054 (0.00446)	0.0005 (0.00428)	-0.0278^{*} (0.01588)
β_{KM}	0.2512 (0.53995)	1.4241^{***} (0.4757)	0.7326 (0.76975)	-0.0023 (0.05161)	0.0916^{*} (0.04804)	0.0093 (0.06072)
β_{LL}	-0.0876 (0.34239)	0.3397 (0.3597)	0.2412 (0.46448)	-0.0355^{*} (0.0183)	0.0499^{***} (0.01913)	0.0209 (0.01845)
β_{LE}	-0.3215 (0.34582)	-0.8072^{**} (0.35269)	0.0108 (0.4639)	-0.0019^{*} (0.00096)	-0.0057^{***} (0.00174)	0.0072 (0.00629)
β_{LM}	0.1518 (0.1605)	-0.2123 (0.16274)	-0.5160^{**} (0.20774)	0.0259 (0.02718)	-0.0380 (0.02806)	-0.0791^{**} (0.03152)
β_{EE}	-25.0307^{***} (1.12522)	13.6234^{***} (1.09236)	-1.8234 (1.52994)	0.0001 (0.00268)	0.0077^{**} (0.00362)	-0.0071 (0.01391)
β_{EM}	-1.0517^{*} (0.6342)	-0.7720 (0.53985)	2.5192^{***} (0.95967)	-0.0036 (0.00699)	-0.0026 (0.00775)	0.0277 (0.02741)
β_{MM}	-0.2413 (0.85543)	-0.4695 (0.74858)	-0.1279 (1.2455)	-0.0200 (0.05867)	-0.0511 (0.05643)	0.0421 (0.07306)
$\beta_{lin.trend}$		-0.0109^{***} (0.00417)	-0.0136^{**} (0.00536)	-0.0004^{***} ($1e{-}04$)		
$\beta_{sq.trend}$				$3e-05^{***}$ ($1e{-}05$)		
β_{y1}	0.0010 (0.0407)	-0.1820^{***} (0.02987)	-0.0660^{**} (0.03257)	0.0175^{***} (0.00299)	0.0028 (0.00317)	0.0182^{***} (0.00334)
β_{y2}	-0.3025^{***} (0.03541)	-0.3755^{***} (0.02483)	-0.3589^{***} (0.02521)	-0.0550^{***} (0.00382)	-0.0629^{***} (0.00369)	-0.0635^{***} (0.00327)
β_{y3}	-0.2746^{***} (0.04123)	-0.2315^{***} (0.02563)	-0.2133^{***} (0.04538)	-0.001^{***} (0.00021)	-0.0005^{*} (0.00027)	0.0002 (0.00116)
N	2,462	2,461	2,473	2,462	2,461	2,473

Notes: The symbols *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively. Cluster-robust standard errors in parentheses.

D Complementarity - Concavity Relationship

In this section, we test whether our finding of complementarity between capital and energy in the production process of energy-intensive firms depends on our definition of subset 3. Specifically, we exclude the less energy-intensive firms from the sample and re-estimate our the two production models with the remaining firms. Moreover, we test the percentage of observations that satisfy the concavity condition, since violations may indicate a misspecification of the underlying production model (Diewert and Wales, 1987).

The LL model generally performs better than the TL model regarding the concavity condition. In the LL model, concavity is satisfied for all observations in S1 and S2 (see Table 10 in Appendix B). However, the LL model has more violations of concavity in S3 than the TL model.[16] The subsample of energy-intensive firms exhibits significant heterogeneity with respect to energy shares. The energy shares of the energy-intensive firms range between 1.85% and 29.1%. This might be an explanation why the concavity condition is not satisfied for all the data points in the LL model.

Figure 12 discloses the relationship between the cross-price elasticities (η_{ke}, η_{ek}) and the concavity measure for the linear logit model and the translog model. In addition, the mean factor shares for each energy intensity subset is displayed. Specifically, the figure shows how the cross-price elasticity between capital and energy changes if the number of firms in S3 is decreased step by step to only include the firms with the highest energy shares. Contemporaneously, the percentage of observations which satisfy concavity are noted for each energy intensity subset.

Table 12: Degree of Complementarity and Concavity between Energy and Capital

Most energy intensive firms (N)	Linear Logit				Translog				Mean factor shares			
	η_{KE}	η_{EK}	t-val	Conc.	η_{KE}	η_{EK}	t-val	Conc.	s_{K}	s_{L}	s_{E}	s_{M}
40 % (2,967)	-0.05	-0.33	-1.01	94.2*	-0.07	-0.40	-0.99	97.0*	0.216	0.358	0.036	0.390
35 % (2,596)	-0.10	-0.63	-1.83	85.6*	-0.08	-0.47	-1.15	96.6*	0.219	0.362	0.039	0.381
33 % (2,473)	-0.09	-0.59	-1.69	90.0*	-0.09	-0.47	-1.20	96.5*	0.215	0.363	0.040	0.382
30 % (2,226)	-0.10	-0.62	-1.78	84.6*	-0.10	-0.50	-1.19	90.6*	0.220	0.358	0.042	0.379
25 % (1,857)	-0.12	-0.64	-1.60	89.0*	-0.10	-0.48	-1.02	99.1*	0.222	0.355	0.047	0.376
20 % (1,491)	-0.21	-1.03	-2.30	64.1*	-0.17	-0.76	-1.63	79.9*	0.228	0.353	0.052	0.367
15 % (1,116)	-0.21	-0.93	-1.86	9.6	-0.06	-0.22	-0.39	70.9*	0.234	0.348	0.060	0.359
10 % (748)	-0.35	-1.32	-2.35	2.4	-0.20	-0.67	-1.28	5.1	0.242	0.346	0.072	0.340

Notes: The table displays the degree of complementarity between capital and energy and the rate of observations that satisfy concavity as well as mean factor shares for different energy intensity subsets. * denotes whether concavity is satisfied at the respective sample means.

The complementarity between capital and energy increases if the size of the subset is decreased. In the 40% subset, the CPE of capital and energy is -0.05 and not statistically significant. The complementarity becomes stronger and significant at the 1% level as we

---

[16] Excluding the observations that violate concavity and re-estimating the two production models does not affect our elasticity estimates.

decrease the sample size of S3, with an CPE of -0.35 in the 10% subset. However, the concavity condition is only satisfied in 2.4% of observations, indicating a misspecification of the underlying cost function.

A look at the factor mean cost shares reveals that the share of capital increases when we exclude the less energy-intensive firms from S3. The capital share increases from 21.6% to 24.2%. Thus, the production of very energy-intensive firms tends to be more capital-intensive and less labor and material-intensive. At the same time, the complementarity between capital and energy increases. This finding suggest that very energy-intensive manufacturing firms would have to reduce their capital stock even more than less energy-intensive firms in S3, after energy price increases. Hence, the adaption costs for very energy-intensive firms tend to be higher.

Another important result of this exercise is that it does not suffice to simply test whether the concavity condition is satisfied at the sample means. In the subsample, where the 20% most energy-intensive firms are considered, only 64.1% of observations satisfy concavity (79.9% in the TL model), whereas concavity is still satisfied at the sample means. Only when the 15% (in TL 10%) most energy-intensive firms are considered, the concavity falls below 10%, and concavity as measured at the sample means is no longer satisfied. Low concavity rates point to severe specification problems and the underlying elasticity estimates are very likely to be biased.

E Distribution of Observations over Sectors and Subsets

Table 13: Manufacturing Sectors and Divisions

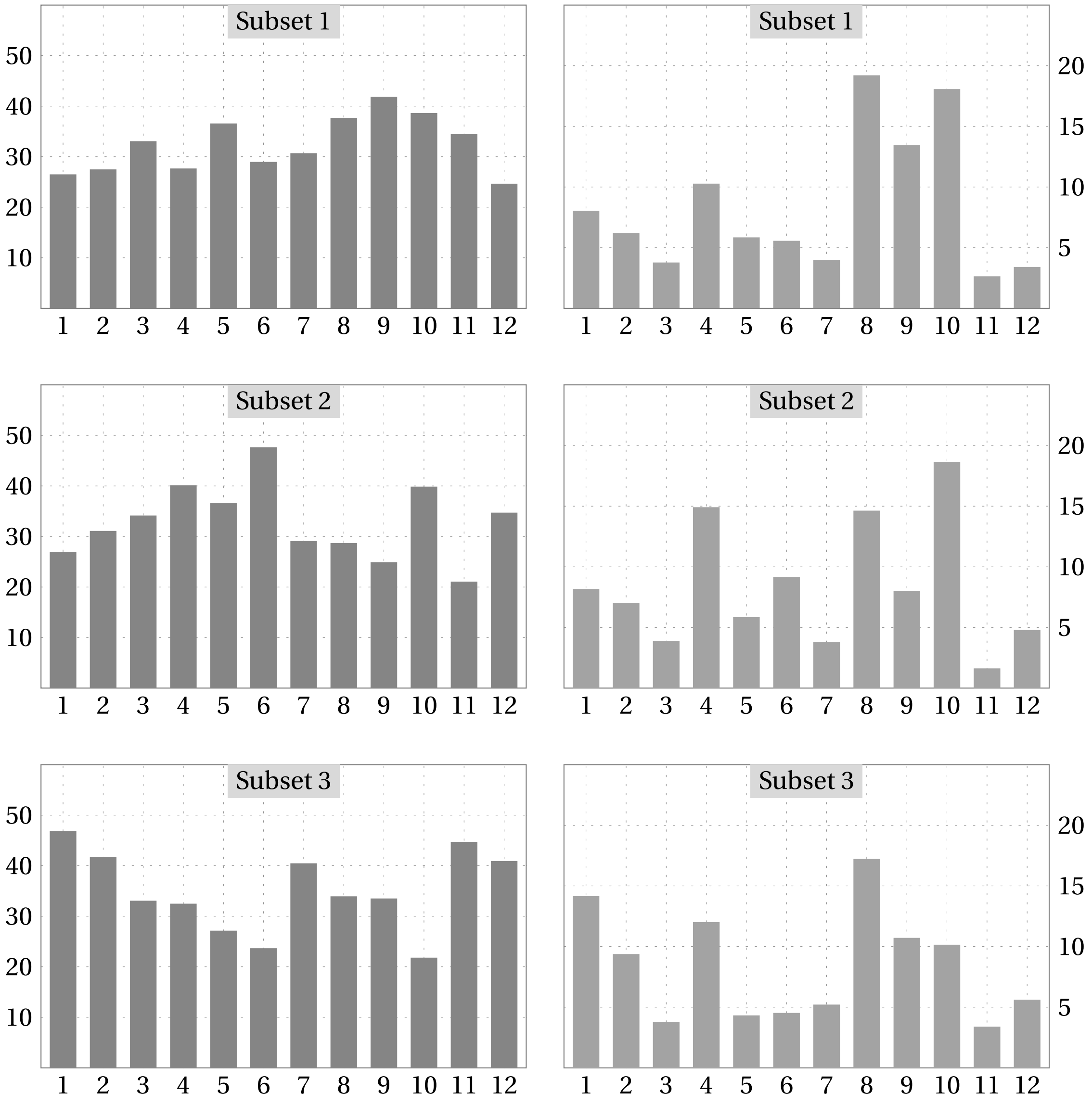
Sector	Division	Industry Description	Obs.
1	15,16	Food products, beverages and tobacco products	746
2	17-19	Textiles, wearing apparel, leather and related products	555
3	20	Wood, products of wood and cork	279
4	21,22	Paper, paper products, printing and publishing	914
5	24	Chemicals, chemical and pharmaceutical products	392
6	25	Rubber and plastic products	471
7	26	Other non-metallic mineral products	317
8	27,28	Basic metals and fabricated metal products	1,256
9	29	Machinery and equipment n.e.c.	790
10	30-33	Electrical equipment, electronic and optical products	1,152
11	34,35	Motor vehicles and other transport equipment	186
12	36,37	Furniture and other manufacturing	338

Notes: Divisions according to NOGA 2002 industrial classification of Switzerland, 2-digit. *n.e.c.*: not elsewhere classified. Sector 12 is a residual division, where the production processes, input materials and use of the produced goods can vary widely.

Table 14: Distribution of Observations over Sectors and Subsets

Subset	1	2	3	4	5	6	7	8	9	10	11	12	N
1	197	152	92	252	143	136	97	472	330	444	64	83	2,462
2	200	172	95	366	143	224	92	359	196	458	39	117	2,461
3	349	231	92	296	106	111	128	425	264	250	83	138	2,473
All	746	555	279	914	392	471	317	1,256	790	1,152	186	338	7,396

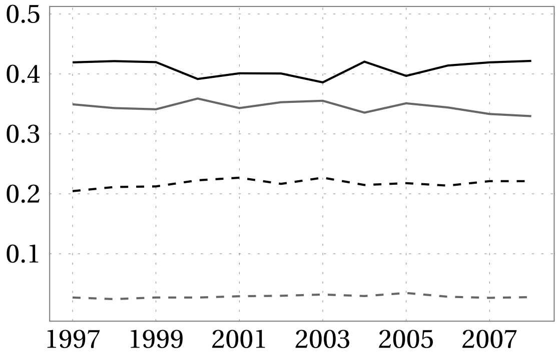
Figure 3: Distribution of observations Within the Subsets



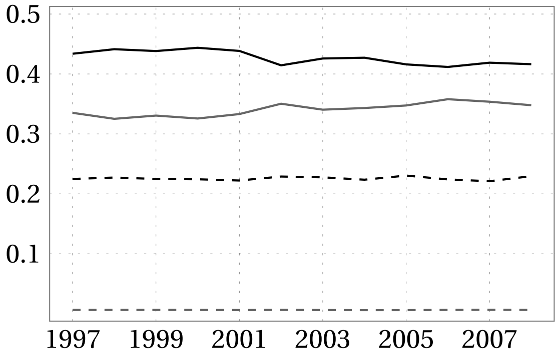
Notes: The panels on the left display the rate of observations as percentages of total observations of each sector. The panels on the right display the rate of observations as the percentage of total observations within the respective subset.

F Factor Cost Shares

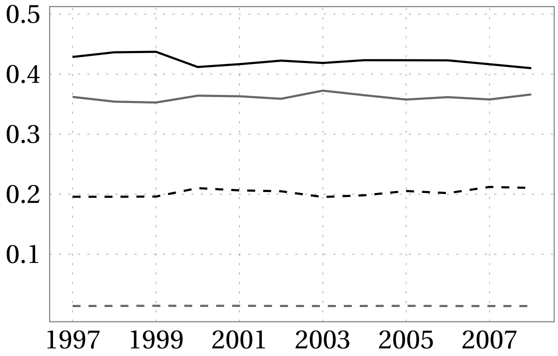
Figure 4: Subset-specific Cost Shares



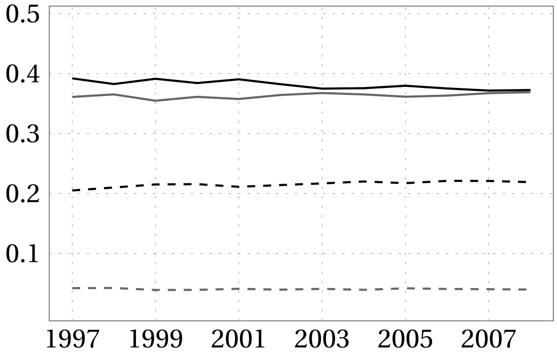
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.214	0.086	0.153	0.205	0.266	0.370
S_L	0.355	0.151	0.278	0.356	0.430	0.553
S_E	0.020	0.004	0.008	0.014	0.023	0.060
S_M	0.410	0.164	0.318	0.408	0.496	0.664
$N = 7,396$						**Whole sample**



	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.226	0.096	0.164	0.212	0.274	0.387
S_L	0.341	0.151	0.272	0.343	0.406	0.528
S_E	0.006	0.002	0.005	0.006	0.008	0.010
S_M	0.427	0.188	0.346	0.436	0.515	0.641
$N = 2,462$						**Subset 1**

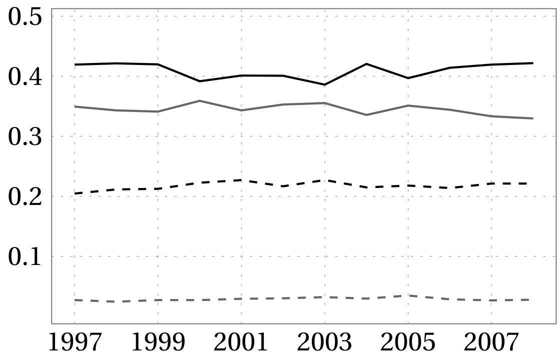


	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.202	0.080	0.145	0.199	0.249	0.339
S_L	0.361	0.134	0.279	0.368	0.439	0.577
S_E	0.014	0.010	0.012	0.014	0.016	0.018
S_M	0.422	0.183	0.328	0.407	0.497	0.735
$N = 2,461$						**Subset 2**

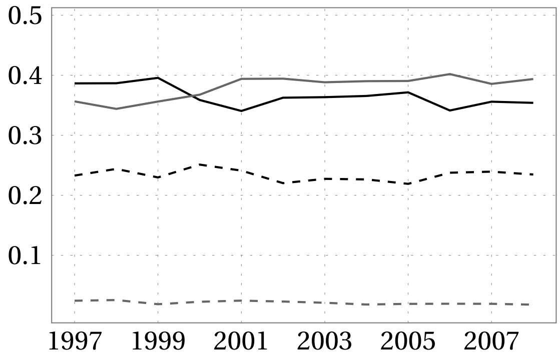


	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.215	0.067	0.153	0.222	0.293	0.444
S_L	0.363	0.157	0.247	0.327	0.443	0.548
S_E	0.040	0.038	0.043	0.057	0.086	0.137
S_M	0.382	0.110	0.229	0.338	0.458	0.605
$N = 2,473$						**Subset 3**

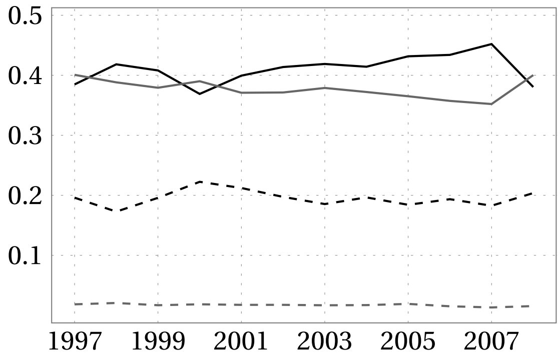
Figure 5: Sector-specific Cost Shares (I)



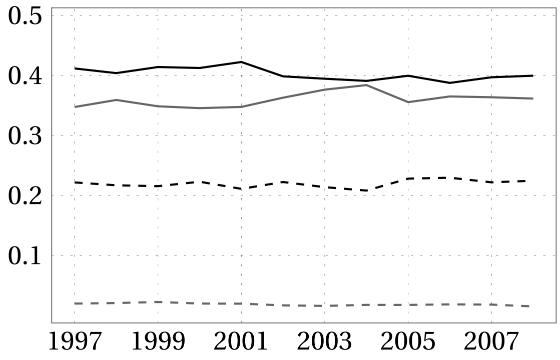
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.217	0.094	0.145	0.215	0.267	0.363
S_L	0.345	0.170	0.273	0.339	0.415	0.511
S_E	0.005	0.028	0.010	0.018	0.030	0.113
S_M	0.409	0.216	0.322	0.411	0.498	0.611
$N = 746$						**Sector 1**



	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.234	0.093	0.163	0.209	0.287	0.478
S_L	0.378	0.162	0.281	0.366	0.462	0.618
S_E	0.021	0.005	0.010	0.015	0.026	0.058
S_M	0.366	0.134	0.225	0.380	0.469	0.652
$N = 555$						**Sector 2**



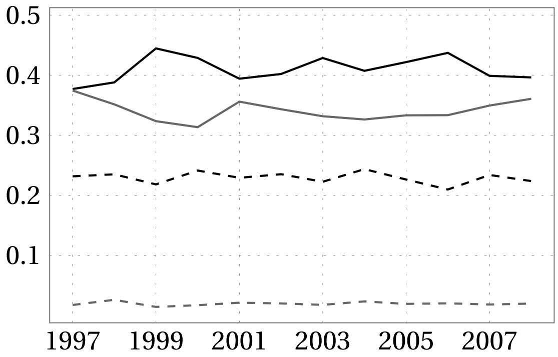
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.194	0.061	0.154	0.191	0.242	0.309
S_L	0.377	0.222	0.320	0.372	0.438	0.547
S_E	0.017	0.004	0.008	0.013	0.026	0.046
S_M	0.411	0.256	0.341	0.393	0.477	0.613
$N = 279$						**Sector 3**



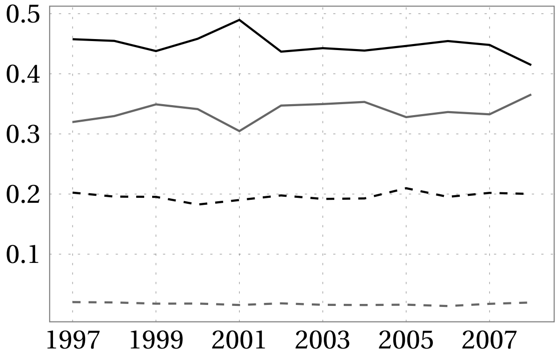
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.219	0.081	0.166	0.218	0.271	0.366
S_L	0.358	0.159	0.286	0.355	0.425	0.588
S_E	0.019	0.004	0.008	0.015	0.020	0.048
S_M	0.404	0.167	0.326	0.390	0.496	0.645
$N = 914$						**Sector 4**

—— Material —— Labor - - - Capital - - - Energy

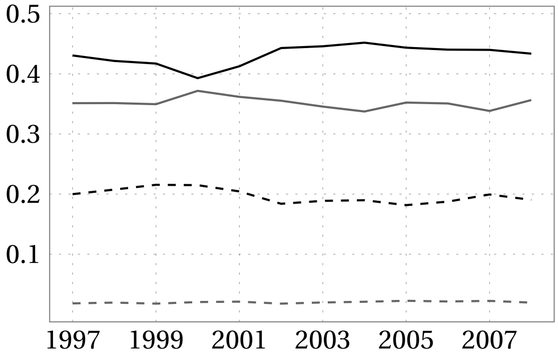
Figure 5: Sector-specific Cost Shares (II)



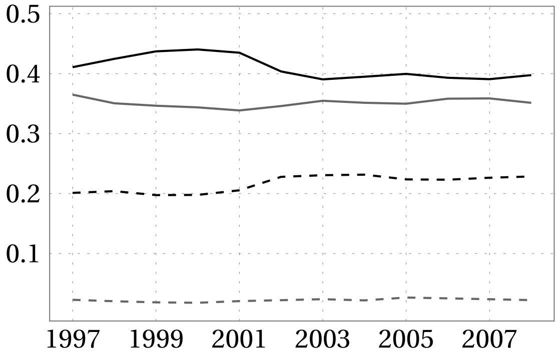
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.214	0.086	0.153	0.205	0.266	0.370
S_L	0.355	0.151	0.278	0.356	0.430	0.553
S_E	0.020	0.004	0.008	0.014	0.023	0.060
S_M	0.410	0.164	0.318	0.408	0.496	0.664
$N = 392$						**Sector 5**



	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.196	0.080	0.149	0.195	0.249	0.321
S_L	0.339	0.114	0.248	0.367	0.433	0.517
S_E	0.017	0.005	0.008	0.014	0.018	0.038
S_M	0.448	0.183	0.331	0.434	0.548	0.766
$N = 471$						**Sector 6**



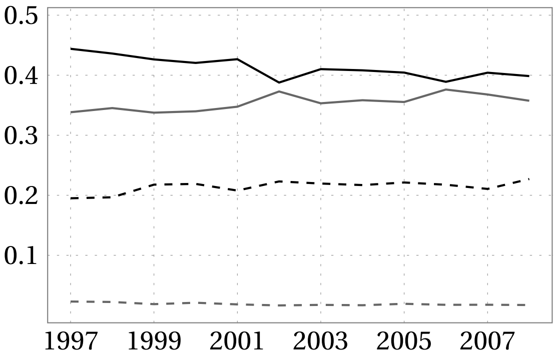
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.197	0.086	0.138	0.186	0.242	0.338
S_L	0.352	0.148	0.307	0.352	0.410	0.540
S_E	0.020	0.005	0.009	0.015	0.023	0.056
S_M	0.431	0.287	0.344	0.415	0.488	0.735
$N = 317$						**Sector 7**



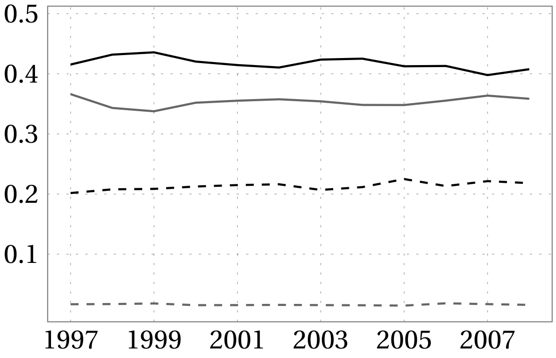
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.218	0.088	0.156	0.209	0.260	0.388
S_L	0.352	0.166	0.278	0.355	0.425	0.526
S_E	0.022	0.004	0.007	0.013	0.026	0.083
S_M	0.408	0.159	0.313	0.412	0.490	0.666
$N = 1,256$						**Sector 8**

—— Material —— Labor - - - Capital - - - Energy

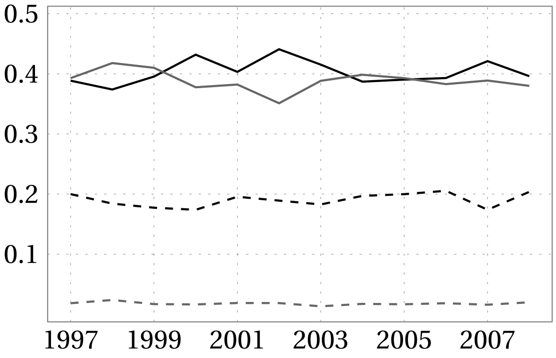
Figure 5: Sector-specific Cost Shares (III)



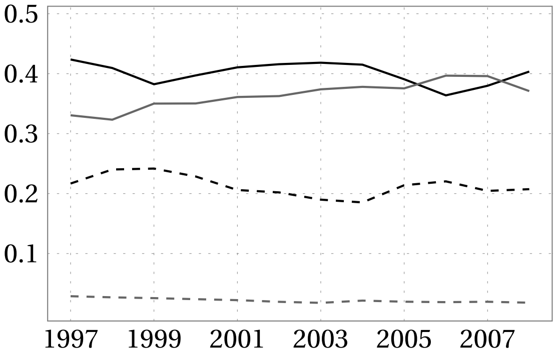
	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.213	0.087	0.147	0.190	0.265	0.403
S_L	0.351	0.174	0.259	0.348	0.430	0.554
S_E	0.019	0.002	0.006	0.013	0.022	0.076
S_M	0.417	0.134	0.304	0.425	0.510	0.657
$N = 790$						**Sector 9**



	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.213	0.098	0.157	0.205	0.261	0.341
S_L	0.353	0.148	0.281	0.362	0.420	0.538
S_E	0.016	0.004	0.008	0.012	0.017	0.043
S_M	0.417	0.213	0.331	0.410	0.494	0.642
$N = 1,152$						**Sector 10**



	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.191	0.073	0.151	0.176	0.220	0.339
S_L	0.388	0.223	0.306	0.380	0.464	0.587
S_E	0.018	0.005	0.008	0.014	0.022	0.047
S_M	0.404	0.196	0.335	0.405	0.474	0.581
$N = 186$						**Sector 11**

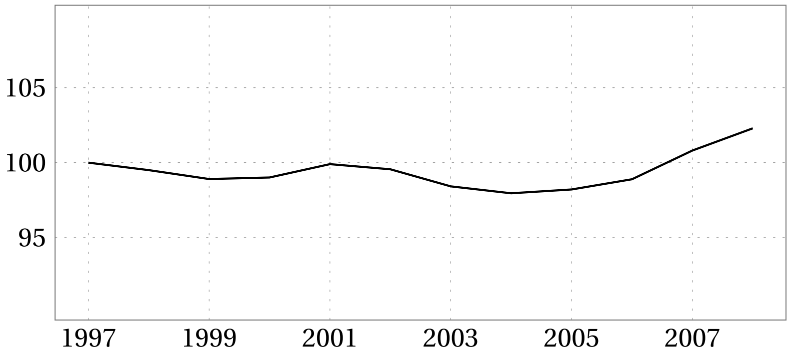


	Mn	$Q_{0.05}$	$Q_{0.25}$	$Q_{0.5}$	$Q_{0.75}$	$Q_{0.95}$
S_K	0.214	0.074	0.133	0.199	0.285	0.400
S_L	0.363	0.148	0.282	0.361	0.454	0.559
S_E	0.022	0.005	0.010	0.016	0.027	0.058
S_M	0.401	0.126	0.273	0.383	0.516	0.732
$N = 338$						**Sector 12**

G Descriptive Statistics on Factor and Output Prices

Capital Price Index

Figure 6: Capital Price Index



Notes: The mean annual price change of capital is 0.21, with a minimum, maximum and standard deviation of -1.15, 1.94 and 0.95, respectively.

Labor Price Indices

Figure 7: Labor Price Indices (I)

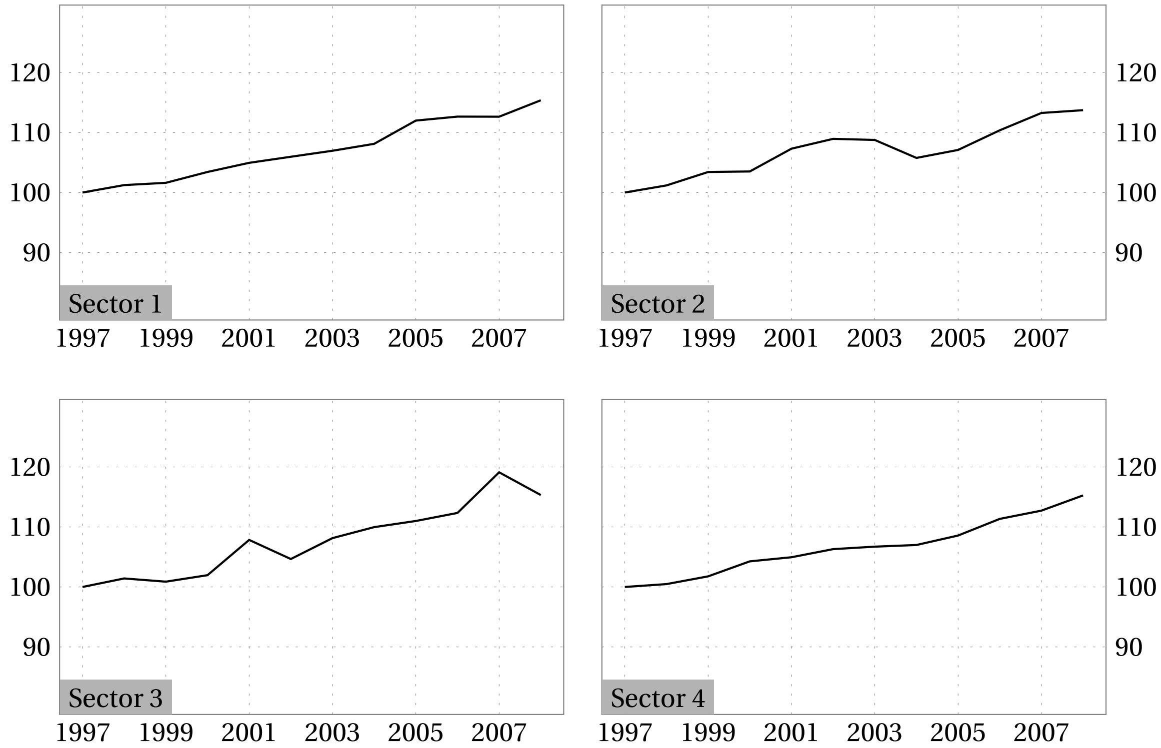
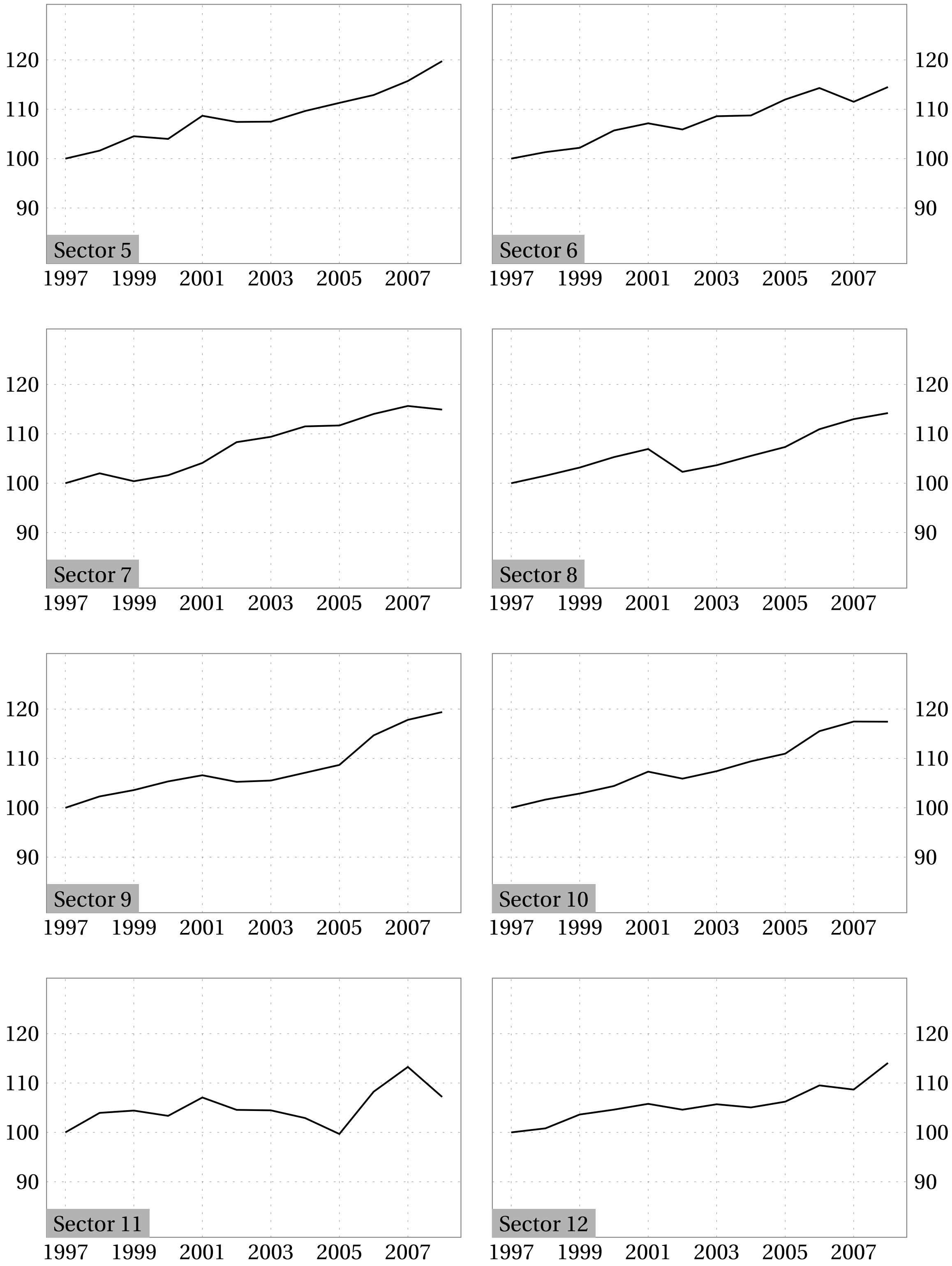


Figure 7: Labor Price Indices (II)



Energy Price Indices

Figure 8: Energy Price Indices (I)

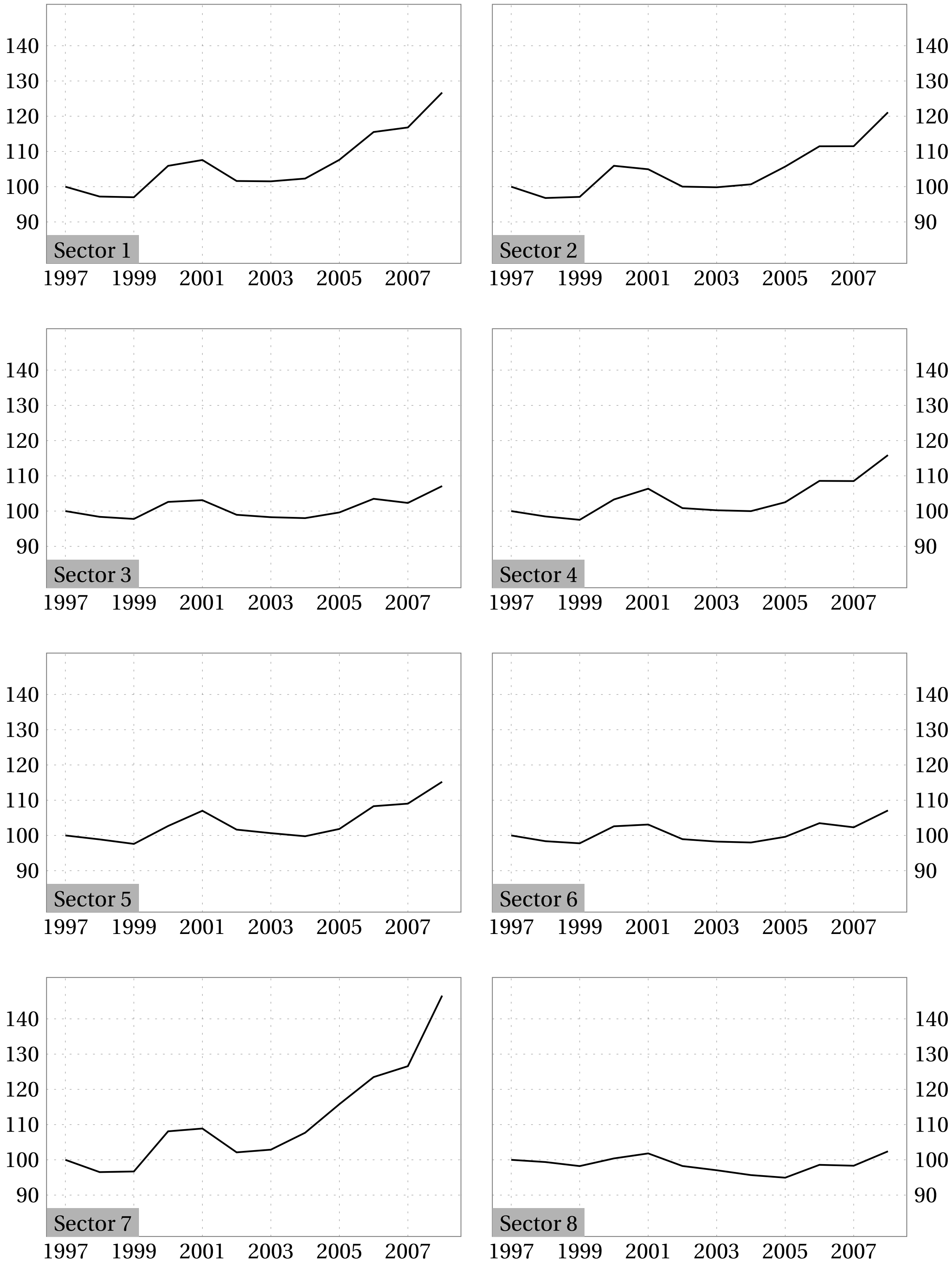
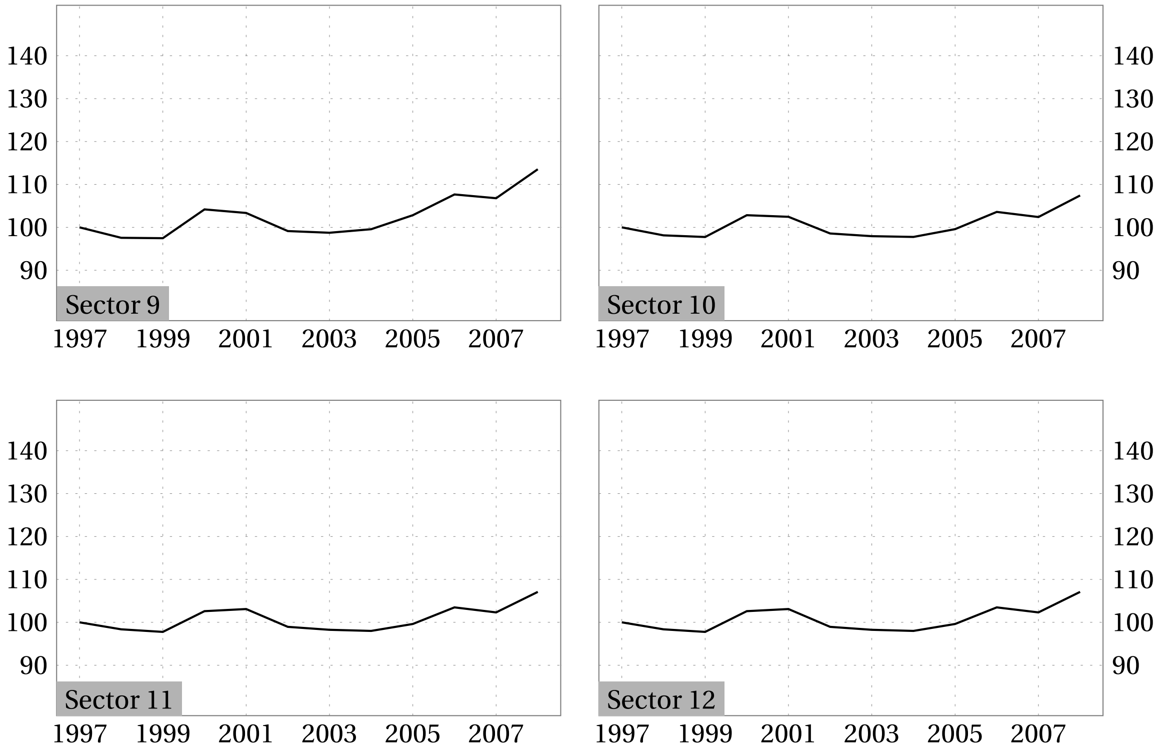


Figure 8: Energy Price Indices (II)



Material Price Indices

Figure 9: Material Price Indices (I)

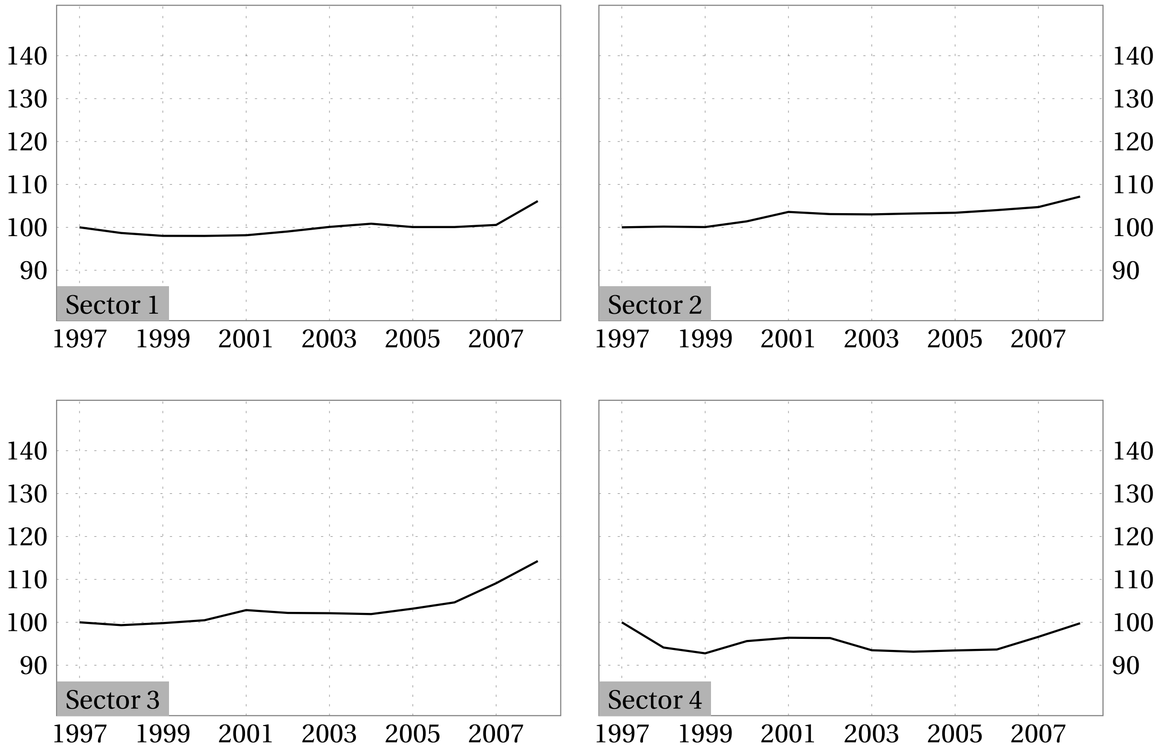
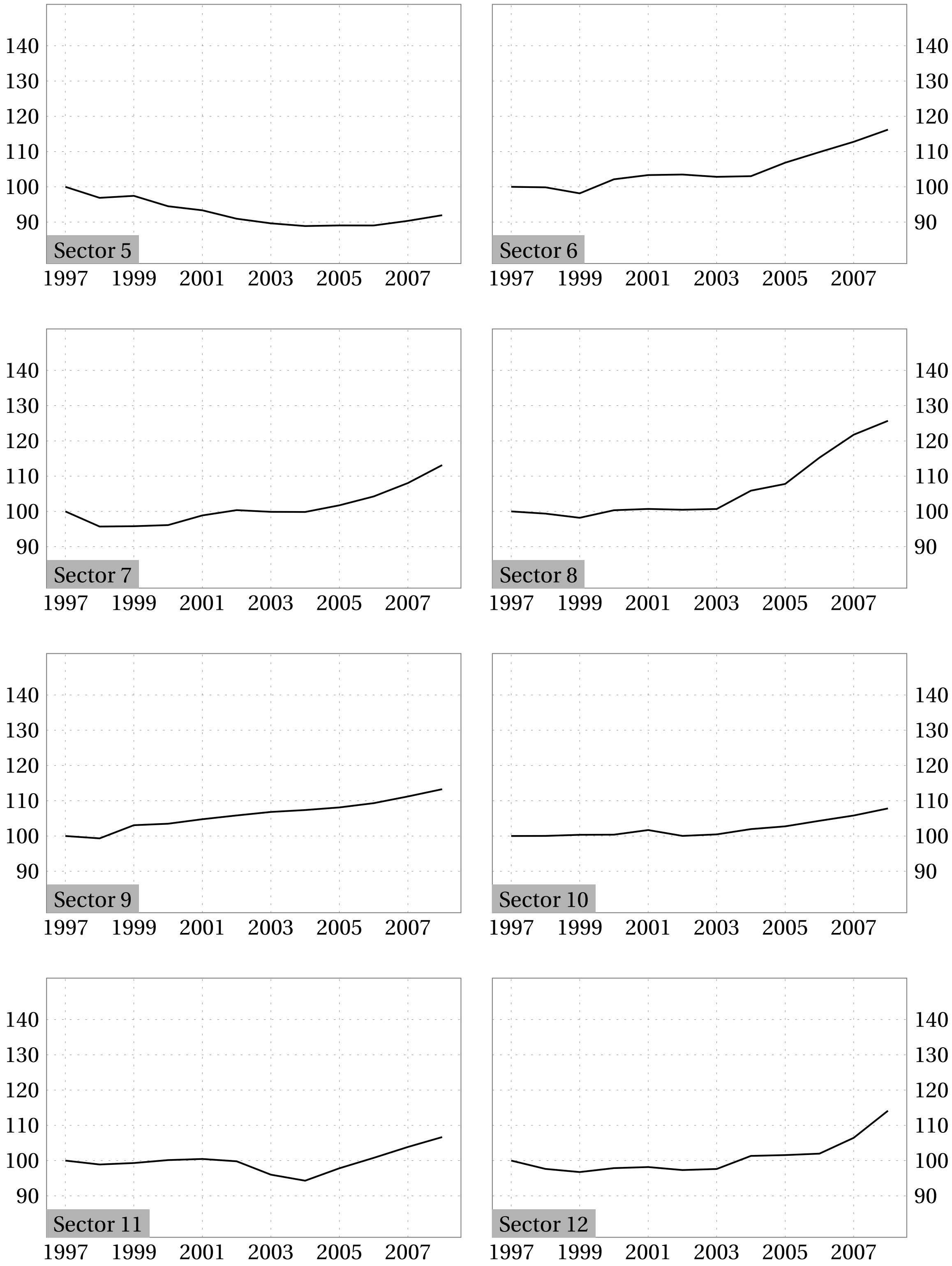


Figure 9: Material Price Indices (II)



Output Price Indices

Figure 10: Output Price Indices (I)

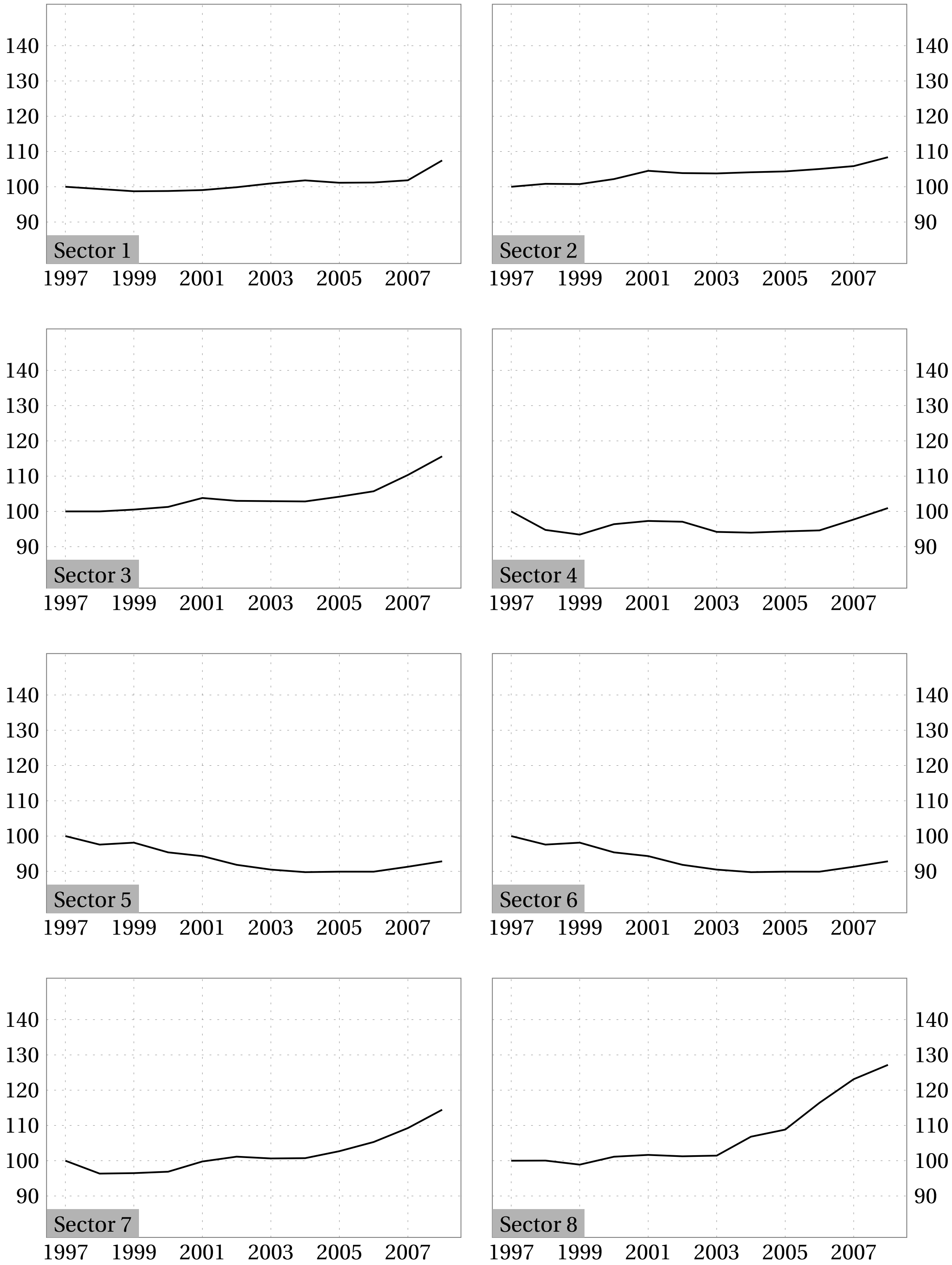
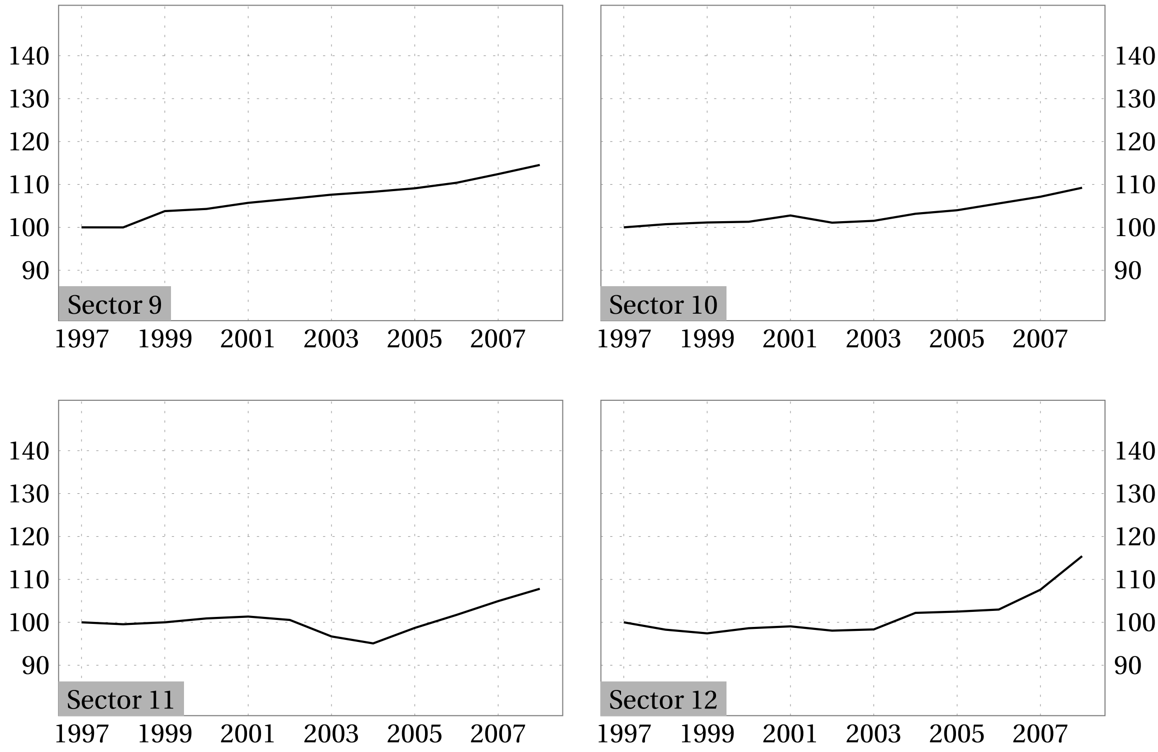


Figure 10: Output Price Indices (II)



Descriptive Statistics on Sectoral Factor Price Indices

Table 15: Sector-specific Annual Price Changes of Input Factors and Output

Sector	Labor				Energy				Material				Output			
	Ave.	Min	Max	SE	Ave.	Min	Max	SE	Ave.	Min	Max	SE	Ave.	Min	Max	SE
1	1.31	-0.01	3.58	1.01	2.27	-5.54	9.19	4.72	0.56	-1.32	5.53	1.81	0.67	-0.66	5.52	1.73
2	1.19	-2.75	3.67	1.79	1.85	-4.69	9.08	4.56	0.64	-0.49	2.33	0.93	0.74	-0.62	2.38	0.96
3	1.34	-3.18	6.03	2.97	0.66	-4.03	4.94	2.84	1.24	-0.66	4.74	1.86	1.34	-0.78	4.79	1.84
4	1.30	0.26	2.56	0.83	1.41	-5.18	6.78	3.74	0.02	-5.88	3.27	2.76	0.12	-5.25	3.32	2.67
5	1.66	-1.15	4.51	1.70	1.36	-5.00	6.35	3.63	-0.75	-3.12	1.78	1.71	-0.66	-2.81	1.69	1.60
6	1.25	-2.44	3.43	1.81	0.66	-4.03	4.94	2.84	1.39	-1.72	4.07	1.95	-0.66	-2.81	1.69	1.60
7	1.28	-1.57	4.05	1.54	3.72	-6.21	15.82	6.46	1.15	-4.29	4.71	2.44	1.26	-3.65	4.76	2.33
8	1.23	-4.32	3.36	1.93	0.24	-3.51	4.15	2.38	2.13	-1.19	6.91	2.77	2.24	-1.15	6.97	2.75
9	1.64	-1.26	5.51	1.66	1.22	-4.08	6.89	3.59	1.15	-0.67	3.76	1.10	1.25	-0.01	3.80	1.02
10	1.48	-1.32	4.11	1.38	0.69	-3.79	5.19	2.92	0.69	-1.63	1.90	1.01	0.81	-1.63	1.95	1.00
11	0.71	-5.36	8.59	4.07	0.66	-4.03	4.94	2.84	0.61	-3.81	3.73	2.36	0.71	-3.83	3.80	2.35
12	1.22	-1.12	4.96	1.82	0.66	-4.03	4.94	2.84	1.24	-2.36	7.22	2.79	1.35	-1.71	7.26	2.74

Chapter 2: Price and Income Elasticities of Swiss Households

1 Introduction

The Swiss government has decided to phase out nuclear power and to reduce CO_2 emissions until 2020 by 20 percent below 1990 levels. To secure long-term energy supply, the objective of the Swiss government is, among the promotion of renewable energy sources, to substantially reduce overall energy consumption and the associated CO_2 emissions (Energy Strategy 2050). In Switzerland, households account for approximately 29 percent of total energy consumption and substantially more if energy used in private transportation is taken into account.[1] Our contribution is aimed at a better understanding of households' energy consumption behavior. This will be key to achieve the objectives of the energy transition in Switzerland.

The literature on energy demand finds large variations in households' energy consumption between countries and household types (Withana et al., 2013). Factors such as regulations in place, the price mix of energy sources and the technologies in use in a country influence the actual consumption behavior of households. There is a number of studies that have estimated demand elasticities for different energy sources of the residential sector in Switzerland. For example, Baranzini and Weber (2013) estimate the elasticity of gasoline demand in Switzerland. They find short-run price elasticities of -0,09 and long-run elasticities of -0,34. Bernstein and Madlener (2011) estimate residential electricity demand elasticities for several OECD countries including Switzerland. They find long-run price elasticities between -0,09 and -0,23. Income elasticities are above unity with values between 1,34 and 1,72. Another example are the studies by Filippini (1999, 2011) on the elasticity of residential energy demand in Switzerland. The former study finds a demand elasticity of -0,30 for electricity and an income elasticity of 0,33. In the latter study, Filippini compares short- and long-run elasticities for peak and off-peak electricity consumption. The short-run peak elasticities vary between -0,77 and -0,84 and the long-run peak elasticities between -1,60 and -2,26. The off-peak elasticities are similar but of slightly lower magnitude. In a recent study, Filippini et al. (2015) estimate price elasticities for residential electricity consumption. Therefore, the authors use a promising index based on the stock of electrical appliances. Filippini et al. find short-run elasticities of -0,4 and long-run elasticities vary between -0,4 and -0,6. All these studies have in common that they rely on single equation models or very basic consumer demand models. In contrast, the employment of sophisticated consumer demand models offer interesting insights on consumption patterns and complement the results of the above mentioned studies that can only take substitution possibilities with other goods into account to a certain extent.

Instead of using a single equation model such as the widely used double-log models or error correction models that (implicitly or explicitly) assume that energy is separable from other consumption goods, we employ a flexible system of demand equations that does not rely on the separability assumption and is consistent with demand theory. This allows us to reflect households' consumption behavior taking into account potential substitution possibilities between energy and other consumption goods. Moreover, it enables us to examine the link between income and the demand for energy. Specifically, we employ the Exact Affine

---

[1] In 2013 the energy use of households was 259,950 TJ and that of private and public transportation (households, industries and agriculture) 313,220 TJ (Overall Energy Statistics for Switzerland, 2013).

Stone Index (EASI) demand system to estimate elasticities and Engel curves for ten expenditure categories, including energy and transportation. In order to capture both static and dynamic effects, we use a repeated cross-section and a constructed pseudo panel dataset on Swiss households from 2001 to 2011 and estimate own-price, cross-price and income elasticities as well as Engel curves. Moreover, we compare the consumption patterns of particular household types such as singles, couples, families or car-owners.

Our results provide evidence that in Switzerland, households' transportation is price inelastic with elasticity estimates between -0.18 and -0.08. Energy use on the other hand is close to a unit elasticity, similar to most other consumption categories we consider. Exceptions are the price elastic groups food out and recreation. Cross-price elasticities of private transportation and energy use vis-a-vis the other categories are relatively modest in magnitude. However, we find significant elasticities indicating that transportation is a complement to housing, clothing and food in, and a substitute to food out and household operations. Energy is a significant complement to household operations and substitutable with food in. The estimated income elasticities show that food in, energy, housing and communication are necessity goods, while food out, clothing, household operations and recreation tend to be luxury goods. The income elasticity of private transportation is unit elastic.

The Engel curves of private transportation, housing and clothing are S-shaped, indicating the importance of our model choice for these categories. The Engel curve of energy is strictly decreasing as is the one for food in and communication. Moreover, we find substantial differences of consumers' energy expenses when comparing different household types. For example, the comparison of the Engel curves of homeowners and tenants shows that the curve of tenants runs halfway below the curve of homeowners. This difference can only partly be explained by the fact that tenants pay a portion of their energy expenses as part of their additional property expenses. In fact, the remaining discrepancy results from differences in the household size, the dimension of the living area and distributional differences in urban and rural areas. As a further result, we find differences between households with a car and households without a car regarding private transportation behavior. Specifically, while car owners spend a higher share of their income on transportation for all income levels, the Engel curve is slightly decreasing while the Engel curve of non-owners is mostly increasing with income.

The remainder of the paper is organized as follows: Section 2 introduces the EASI demand system and shows how price and income elasticities as well as Engel curves are derived. Section 3 shows how the pseudo panel is constructed from the repeated cross section data and outlines the estimation approach. Section 4 describes the employed data, Section 5 presents the results and Section 6 concludes.

2 Modeling Approach

2.1 The EASI Demand System

The Exact Affine Stone Index (EASI) demand system, proposed by Lewbel and Pendakur (2009), belongs to the class of consumer demand models such as the Almost Ideal Demand System (AIDS) and the Quadratic Almost Ideal Demand System (QAIDS).[2] It possesses several advantages over the latter two consumer demand models. First, real expenditures can be considered up to an arbitrary higher order polynomial enabling the Engel curves to assume

---

[2] Examples of empirical studies using Swiss data and using the AIDS or the QUAIDS model are Abdulai (2002) on food categories using a QUAIDS model and Filippini (1995) on electricity using a rudimentary AIDS model.

any shape. Secondly, interactions of demographic characteristics with prices and expenditures can be included easily. Finally, linearity in parameters and additive error terms, make empirical implementation and interpretation straightforward. Results from studies based on the family of consumer demand models offer therefore interesting insights on consumption patterns and complement the results of related demand models that do not take into account substitution possibilities with other goods.

According to (Lewbel and Pendakur, 2009), the class of EASI cost functions can be characterized by the following equation:

$$C(\mathbf{p},u,\mathbf{z},\varepsilon) = u + \mathbf{p}'\mathbf{m}(u,\mathbf{z},\varepsilon) + T(\mathbf{p},\mathbf{z}) + S(\mathbf{p},\mathbf{z})u, \tag{1}$$

where $\mathbf{p}$ is the log of the price vector of J goods, u is utility, $\mathbf{z}$ are demographic characteristics and ε is an additive error term. The EASI model allows to include interaction terms among the variables of prices, expenditures and demographic characteristics. For the estimation of the EASI demand system, the authors derive the implicit Marshallian demand functions and a measure of real expenditures.

The first step is to derive Hicksian demand functions from the EASI cost function (Equation (1)) by applying Shepard's lemma. The Hicksian demand, e.g. the vector of budget shares $\mathbf{w} = \omega(\mathbf{p},u,\mathbf{z},\varepsilon)$, is a function of $\mathbf{p}$, $\mathbf{z}$, ε and the respective utility level u. Then, Lewbel and Pendakur (2009) suggest to express the utility level u by a function $g(\mathbf{w},\mathbf{p},x,\mathbf{z})$ and call it implicit utility y. Substituting this expression into Hicksian demands leads to a modified version of Marshallian demand, what the authors call implicit Marshallian demand function $\mathbf{w} = \omega(\mathbf{p},y,\mathbf{z},\varepsilon)$. Note that the expression for the implicit Marshallian demand function is equal to the Hicksian demand function after replacing unobservable utility level u by the implicit utility function y. The main advantage of this transformation is that the implicit utility function only depends on observed data ($\mathbf{w}$, $\mathbf{p}$, $\mathbf{z}$, x) and can be interpreted as a measure of real expenditures. To recapitulate, instead of obtaining Marshallian demands by solving for indirect utility u as a function of $\mathbf{p}$, $\mathbf{z}$ and x and afterwards substituting the term into Hicksian demands, Lewbel and Pendakur (2009) suggest a cost function with the objective of directly modeling utility as a function of shares, prices, household characteristics and income.

Lewbel and Pendakur (2009) propose the following EASI cost function specification for the empirical implementation:

$$C(\mathbf{p},u,\mathbf{z},\varepsilon) = u + \mathbf{p}'\left[\sum_{r=0}^{R}\mathbf{b}_r u^r + \mathbf{C}\mathbf{z} + \mathbf{D}\mathbf{z}u\right] + \frac{1}{2}\sum_{l=0}^{L} z_l \mathbf{p}'\mathbf{A}_l\mathbf{p} + \frac{1}{2}\mathbf{p}'\mathbf{B}\mathbf{p}u + \mathbf{p}'\varepsilon, \tag{2}$$

where the employed function for the term $\mathbf{m}(u,\mathbf{z},\varepsilon)$ in Equation (1) consists of a polynomial in y of degree R as well as interaction terms with demographic characteristics $\mathbf{z}$. Applying Shepard's Lemma and replacing u by y, we obtain the following implicit Marshallian demand function.

$$\mathbf{w} = \sum_{r=0}^{R}\mathbf{b}_r y^r + \mathbf{C}\mathbf{z} + \mathbf{D}\mathbf{z}y + \sum_{l=0}^{L} z_l \mathbf{A}\mathbf{p} + \mathbf{B}\mathbf{p}y + \varepsilon. \tag{3}$$

Integrating Equation (3) into Equation (2) and solving for u, respectively y, gives the closed-form solution for implicit utility (y) as presented in Equation (4). Implicit utility is an affine transformation of the log Stone index deflated expenditures (Lewbel and Pendakur, 2009). We simultaneously estimate Equation (3) and (4), using nonlinear three-stage least squares (3SLS) methods. Detailed information about the estimation method is given in Section 3.

$$y = g(\mathbf{w}, \mathbf{p}, x, \mathbf{z}) = \frac{x - \mathbf{p}'\mathbf{w} + \sum_{l=0}^{L} z_l \mathbf{p}'\mathbf{A}_l \mathbf{p}/2}{1 - \mathbf{p}'\mathbf{B}\mathbf{p}/2}. \tag{4}$$

2.2 Price and Income Elasticities

Following Hoareau et al. (2012), we can derive semi-elasticities of budget shares (w) with respect to prices ($\mathbf{p}$), demographic characteristics ($\mathbf{z}$) and real expenditures (y). The formula is displayed in Equation (5).

$$\zeta_i = \nabla_i \omega(\mathbf{p}, y, \mathbf{z}, \varepsilon) \qquad \text{for} \qquad i = \mathbf{p}, \mathbf{z}, y. \tag{5}$$

The estimated coefficients of the EASI model can directly be interpreted as marginal effects. The derivation of price and income elasticities is more cumbersome because we have to investigate how actual quantities change. Below, we present the expressions for price and the income elasticities based on the functional specification of Equation (2).[3]

Price elasticities measure the relative change in the quantity of good i (q_i) due to a relative change in the price of good j (p_j). Equation (6) depicts the expression of the cross-price elasticity (η_{ij}) and the own-price elasticity (η_{ii}).

$$\eta_{ij} \equiv \frac{\partial \ln q_i}{\partial \ln p_j} = \frac{H}{w_i}, \qquad \eta_{ii} \equiv \frac{\partial \ln q_i}{\partial \ln p_i} = \frac{H}{w_i} - 1, \tag{6}$$

$$\text{where } H = p_j \frac{\partial y}{\partial p_j} \left(\sum_{r=1}^{R} b_{ri} y^{r-1} + \sum_{l=1}^{L} d_{li} z_l + \sum_{j=1}^{I} b_{ji} \ln(p_j) \right) + \sum_{l=0}^{L} a_{lji} z_l + b_{ji} y.$$

Analogously, the impact of changes in income (x) on the demand of good j can be calculated as displayed in Equation (7):

$$\varepsilon_{ix} \equiv \frac{\partial \ln q_i}{\partial \ln x} = 1 + \frac{\sum_{r=1}^{R} b_{ri} y^{r-1} + \sum_{l=1}^{L} d_{li} z_l + \sum_{j=1}^{I} b_{ji} \ln(p_j)}{w_i}. \tag{7}$$

Engel curves allows an in-depth analysis of households' consumption patterns subject to their income. Specifically, an Engel curve describes how an households' demand for a good, expressed either as real expenditures or shares, varies as a function of income or total expenditures, holding prices constant (Lewbel, 2008). In contrast to related consumer demand models, Engel curves from the EASI model can replicate almost any shape over real expenditures. Moreover, empirical evidence clearly shows that the actual shape of an Engel curve depends on the good of interest and on households characteristics. The EASI model is able to explain much of the observed variation in households consumption behavior as interaction terms between observable characteristics, prices and income are included and it takes into account unobserved preference heterogeneity.

3 Methodology

3.1 Cross Section and Pseudo-Panel Data

The application of cross-section data allows us to catch the static long-term degree of consumer response with respect to price changes. Certainly, short-run effects might also be interesting when dealing with elasticity estimates and their magnitude. Unfortunately, the latter

---

[3] For a detailed derivation of price and income elasticities see Hoareau et al. (2012).

cannot be derived from cross-section data, as the specific individual demand adjustment over time is not observed. Instead, one needs to make use of panel data, tracing individuals i over time t. However, this type of data is rare in the majority of countries. In most instances, the survey design is according to the concept of repeated cross-sections, i.e. a collection of the same information for different individuals over time. Note however, that there are some severe drawbacks of using non-panel data. Baltagi (2005) provides an overview of specific benefits from using panel data instead based on Hsiao (2003) and Klevmarken (1989). Those include, among others, the possibility of controlling for individual heterogeneity as well as the gain of more informative data, more variability, less collinearity among the variables, more degrees of freedom and more efficiency. Moreover, panel data are better in catching the dynamic adjustment and in identifying and measure effects that are neither detectable in cross-section nor in pure time series data. Especially the latter two benefits of panel data are of interest if one seeks to distinguish static from dynamic consumer response to price and income changes.

Following the seminal idea of Deaton (1985), the use of pseudo panel data might—in our application—tackle the issue of catching the dynamic adjustment. Accordingly, rather than tracing individuals over time, one can provide a remedy by using "cohorts" instead. A cohort is defined as a group of individuals sharing certain time invariant characteristics and hence feature a fixed affiliation to the group. When cohort means are used as observations it is considered a pseudo panel. As Verbeek (2008) points out, besides the two dimensions of sample size N and time horizon T in genuine panel data, there are two more dimensions in the case of pseudo panel data. Those are the number of cohorts C and the number of observations per cohort n_C forming an inverse relationship per construction given fixed values for N and T. Among others, he distinguishes the most reasonable specifications in which either (i) $N \to \infty$, C fixed, so that $n_C \to \infty$ or (ii) $N \to \infty$ and $C \to \infty$, with n_C fixed. Given that the number of observations is typically limited in empirical applications, there is always a trade-off between the optimal number of cohorts and the number of observations per cohort.

One distinct advantage of this approach is the diminishing of sample attrition, a severe issue in some panel data sets. However, taking cohort means rather than individual observation can be costly in terms of an optimal information usage. A priori it is not clear whether static information on the micro-level is lost in this procedure or whether it was efficiently condensed for the benefit of information on dynamic response. Furthermore, the calculation of cohort means is done for a specific set of individuals rather than the whole population what might end up in measurement errors. However, if the groups are large enough, measurement errors can be ignored. As Bernard et al. (2011) conclude, there is no general inferiority of pseudo panel data towards "real" panel data. They determine a trade-off between more precise (static) information subject to attrition and the measurement error arising in more complete pseudo panels with additional dynamic information.

Following Verbeek (2008), one condition for the within estimator for pseudo panel data to be consistent is a genuine time variation in cohort averages used for estimation. Furthermore, according to Moffitt (1993) letting $n_C \to \infty$ and using asymptotics as in (i), the estimator for β arrives at consistency. However, Verbeek and Nijman (1992) show substantial measurement errors by small-sample bias to occur even in settings where $\bar{n}_c$ is large. This problem can usually resolved by applying the k-means algorithm for clustering the observation into cohorts with minimum variance within the cluster (cohesion) and maximum variance between them (separation).[4] This approach makes efficient use of information gained from specific consumption patterns caused by homogeneous and heterogeneous features.

---

[4] An alternative has been presented by Cottrell and Gaubert (2003), who use the neural network concept of Kohonen mapping as introduced by Kohonen (1989) to attain an optimal number of cohorts.

3.2 Estimation Approach

For the estimation of the EASI model, we follow Lewbel and Pendakur (2009) and estimate Equation (3) and (4) simultaneously, by using nonlinear three-stage least squares (3SLS) methods.[5] This estimation method allows us to account for potential endogeneity issues, while the symmetry conditions are satisfied. We base our estimation approach on a pooled regression using 3SLS on repeated cross section data and transformed pseudo-panel data with cohort fixed effects. While the first model approach is straightforward, the fixed effects model is stated explicitly below. Consider the following linear equation model with n individuals:

$$y_{nt} = \alpha_n + x'_{nt}\beta + \varepsilon_{nt}, \tag{8}$$

where y_{nt} is the endogenous variable, x_{nt} the exogenous variable at time t, while α_n is a random variable capturing the unobserved and time-constant heterogeneity across individuals (cohorts) n. Furthermore, β is the vector of coefficients and ε_{nt} denotes the error term with elements being *iid* over n and t. Before the fixed effects model can be estimated, the data has to be transformed. According to Cameron and Trivedi (2009), this is done by calculating the variables' mean over time in the individual-specific effects model.

$$\begin{aligned} &\bar{y}_n = \alpha_n + \bar{x}'_n\beta + \bar{\varepsilon}_n, \text{ with} \\ &\bar{y}_n \equiv \frac{1}{T}\sum_{t=1}^{T} y_{nt},\ \bar{x}_n \equiv \frac{1}{T}\sum_{t=1}^{T} x_{nt} \qquad \text{and} \qquad \bar{\varepsilon}_n \equiv \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{nt} \end{aligned} \tag{9}$$

Subsequently, the within transformation is performed by subtracting Equation (9) from (8) which yields the fixed effects model presented below.

$$\begin{aligned} y_{nt} - \bar{y}_n &= (x_{nt} - \bar{x}_n)'\beta + (\varepsilon_{nt} - \bar{\varepsilon}_n) \\ \ddot{y}_{nt} &= \ddot{x}'_{nt}\beta + \ddot{\varepsilon}_{nt}, \qquad n = 1,...,N \text{ and } t = 1,...,T \end{aligned} \tag{10}$$

This model framework is used to estimate the Equations (3) and (4) under the usual symmetry conditions for the level of prices $A_l = A'_l$, for all l and the prices interacted with implicit utility y $(B = B')$. As the individual-specific effect α_n is time-invariant it cancels out. The variables $\ddot{y}_{nt}$ and $\ddot{x}_{nt}$ vary within the observations of an cohort n. However, the correlation between individuals (cohorts) and over time is not considered. Consequently, the estimated standard errors are not valid and have to be corrected. Applying cluster-robust standard errors, treating each cohort as a cluster is the usual method of standard error correction. We employ an alternative possibility to estimate a cluster-robust covariance matrix, which consists in bootstrapping by resampling the series randomly k times. This procedure was first described in Efron (1979).

4 Data and Specification Tests

4.1 Data Description

We use data on household expenditures and demographic characteristics from the Swiss Household Budget Survey (HBS), gathered by the Swiss Federal Statistical Office (SFSO) for the period from 2001 to 2011. For the estimation of the EASI model, we consider monthly

---

[5] A consistent and efficient alternative would be the general methods of moments (GMM) estimator. However, (Lewbel and Pendakur, 2009, pp. 839) found that the weighting matrix is numerically less stable than 3SLS.

expenditures of the following ten categories: food and beverages (named in the following *food in*), meals in restaurants and hotels (*food out*), clothing and footwear (*clothing*), *energy*, *housing*, *household operations*, private transportation (*transportation*), *communication*, *recreation* and *health*.

The HBS contains information about the time period when the survey was conducted. This allows to apply monthly price variables, leading to 132 distinct price vectors, normalized to prices in January 2010. After excluding observations from households with monthly disposable incomes below 1,000 and above 20,000 CHF, as well as keeping only observations with positive expenditures for transportation, recreation, health and household operations, we are left with a total of 27,332 observations. From the information on households' expenditures, household-specific budget shares can be calculated for all categories. In line with Lewbel and Pendakur (2009), log prices are used and large durables such as washing machines, lawnmowers and cars are excluded.

Table 1: Descriptive Statistics on Household Consumption

Variable	Mean	SE	Min	Max	Variable	Mean	SE	Min	Max
Budget Shares					*Average Price Level*				
s.foodin	0.17	0.08	0.00	0.73	p.total	-0.04	0.03	-0.09	0.01
s.foodout	0.11	0.08	0.00	0.71	*Log Expenditures*				
s.cloth	0.05	0.06	0.00	0.57	x (nom)	8.30	0.45	6.83	9.87
s.ener	0.03	0.03	0.00	0.63	x (real)	8.34	0.44	6.91	9.9
s.hous	0.31	0.14	0.00	0.84	*Household Characteristics*				
s.furn	0.06	0.07	0.00	0.78	num persons	2.55	1.28	1	11
s.trans	0.07	0.06	0.00	0.83	num kids	0.55	0.92	0	8
s.com	0.04	0.03	0.00	0.36	*Household Dummies*				
s.recr	0.11	0.08	0.00	0.82	singles	0.21	0.41		
s.health	0.04	0.08	0.00	0.82	couples	0.37	0.48		
Log Prices					families	0.31	0.46		
p.foodin	-0.02	0.02	-0.08	0.02	others	0.11	0.31		
p.foodout	-0.06	0.05	-0.14	0.02	old HH	0.17	0.38		
p.cloth	-0.09	0.08	-0.24	0.05	young HH	0.16	0.37		
p.ener	-0.15	0.14	-0.35	0.15	sex	0.27	0.44		
p.hous	-0.07	0.05	-0.15	0.02	rent	0.51	0.50		
p.furn	-0.02	0.01	-0.03	0.01	car	0.83	0.37		
p.trans	-0.08	0.12	-0.28	0.20	*Seasonal Dummies*				
p.com	0.14	0.11	-0.01	0.28	q2	0.25	0.43		
p.recr	0.02	0.02	-0.05	0.04	q3	0.25	0.43		
p.health	0.00	0.01	-0.02	0.01	q4	0.24	0.43		

Table 1 provides an overview of summary statistics for the estimation sample. Housing represents by far the largest average share accounting for 31 percent of disposable income, followed by food in, recreation and food out, with shares above 10 percent. The budget shares for transportation, health, household operations, clothing, communication and energy range between 3 and 8 percent of income. The dataset is approximately balanced between homeowners and tenants, whereas only 27 percent of households are represented by a woman. Roughly, a fifth of households are single households, 37 percent are couples, 31 percent are families with children and 11 percent represent the remaining households. Since households are very diverse and heterogeneous, we define a reference household based on the demographic characteristics of the an average Swiss household to calculate meaningful Engel curves with ample confidence intervals. This reference household is defined as a family with two kids that owns at least one car, is a homeowner, and is represented by a middle-aged male reference person.

Figure 1: Monthly Price Indices by Expenditure Category

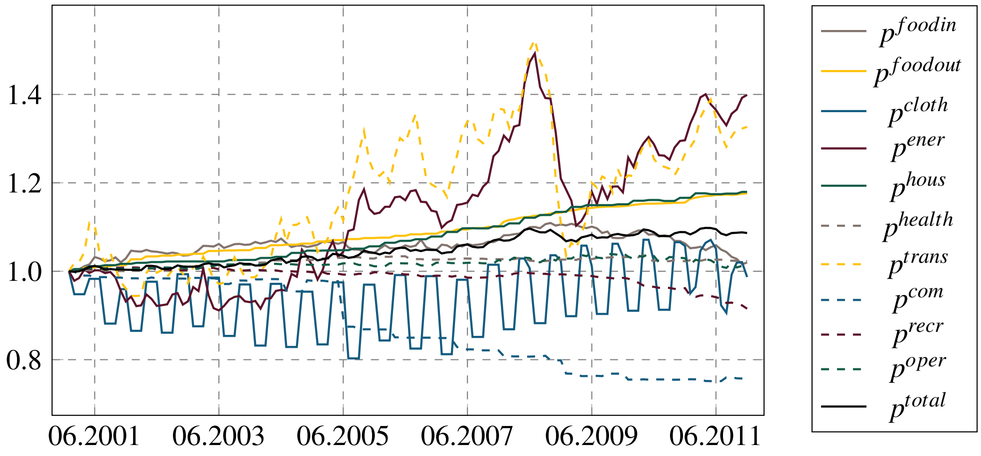


Figure 1 displays the price indices of the ten consumption categories over the period from 2001 to 2011. It shows substantial differences in the development of prices over time. The largest variations in prices is observed for the category energy. Energy prices started to rise in 2005 and peaked in 2008. Subsequently, energy price decreased considerably and began to rise again in 2009, resulting in 40 percent higher energy prices in 2011, compared to the price level in 2001. Since prices of gasoline and diesel depend on the oil price, a similar development is depicted for prices of private transportation, although less pronounced. The prices of housing and of food out have steadily increased over time, the price of food in shows only a moderate increase. On the other hand, the prices of communication have fallen after 2005 by roughly 30 percent and the prices of recreation have fallen after 2009 by approximately 10 percent until 2011 in Switzerland. The prices for health services and household operations were nearly constant over time. Finally, for some of the categories, seasonalities in prices are observed, especially for clothing. We include quarterly dummies into our estimation to account for these seasonalities.

Figure 2: Mean Budget Shares by Expenditure Category

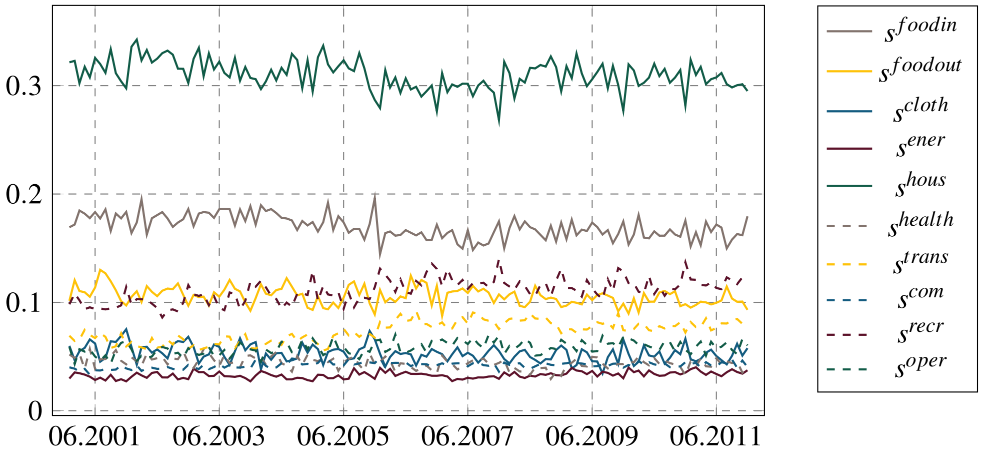


Figure 2 displays budget shares of the nine consumption categories over time. There is little variation in the magnitude of the budget shares. The most noticeable changes are increasing values for recreation and transportation. On the other hand, the mean shares of food in and housing slightly decrease over time. In summary, the average budget shares of the nine categories remain relatively constant over time.

The expenditure shares of the two categories energy and private transportation differ considerably. Table 2 displays the expenditure share for energy used at home. The shares are computed as expenses for energy divided by overall disposable income. In addition, we also show the absolute costs in CHF for energy that arise during one month. For the purpose of comparison, we normalize the monthly costs by dividing by the number of persons in a household. The differences in the consumption patterns between different household types do, in general, not depend on the income level. At the bottom, the average energy expenditures in CHF and relative to income, are displayed for the income quintiles. While the absolute expenses for energy are increasing with income, the relative share is decreasing.

Table 2: Distribution of Energy Shares by Household Type and Quintile

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household type										
Singles	6.60	78.49	3.42	64.63	3.12	73.30	2.69	79.11	2.12	95.56
Couples	6.47	121.35	4.31	122.51	3.67	129.12	3.19	140.58	2.60	175.84
Families	4.10	119.23	3.27	133.48	2.92	143.70	2.68	161.50	2.31	198.31
Others	5.01	139.41	3.90	166.78	3.42	178.47	2.96	191.85	2.90	259.31
Age										
Young	3.54	85.79	2.50	78.89	2.10	76.92	1.71	72.34	1.31	76.54
Middle Aged	4.88	121.40	3.66	129.91	3.32	136.83	2.92	142.98	2.41	163.99
Old	7.29	114.40	4.65	116.84	4.09	125.98	4.02	155.78	3.35	205.44
Housing Situation										
Owner	7.22	147.94	5.26	177.63	4.73	190.48	4.25	205.59	3.56	246.23
Tenant	3.30	74.54	2.42	71.77	2.12	73.72	1.82	75.46	1.41	81.85
Transport Type										
Carowner	5.49	125.72	3.85	130.67	3.43	136.11	2.99	141.09	2.52	168.98
Non-carowner	5.32	90.85	3.31	90.66	2.77	91.44	2.60	107.03	2.05	122.57
Average	5.44	114.56	3.69	119.09	3.26	124.79	2.90	133.13	2.41	158.64

Notes: Households' energy consumption at home by household type and income quintile.

Table 3 displays the expenditure share for private transportation by household type and income quintiles. The average expenditures for transportation are increasing in income. In contrast to energy, the relative expenses for transportation are also increasing with income. Not surprisingly, we find the largest differences between car owners and non-owners.

Table 3: Distribution of Transport Shares by Household Type and Quintile

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household type										
Singles	7.00	95.39	7.05	138.11	7.46	179.93	8.25	248.58	8.12	367.96
Couples	7.18	146.16	7.13	207.97	7.22	260.90	7.62	344.31	7.32	504.23
Families	6.65	206.43	6.56	272.99	7.01	351.29	7.07	434.59	6.92	586.81
Others	7.29	224.91	7.31	324.52	7.94	427.56	7.83	516.03	7.76	713.22
Age										
Young	7.20	189.15	7.22	229.38	7.65	280.90	8.22	345.12	8.19	477.06
Middle Aged	6.99	194.43	6.88	256.00	7.28	312.77	7.62	379.52	7.60	513.17
Old	6.70	124.63	6.69	179.81	6.88	226.52	7.12	290.11	6.55	410.04
Housing Situation										
Owner	7.38	183.30	7.08	258.26	7.32	321.32	7.44	386.46	7.27	526.22
Tenant	6.37	169.14	6.74	219.76	7.24	269.36	7.83	339.56	7.75	458.16
Transport Type										
Carowner	7.26	187.70	7.34	256.54	7.68	312.00	8.11	385.86	7.90	518.51
Non-Carowner	5.46	127.54	4.87	153.91	5.21	198.79	5.34	233.81	5.68	356.38
Average	6.95	177.29	6.91	238.51	7.28	293.64	7.66	360.85	7.52	490.93

Notes: Households' expenses for private transportation by household type and income quintile.

Figure 4 displays how households' energy consumption at home breaks down into expenses for electricity and fossil fuels. The largest differences are found between owner and tenants, the latter exhibiting approximately 20 percentage points higher shares for electricity. One explanation for this large differences is that, in Switzerland, tenants heating costs are often included in the additional charges of the rent. So in reality, the electricity share is higher for tenants than depicted in the table. Unfortunately, we are not able to further breakdown the rent category and correct the electricity share of tenants.

Table 4: Households' Energy Consumption Subdivided into Electricity and Fuels

Income Quintiles	Bottom			2nd			3rd			4th			Top		
	CHF	Elect.	Fuels	CHF	Elect.	Fuels	CHF	Elect.	Fuels	CHF	Elect.	Fuels	CHF	Elect.	Fuels
Household Type															
Singles	83.18	0.61	0.39	63.32	0.68	0.32	74.89	0.61	0.39	79.07	0.59	0.41	97.51	0.56	0.44
Couples	120.76	0.59	0.41	125.73	0.59	0.41	130.01	0.58	0.42	137.01	0.56	0.44	176.02	0.48	0.52
Families	118.53	0.72	0.28	133.38	0.67	0.33	143.97	0.61	0.39	160.07	0.57	0.43	194.88	0.58	0.42
Other	138.78	0.68	0.32	165.89	0.62	0.38	179.32	0.61	0.39	193.63	0.57	0.43	260.14	0.48	0.52
Age															
Young	85.11	0.74	0.26	79.15	0.74	0.26	74.47	0.73	0.27	70.81	0.73	0.27	73.41	0.68	0.32
Middle Aged	123.17	0.69	0.31	133.38	0.64	0.36	139.80	0.61	0.39	143.71	0.57	0.43	166.00	0.54	0.46
Old	124.27	0.56	0.44	132.86	0.55	0.45	142.29	0.50	0.50	166.41	0.45	0.55	222.60	0.39	0.61
Housing Situation															
Owner	149.18	0.61	0.39	178.39	0.57	0.43	192.84	0.53	0.47	205.13	0.50	0.50	246.50	0.46	0.54
Tenant	75.83	0.81	0.19	73.17	0.80	0.20	72.81	0.77	0.23	74.99	0.73	0.27	81.83	0.67	0.33
Transport Type															
Carowner	121.31	0.66	0.34	128.44	0.63	0.37	133.25	0.59	0.41	137.39	0.56	0.44	166.53	0.51	0.49
Non-carowner	102.47	0.67	0.33	105.40	0.65	0.35	106.49	0.63	0.37	117.12	0.58	0.42	134.66	0.55	0.45
Average	118.05	0.66	0.34	124.39	0.64	0.36	128.90	0.60	0.40	134.06	0.57	0.43	161.12	0.52	0.48

Notes: *Elect.* denotes the share of electricity and *Fuel* the share of fossil fuels and others of households overall energy consumption at home.

Figure 18 and 19 in the Appendix display the regional differences in Switzerland. We find that the energy expenses relative to households' disposable income are largest in the region Ticino. Comparing the composition of household types between the different regions shows that the composition of household types within a specific region is a major driver for energy expenses. Especially, whether a household lives in a rural or an urban area or whether the household is a tenant or owner.

4.2 Model Specification

We drop the share equation of health to obtain a non-singular system of equations. To capture the variation in households consumption behavior, we consider observable households' characteristics and characteristics specific to the households' reference person. Specifically, we include the sex of the reference person and dummies for young and old household. A household is considered young if the reference person's age is below 35 and old if it is above 65. Moreover, information on the landlord/tenant situation, the household size and on whether children are living in the household is considered. To control for seasonal differences, we also include quarterly dummies.

Table 5 provides information on the model specification for the case of cross-section data. We consider interaction terms between $\mathbf{p}$ and y, $\mathbf{z}$ and y and $\mathbf{p}$ and $\mathbf{z}$ as well as any combination among them. According to BIC, we choose the model with interactions between demographic variables and implicit utility. The rank of y is considered to be of order 3.[6] We further use information about the specific month in which the household has been interviewed.[7]

---

[6] The model specifications for *rank* $y < 3$ show similar pattern concerning interactions of exogenous variables but lower BIC values and therefore are neglected in Table 5.

[7] Significant seasonal differences have been detected in the consumption patterns of households obtained from the cross section model.

Table 5: Model Specification

Interaction			Power of y	$\log\lvert\hat{\Sigma}_\varepsilon\rvert$ [a]	Number of parameters	*BIC* [b]	*AIC* [c]
$\mathbf{p}, y$	$\mathbf{z}, y$	$\mathbf{p}, \mathbf{z}$					
			3	-145.938	198	-4668088	-4670123
		x	3	-145.983	783	-4663443	-4670376
	x		3	-146.046	315	-4670326	-4673340
	x	x	3	-146.090	900	-4665652	-4673565
x			3	-145.949	243	-4667962	-4670373
x		x	3	-145.997	828	-4663447	-4670757
x	x		3	-146.058	360	-4670235	-4673626
x	x	x	3	-146.106	945	-4665703	-4670138

Notes: [a] Calculated as $\hat{u}_i^\top \hat{u}_j / T$ with T being the number of observations per equation. [b] Calculated as $n \cdot \log\lvert\hat{\Sigma}_\varepsilon\rvert + \log(n)\,(\sum_{i=1}^{m} p_i + 0.5 \cdot m(m+1))$ with m equals the number of equations, n denoting the number of observations per equation and p_i the number of independent parameters in equation i. [c] Calculated as $n \cdot \log\lvert\hat{\Sigma}_\varepsilon\rvert + 2\sum_{i=1}^{m} p_i + m(m+1)$ with m equals the number of equations, n denoting the number of observations per equation and p_i the number of independent parameters in equation i.

The construction of the pseudo-panel with the k-means algorithm is covered in detail in Section A in the Appendix. Similar to the cross-section data, the information criterion is applied to determine the optimal number of cohorts (C). After applying the k-means algorithm, we were left with a panel consisting of 484 observations gained by 11 cohorts (C) over the quarterly time period from 2001 to 2011. Empirical studies such as Browning et al. (1985), Banks et al. (1994), Blundell et al. (1994), Alessie et al. (1997), Blundell et al. (1998) and Propper et al. (2001) employ mean cohort sizes $\bar{n}_C$ ranging from 80 to more than 1500 while the number of cohorts has a minimum in 5 and a maximum in 90. Hence, our pseudo-panel is suitable for the estimation of the EASI model.

5 Price and Income Effects

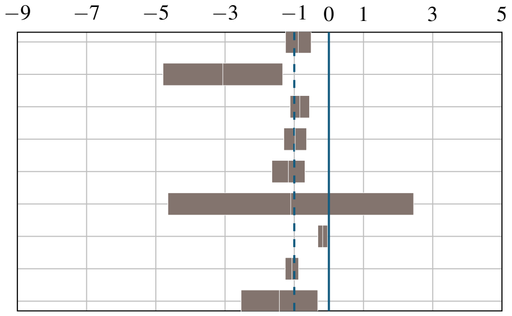
5.1 Own-price Elasticities

The effects of a price change on the quantity consumed for the nine categories are displayed in Table 6. The cross-section own-price elasticities (OPE) in the upper panel are all negative and are at least significant on the five percent level, with the exception of household operations. The highest elasticity is estimated for food out, where a price increase of one percent causes a reduction in the quantity consumed of approximately 3 percent. Food in, clothing, energy, housing, household operations, communication and recreation are all close to unit elastic demand. In stark contrast, private transportation is price inelastic with an OPE of –0.18.

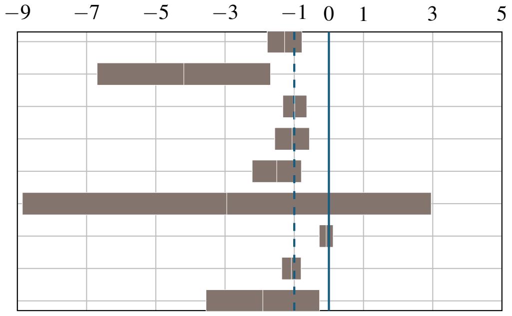
The lower panel provides estimates on own-price elasticities obtained from the pseudo panel estimation. In general, the estimates are similar to those from cross-section data. However, while the magnitude of the OPE of private transportation is even lower and insignificant, the OPEs of all other categories are slightly higher. On average, own-price elasticity estimates from the pseudo panel data set exhibit a slightly higher degree of variability.

Table 6: Own-price Elasticities

Cross-section	Estimate	SE	t-value
η_{foodin}	-0.88	0.19	-4.67
$\eta_{foodout}$	-3.06	0.88	-3.47
$\eta_{clothing}$	-0.84	0.14	-5.86
η_{energy}	-0.97	0.17	-5.78
$\eta_{housing}$	-1.17	0.24	-4.78
η_{oper}	-1.10	1.81	-0.61
η_{trans}	-0.18	0.07	-2.48
$\eta_{communic}$	-1.07	0.10	-10.80
η_{recr}	-1.43	0.57	-2.53



Pseudo panel	Estimate	SE	t-value
η_{foodin}	-1.28	0.26	-5.00
$\eta_{foodout}$	-4.19	1.28	-3.28
$\eta_{clothing}$	-0.99	0.18	-5.57
η_{energy}	-1.06	0.26	-4.16
$\eta_{housing}$	-1.51	0.36	-4.15
η_{oper}	-2.95	3.01	-0.98
η_{trans}	-0.08	0.10	-0.77
$\eta_{communic}$	-1.08	0.14	-7.56
η_{recr}	-1.91	0.84	-2.28



5.2 Cross-price Elasticities

Table 7 displays the cross-price elasticities (CPE) of Swiss households. Categories that experience a price change are depicted on the vertical axis. As a consequence, the consumption of the categories on the vertical axis adjusts by the stated values in the table. For example, assume that the price of *food in* increases by 1%, then the shares of *food out* and *clothing* decrease by 0.39% and 0.66%, respectively. OPEs are depicted on the diagonal. As the focus lies on the categories energy and private transportation, we have a closer look on the substitution patterns of these two categories. We find that in the cross-section (upper panel), transportation is a complement to food in, clothing and housing and a substitute to food out. In the pseudo panel (lower panel), clothing and housing remain significant complements. Energy is estimated as a significant substitute to food in the static model and as a significant complement to household operations in the dynamic model.

Table 8 provides heatmaps of cross-price elasticity estimates for the cross-section (upper panel) and the pseudo panel (lower panel) data set. The comparison between cross-section and the pseudo panel shows that the substitution patterns are very similar. When a CPE is significant in both models, it exhibits the same pattern of substitutability or complementarity, and it is also of similar magnitude.

Table 7: Cross-price Elasticities

Cross-section

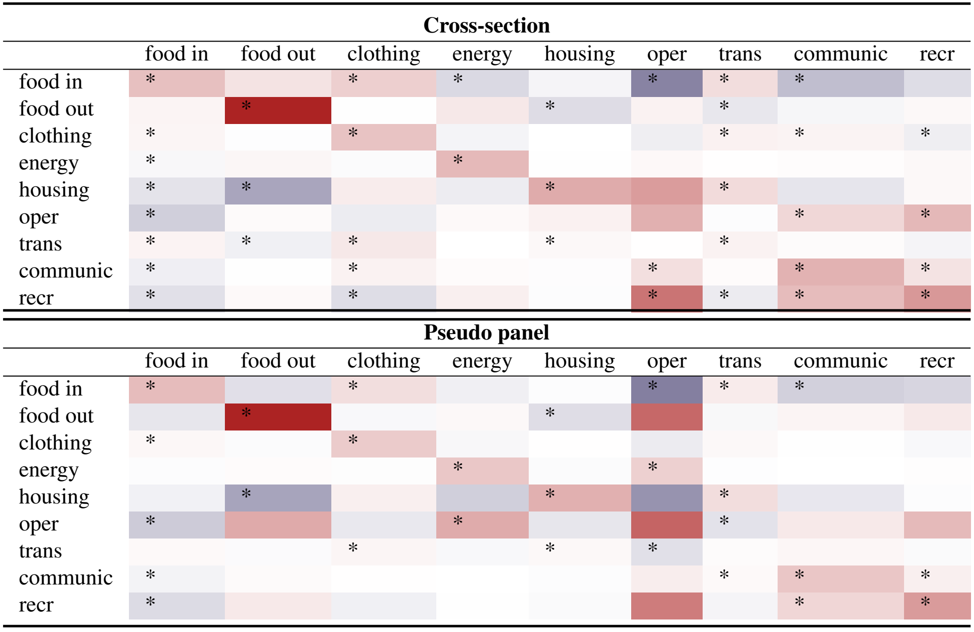
	food in	food out	clothing	energy	housing	oper	trans	communic	recr
food in	−0.88 [−4.67]	−0.39 [−0.99]	−0.66 [−3.74]	0.49 [1.74]	0.14 [1.19]	1.59 [2.46]	−0.48 [−4.12]	0.84 [4.29]	0.44 [1.35]
food out	−0.15 [−0.62]	−3.06 [−3.47]	0.02 [0.08]	−0.32 [−0.79]	0.44 [1.96]	−0.18 [−0.15]	0.31 [1.89]	0.12 [0.43]	−0.1 [−0.18]
clothing	−0.15 [−2.62]	0.02 [0.21]	−0.84 [−5.86]	0.14 [1.13]	0 [−0.1]	0.22 [1.09]	−0.2 [−3.32]	−0.17 [−1.97]	0.22 [2.29]
energy	0.1 [1.78]	−0.13 [−1.02]	0.05 [0.64]	−0.97 [−5.78]	0.01 [0.27]	−0.09 [−0.39]	−0.02 [−0.28]	−0.04 [−0.54]	−0.1 [−0.94]
housing	0.37 [1.73]	1.16 [1.74]	−0.26 [−0.96]	0.24 [0.56]	−1.17 [−4.78]	−1.38 [−1.28]	−0.49 [−2.73]	0.34 [1.08]	−0.1 [−0.22]
oper	0.62 [2.83]	−0.07 [−0.11]	0.25 [1.14]	−0.08 [−0.2]	−0.2 [−0.99]	−1.1 [−0.61]	0.03 [0.21]	−0.55 [−1.91]	−1 [−1.72]
trans	−0.16 [−3.23]	0.2 [1.71]	−0.31 [−3.8]	0 [0.04]	−0.1 [−2.39]	−0.01 [−0.06]	−0.18 [−2.48]	−0.06 [−0.76]	0.14 [1.46]
communic	0.21 [4.42]	0.02 [0.14]	−0.18 [−2.61]	−0.05 [−0.49]	0.03 [0.79]	−0.45 [−2.15]	−0.05 [−1.24]	−1.07 [−10.8]	−0.39 [−4.19]
recr	0.4 [1.89]	−0.09 [−0.15]	0.44 [2.21]	−0.22 [−0.64]	0.04 [0.25]	−1.94 [−1.76]	0.26 [1.79]	−0.94 [−3.8]	−1.43 [−2.53]

Pseudo panel

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
food in	−1.28 [−5]	0.56 [0.97]	−0.63 [−2.76]	0.27 [0.68]	0.06 [0.34]	2.26 [2.41]	−0.38 [−2.31]	0.82 [3.1]	0.74 [1.57]
food out	0.44 [1.21]	−4.19 [−3.28]	0.13 [0.42]	−0.13 [−0.21]	0.59 [1.79]	−2.88 [−1.58]	0.13 [0.54]	−0.2 [−0.52]	−0.41 [−0.49]
clothing	−0.15 [−1.96]	0.08 [0.5]	−0.99 [−5.57]	0.13 [0.73]	−0.02 [−0.36]	0.35 [1.22]	−0.13 [−1.6]	0.02 [0.15]	0.13 [0.91]
energy	0.05 [0.69]	−0.07 [−0.37]	0.04 [0.38]	−1.06 [−4.16]	0.07 [1.02]	−0.89 [−2.57]	0.03 [0.33]	−0.01 [−0.08]	−0.03 [−0.2]
housing	0.25 [0.8]	1.6 [1.68]	−0.31 [−0.84]	0.85 [1.27]	−1.51 [−4.15]	1.9 [1.17]	−0.65 [−2.39]	0.41 [0.9]	0.05 [0.07]
oper	0.92 [2.68]	−1.62 [−1.54]	0.41 [1.29]	−1.6 [−2.44]	0.44 [1.36]	−2.95 [−0.98]	0.51 [1.93]	−0.43 [−1.02]	−1.31 [−1.43]
trans	−0.11 [−1.56]	0.08 [0.48]	−0.2 [−1.84]	0.13 [0.59]	−0.14 [−2.13]	0.55 [1.76]	−0.08 [−0.77]	−0.17 [−1.5]	0.09 [0.66]
communic	0.22 [3.32]	−0.1 [−0.67]	−0.02 [−0.19]	0 [0.02]	0.05 [0.78]	−0.33 [−1.18]	−0.11 [−1.77]	−1.08 [−7.56]	−0.31 [−2.39]
recr	0.63 [1.98]	−0.41 [−0.46]	0.27 [0.92]	0.01 [0.02]	0.09 [0.39]	−2.49 [−1.46]	0.19 [0.86]	−0.78 [−2.15]	−1.91 [−2.28]

Notes: Elasticity estimates from cross-section (upper panel) and pseudo panel (lower panel). Goods with negative cross-price elasticities are complements and goods with a positive cross-price elasticity substitutes. OPEs are depicted on the diagonal. The t-values are indicated by square brackets.

Table 8: Heatmaps of the Cross-price Elasticities



Cross-section

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
food in	*		*	*		*	*	*	
food out		*			*		*		
clothing	*		*				*	*	*
energy	*			*					
housing	*	*			*		*		
oper	*							*	*
trans	*	*	*		*		*		
communic	*		*			*		*	*
recr	*		*			*	*	*	*

Pseudo panel

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
food in	*		*			*	*	*	
food out		*			*				
clothing	*		*						
energy				*		*			
housing		*			*		*		
oper	*			*			*		
trans			*		*	*			
communic	*						*	*	*
recr	*							*	*

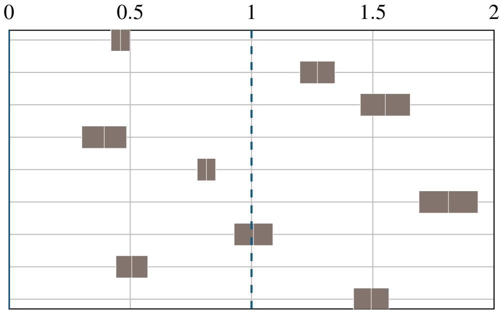
Notes: Heatmaps from cross section (upper panel) and pseudo panel (lower panel). While the cell-color indicates whether the goods are complements (red) or substitutes (blue), the opacity reflects the magnitude of the effect. OPEs are depicted on the diagonal. Significance on the 10 percent level is indicated by a *.

5.3 Income Elasticities

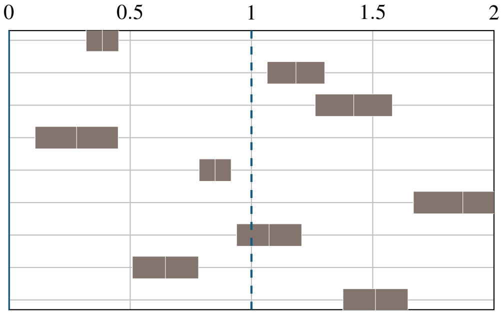
Table 9 provides the estimates of income elasticities from the cross-section (upper panel) and the pseudo panel (lower panel) data. Income elasticities capture the effect of an increase in (disposable) income on the consumed quantity of goods. All income elasticities are greater than zero, indicating that all expenditure groups are normal goods. Our results show that food in, energy, housing and communication are necessities with elasticities smaller than one. On the other hand, food out, clothing, household operations and recreational activities are luxuries with elasticities greater than one. This implies that the demand for these categories increases over-proportionally if income increases. Finally, for private transportation a unit elastic demand is found. The dynamic model leads to similar income elasticity estimates.

Table 9: Income Elasticity Estimates

Cross section	Estimate	SE	t-value
ε_{foodin}	0.46	0.02	22.85
$\varepsilon_{foodout}$	1.27	0.04	34.36
$\varepsilon_{clothing}$	1.55	0.05	29.54
ε_{energy}	0.39	0.05	8.33
$\varepsilon_{housing}$	0.81	0.02	42.04
ε_{oper}	1.81	0.06	29.16
ε_{trans}	1.01	0.04	24.63
$\varepsilon_{communic}$	0.51	0.03	15.11
ε_{recr}	1.49	0.04	40.05



Pseudo panel	Estimate	SE	t-value
ε_{foodin}	0.39	0.03	11.24
$\varepsilon_{foodout}$	1.18	0.06	19.55
$\varepsilon_{clothing}$	1.42	0.08	17.51
ε_{energy}	0.28	0.09	3.19
$\varepsilon_{housing}$	0.85	0.03	25.20
ε_{oper}	1.87	0.10	17.97
ε_{trans}	1.07	0.07	15.64
$\varepsilon_{communic}$	0.65	0.07	9.27
ε_{recr}	1.51	0.07	22.08



5.4 Engel Curves

The size of the categories' expenditure shares depends considerably on the income level of households in Switzerland. Table 10 displays average expenses of energy and private transportation by income quintiles. The energy share, measured as energy expenses divided by total disposable income, is decreasing in income. Low-income households use more than 4 percent of their disposable income for energy-related expenditures. Expenditure shares of private transportation are even higher and attain their maximal value of 10 percent in the 4th quintile of the income distribution.

Engel curves offer an accurate visualization of the relationship between income and the demand for a specific good. Figure 3 depicts the Engel curves of each good for the reference household. The reference household is a family with two kids that owns at least one car, is a homeowner, and is represented by a middle-aged male reference person. We calculate Engel curves for the relatively homogeneous reference household to obtain meaningful results with relatively small confidence intervals.

Table 10: Energy and Transportation Expenditures

	Income	Energy		Transport	
Quintiles	CHF	CHF	% Inc	CHF	% Inc
Btm	2,782	121	4.42	252	8.41
2nd	3,656	122	3.24	353	8.95
3rd	4,344	131	2.85	452	9.68
4th	5,100	137	2.54	541	10.00
Top	7,062	162	2.19	728	9.93

Notes: *Income* depicts households' monthly disposable income normalized by the household size.

The Engel curves of food in, energy and communication decline continuously as disposable income increases. In contrast, the Engel curves of the categories household operations, recreation and clothing are rising continuously as households' income increases. For housing, food out and private transportation, the curvature of the Engel curves are more complex. While the curvature of food out and recreation is well described by a quadratic function, the Engel curves of housing and private transportation reveal an S-shaped form. As mentioned before and argued in Lewbel and Pendakur (2009), S-shaped Engel curves cannot be captured in rank restricted models like the AIDS model and its quadratic extension the QUAIDS. Using a demand model with only linear or quadratic Engel curves might lead to biased results, especially for households in the lowest or the highest percentiles. The Engel curves of energy and private transportation reveal that the consumption shares of these categories are higher for low-income households. Hence, policy instruments that affect the prices of energy sources and fuels tend to hit poorer households hard.

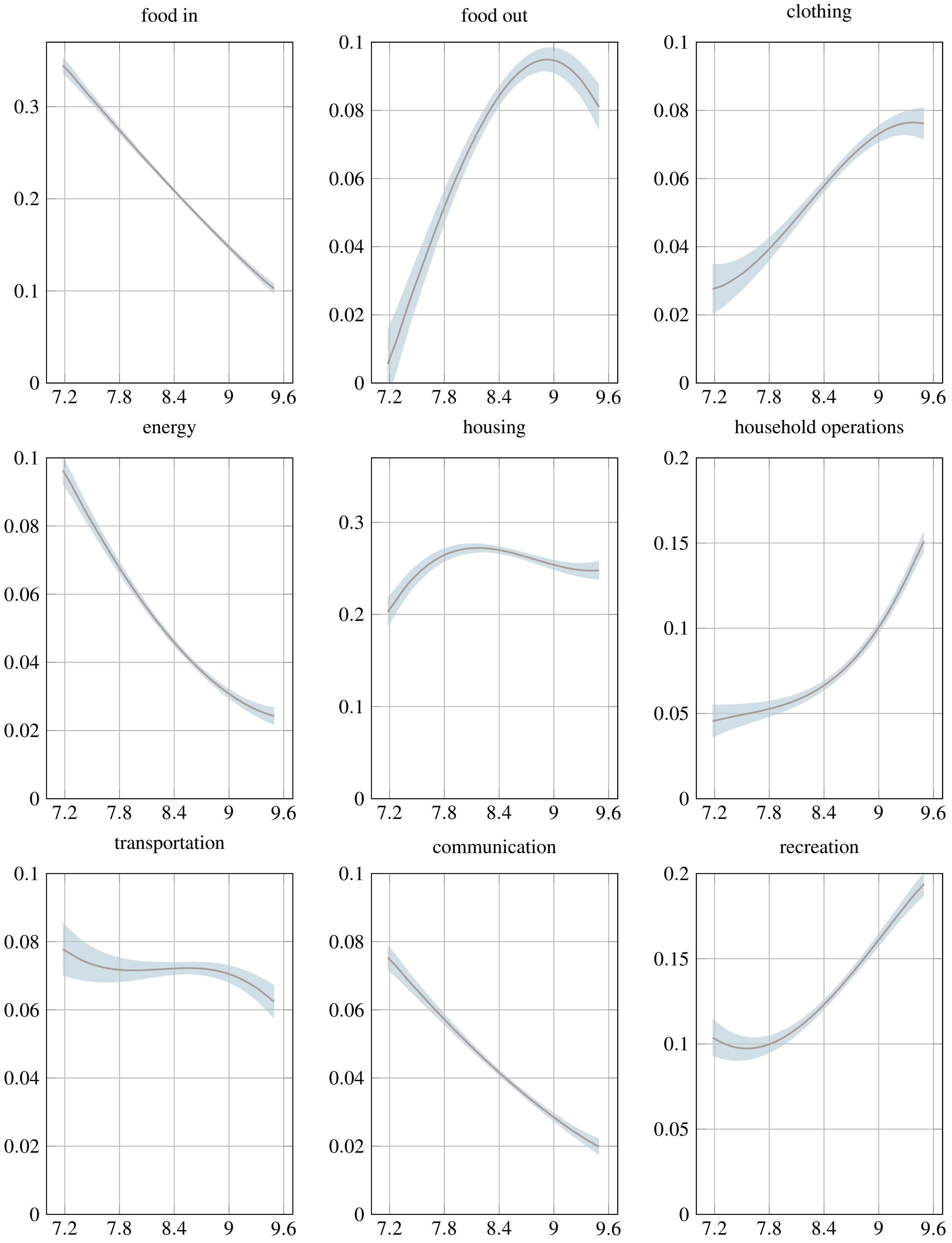
Figure 4 compares the Engel curves of tenants and homeowners for the categories energy and housing. For low-income households that own a house we see a significantly higher share of energy consumption (almost 10 percent) compared to a tenant household (slightly over 4 percent). At the same time, the share for housing for the same income group is much higher for tenants (over 45 percent) as for homeowners (around 20 percent). In both cases, the gap diminishes as income increases. While there is a distinct decrease of the expenditure share of energy for higher incomes for both household types, this is not the case for housing. There, a decline of the expenditure share associated with an increase in household income can only be observed for tenants.

The reason for the differences in the Engel curves in terms of both magnitude and shape is mainly driven by the distributional differences of household types in the two subsets of tenants and homeowners. For instance, the average household size of homeowners (2.8) is greater than that of tenants (2.3). Another reason for the large difference is that tenants pay a portion of their energy expenses as part of their additional property expenses and differences in the payment schedule.[8] Tenants energy share might therefore be downward biased. The remaining discrepancy can be explained by differences in living area dimension and the distributional differences in urban and rural areas.

---

[8] In the case of energy, tenants are often charged by an advance payment schedule, while homeowners pay their actual energy consumption.

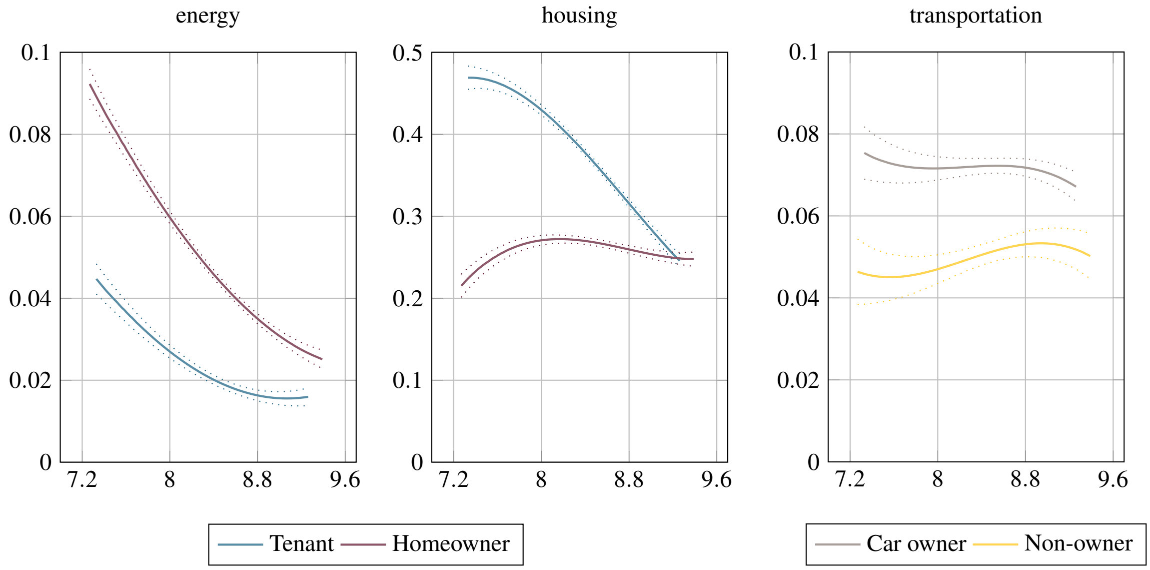
Figure 3: Engel Curves by Expenditure Category



Notes: The shaded area respresents the lower and upper bounds of the 95% confidence interval. The Engel curves have been derived from the cross-section data and represent the consumption behavior of the reference household. Income is the logarithm of normalized monthly disposable income.

In the third panel of Figure 4, the Engel curves for private transportation are displayed for car owners and non-owners. While the Engel curve of car owners is always above the one of non-owners, the non-owners slightly increase their expenditure share with rising income. The discrepancies disclose the importance of demographic characteristics.

Figure 4: Engel Curves of Homeowners, Tenants, Car Owners and Non-owners



Note: The dotted lines represent lower and upper bounds of the 95% confidence interval.

6 Summary

The elasticity estimates presented in this paper indicate that food out and recreation are the most price elastic categories in Swiss households, followed by food in and energy. While most other categories exhibit OPEs close to unity, transportation clearly is price inelastic. Cross-price effects are small for most expenditure categories, energy and private transportation are no exception. However, we do find some interesting substitution patterns of energy and transportation with the rest of the households' consumption categories, indicating the need of taking into account all these substitution effects. The estimated income elasticities show that food in, energy, housing and communication are necessity goods, while food out, clothing, housing equipment, recreation tend to be luxury goods. The income elasticity of transportation is close to unity. A comparison of Engel curves of different household types reveals considerable differences in the energy and transportation spending patterns. All these results hold under both considered specifications, cross-section and pseudo-panel.

The relationship between residential energy consumption and the efficiency of heating systems and appliances is of great importance regarding the objectives to decrease overall energy use. Unfortunately, the limitations of the household expenditure data do not allow to take these characteristics into account. Quantitative studies that analyze how new technologies and more efficient appliances affect the energy use of households in Switzerland are needed to shed more light on this relationship. Another important point to mention is that we solely consider short- and medium-term effects of price changes. The long-term effects might be of greater magnitude as other studies tend to indicate. Further research is needed to measure the long-term price and income elasticities of Swiss households.

References

Abdulai, A. (2002, March). Household Demand for Food in Switzerland. A Quadratic Almost Ideal Demand System. *Swiss Journal of Economics and Statistics (SJES) 138*(I), 1–18.

Alessie, R., M. P. Devereux, and G. Weber (1997, January). Intertemporal consumption, durables and liquidity constraints: A cohort analysis. *European Economic Review 41*(1), 37–59.

Baltagi, B. (2005). *Econometric analysis of panel data* (3. ed. ed.). Chichester [u.a.]: Wiley.

Banks, J., R. Blundell, and I. Preston (1994, August). Life-cycle expenditure allocations and the consumption costs of children. *European Economic Review 38*(7), 1391–1410.

Baranzini, A. and S. Weber (2013). Elasticities of gasoline demand in Switzerland. *Energy Policy 63*(C), 674–680.

Bernard, J.-T., D. Bolduc, and N.-D. Yameogo (2011, January). A pseudo-panel data model of household electricity demand. *Resource and Energy Economics 33*(1), 315–325.

Bernstein, R. and R. Madlener (2011). Responsiveness of Residential Electricity Demand in OECD Countries: A Panel Cointegation and Causality Analysis. FCN Working Papers 8/2011, E.ON Energy Research Center, Future Energy Consumer Needs and Behavior (FCN).

Blundell, R., M. Browning, and C. Meghir (1994, January). Consumer demand and the life-cycle allocation of household expenditures. *Review of Economic Studies 61*(1), 57–80.

Blundell, R., A. Duncan, and C. Meghir (1998, July). Estimating labor supply responses using tax reforms. *Econometrica 66*(4), 827–862.

Browning, M., A. Deaton, and M. Irish (1985, May). A profitable approach to labor supply and commodity demands over the life-cycle. *Econometrica 53*(3), 503–43.

Cameron, A. C. and P. K. Trivedi (2009, May). *Microeconometrics: Methods and Applications*. Cambridge University Press.

Cottrell, M. and P. Gaubert (2003). Efficient estimators: The use of neural networks to construct pseudo panels. Université Paris1 Panthéon-Sorbonne (Post-Print and Working Papers) hal-00122817, HAL.

Deaton, A. (1985). Panel data from time series of cross-sections. *Journal of Econometrics 30*(1-2), 109–126.

Efron, B. (1979). Bootstrap methods: Another look at the jackknife. *The Annals of Statistics 7*(1), 1–26.

Filippini, M. (1995). Swiss Residential Demand for Electricity by Time-of-Use: An Application of the Almost Ideal Demand System. *The Energy Journal 0*(Number 1), 27–40.

Filippini, M. (1999). Swiss residential demand for electricity. *Applied Economics Letters 6*(8), 533–538.

Filippini, M. (2011, October). Short- and long-run time-of-use price elasticities in Swiss residential electricity demand. *Energy Policy 39*(10), 5811–5817.

Filippini, M., S. Datta, and N. Boogen (2015). An Evaluation of the Impact of Energy Efficiency Policies on Residential Electricity Demand in Switzerland. Technical report, Swiss Federal Office of Energy (SFOE).

Hoareau, S., G. Lacoix, M. Hoareau, and L. Tiberti (2012). Exact affine stone index demand system in r: The easi package. Technical report, University of Laval.

Hsiao, C. (2003). *Analysis of panel data* (2. ed ed.). Number 34 in Econometric Society monographs. Cambridge [u.a.]: Cambridge Univ. Press.

Klevmarken, N. A. (1989, March). Introduction. *European Economic Review 33*(2-3), 523–529.

Kohonen, T. (1989). *Self-Organization and Associative Memory* (3 ed.). Berlin: Springer Verlag.

Lewbel, A. (2008). Engel curve. In S. N. Durlauf and L. E. Blume (Eds.), *The New Palgrave Dictionary of Economics*. Basingstoke: Palgrave Macmillan.

Lewbel, A. and K. Pendakur (2009, June). Tricks with Hicks: The EASI demand system. *American Economic Review 99*(3), 827–63.

Moffitt, R. (1993, September). Identification and estimation of dynamic models with a time series of repeated cross-sections. *Journal of Econometrics 59*(1-2), 99–123.

Propper, C., H. Rees, and K. Green (2001). The demand for private medical insurance in the uk: A cohort analysis. *The Economic Journal 111*(471), pp. C180–C200.

Verbeek, M. (2008). *Pseudo-Panels and Repeated Cross-Sections.* Number Bd. 2 in The Econometrics of Panel Data. Springer Berlin Heidelberg.

Verbeek, M. and T. Nijman (1992). Can cohort data be treated as genuine panel data? *Empirical Economics 17*(1), 9–23.

Withana, S., P. ten Brink, B. Kretschmer, L. Mazza, P. Hjerp, and R. Sauter (2013). Evaluation of environmental tax reforms: International experiences. Technical report, Institute for European Environmental Policy (IEEP).

A Construction of the Pseudo Panel

In order to estimate the dynamic response of households towards relative price or income changes, the dataset as presented in Section 4.1 is extended by a time dimension. This is done by constructing a pseudo panel as introduced in Section 3.1. The cohorts of the pseudo panel are constructed by using the concept to the k-means algorithm for standard clustering.

The set-up is straightforward and can be stated as follows:

1. Choose k (arbitrary) points from the dataset to serve as original cluster centroids $(c_1, ..., c_k)$.
2. Each data point is assigned to a cluster such that the increase of within clusters variance is minimized.
3. Update group centroids.
4. Steps (2) and (3) are repeated until the process has converged.

The number of clusters can be determined by standard measures like the Bayesian information criterion (BIC) or the Akaike information criterion (AIC). As the Akaike information criterion (AIC) prefers in general bigger models compared to Bayesian information criterion (BIC), one has to consider the trade-off between model precision as represented by sample size (number of cohorts, C) and the measurement error of population means occurring through small cohort sizes.[9] Based on the fact that the standard deviation of individuals per cohort is sufficiently small, a mean cohort size ($\bar{n}_c$) of 66 should be enough to avoid measurement errors.

We set the maximum cohort size to 25. In order to attain cohorts of minimum within and maximum between variance, we consider information on expenditure shares, similar to Cottrell and Gaubert (2003). This approach appears convincing as different shares represent different consumption preferences and thus a measure of inter-group heterogeneity as well as intra-group homogeneity. As these patterns show substantial heterogeneity for each level of income, we cluster the observations first by income quintile and apply k-means afterwards. AIC suggests clustering the observations into 19 cohorts. However, as the number of observations per cohort significantly differs, measurement errors become more severe. Hence, we follow BIC and set the number of cohorts to 11.[10]

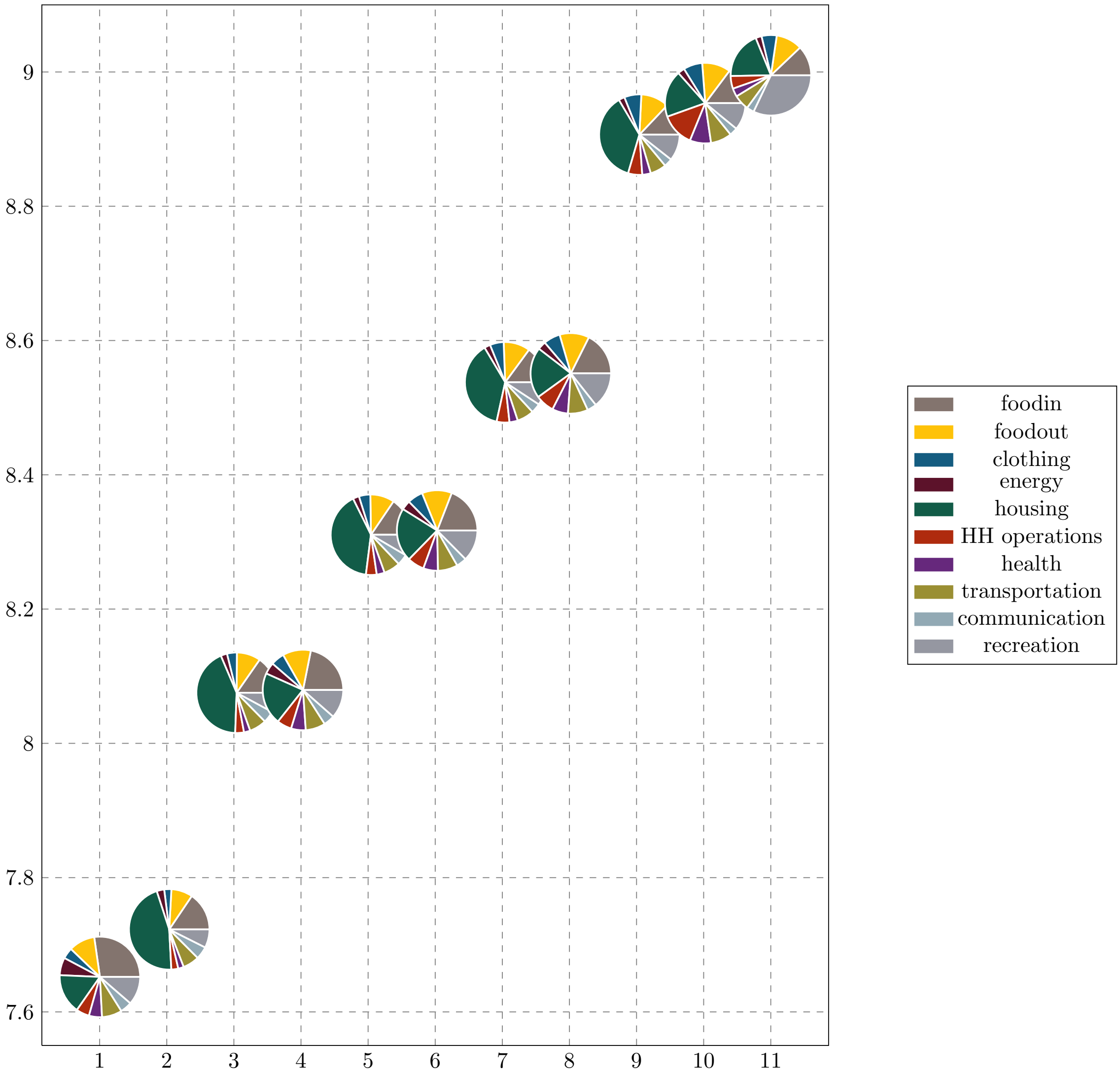
The cohorts obtained from the nested clustering approach arranged according to their income are illustrated in Figure 5. The main differences can be detected for the categories of housing, food in, recreation as well as household operations. Other goods seem to be more or less equally consumed by the groups, hence, they do not serve as optimal variables to maximize cohesion and separation in our dataset.

---

[9] The calculations are as follows: $AIC = SSW + 2 \cdot m \cdot k$ and $BIC = SSW + 0.5 \cdot \ln(n) \cdot m \cdot k$, where SSW denotes the total within-cluster sum of squares, k the number of clusters, m is the number of means and n the number of data points.

[10] Note that we do not find extreme differences in the model fit compared to the specification preferred by AIC.

Figure 5: Pseudo-panel Construction: Consumption Patterns of the 11 Cohorts



Notes: The 11 cohorts (x-axis), obtained from the kmeans algorithm, are ordered by households' log income. The month to which the consumption pattern refers to is neglected for simplicity.

B Parameter Estimates

Table 11: Parameter Estimates of the EASI Model from Repeated Cross-section

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
$\beta^{Constante}$	0.924 [0.86]	2.608 [2.12]	4.771 [5.45]	0.51 [1.05]	−17.867 [−9.49]	−4.568 [−4.05]	3.611 [3.86]	0.248 [0.56]	7.245 [5.61]
β^{y^1}	−0.07 [−0.18]	−1.067 [−2.46]	−1.62 [−5.25]	−0.058 [−0.34]	6.004 [9.04]	1.797 [4.52]	−1.293 [−3.91]	−0.036 [−0.23]	−2.317 [−5.08]
β^{y^2}	−0.008 [−0.18]	0.153 [2.96]	0.192 [5.22]	−0.004 [−0.21]	−0.674 [−8.51]	−0.236 [−4.98]	0.157 [3.99]	0.001 [0.03]	0.253 [4.66]
β^{y^3}	0.001 [0.31]	−0.007 [−3.55]	−0.008 [−5.34]	0.001 [0.68]	0.026 [8.14]	0.01 [5.58]	−0.006 [−4.06]	0 [0.15]	−0.009 [−4.28]
$\beta^{num.pers}$	0.545 [1.31]	−0.925 [−1.94]	−1.289 [−3.8]	0.291 [1.54]	1.545 [2.12]	0.138 [0.32]	−0.041 [−0.11]	0.213 [1.25]	−1.015 [−2.03]
$\beta^{sq.num.pers}$	−0.093 [−0.58]	0.342 [1.85]	0.496 [3.77]	−0.117 [−1.59]	−0.641 [−2.26]	−0.017 [−0.1]	0.032 [0.23]	−0.061 [−0.93]	0.26 [1.34]
β^{tenant}	−0.259 [−16.49]	−0.246 [−13.64]	−0.099 [−7.71]	−0.173 [−24.25]	1.19 [43.1]	0.003 [0.19]	−0.069 [−5.02]	−0.007 [−1.09]	−0.178 [−9.39]
β^{carown}	−0.074 [−4.12]	−0.066 [−3.19]	−0.021 [−1.42]	0.015 [1.84]	0.059 [1.87]	0.008 [0.4]	0.085 [5.39]	0.011 [1.49]	−0.046 [−2.12]
$\beta^{NumKids}$	−0.006 [−0.22]	−0.012 [−0.4]	0.021 [0.96]	0.003 [0.25]	−0.084 [−1.81]	−0.004 [−0.13]	−0.021 [−0.93]	−0.018 [−1.63]	0.06 [1.9]
β^{single}	0.041 [0.19]	−0.253 [−1.04]	−0.638 [−3.67]	0.099 [1.02]	1.042 [2.79]	−0.024 [−0.11]	−0.044 [−0.24]	0.097 [1.11]	−0.593 [−2.31]
$\beta^{Families}$	−0.251 [−3.52]	0.013 [0.16]	0.155 [2.67]	−0.04 [−1.24]	0.237 [1.89]	−0.028 [−0.38]	−0.033 [−0.53]	0.013 [0.44]	0.151 [1.76]
β^{MPHH}	−0.114 [−1.64]	0.004 [0.06]	0.159 [2.81]	−0.015 [−0.47]	0.038 [0.31]	0.048 [0.66]	−0.067 [−1.11]	0.015 [0.53]	0.107 [1.28]
β^{oldHH}	0.118 [5.95]	0.105 [4.62]	0.104 [6.43]	−0.009 [−0.98]	−0.106 [−3.02]	0.038 [1.8]	−0.019 [−1.1]	−0.082 [−10.04]	0.044 [1.85]
$\beta^{youngHH}$	−0.125 [−5.46]	0.137 [5.21]	0.034 [1.82]	−0.021 [−2]	0.002 [0.06]	−0.149 [−6.17]	0.006 [0.31]	0.096 [10.17]	−0.033 [−1.18]
β^{Q2}	0.027 [1.36]	−0.001 [−0.03]	−0.029 [−1.84]	−0.031 [−3.49]	0.043 [1.27]	−0.026 [−1.25]	−0.02 [−1.16]	−0.006 [−0.78]	0.043 [1.83]
β^{Q3}	0.042 [2.14]	−0.009 [−0.42]	−0.003 [−0.17]	−0.027 [−3.07]	0.007 [0.21]	−0.025 [−1.23]	0.007 [0.4]	0.004 [0.44]	−0.001 [−0.02]
β^{Q4}	0.051 [2.58]	0.015 [0.66]	−0.043 [−2.69]	−0.02 [−2.2]	−0.027 [−0.8]	0.003 [0.14]	0.004 [0.25]	0.002 [0.28]	0.017 [0.72]
$\beta^{y*num.pers}$	−0.055 [−1.12]	0.114 [2.02]	0.148 [3.7]	−0.035 [−1.55]	−0.163 [−1.89]	−0.023 [−0.44]	0.002 [0.05]	−0.03 [−1.47]	0.117 [1.96]
$\beta^{y*sq.num.pers}$	0.012 [0.64]	−0.042 [−1.92]	−0.057 [−3.68]	0.014 [1.64]	0.065 [1.96]	0.003 [0.14]	−0.002 [−0.15]	0.01 [1.26]	−0.03 [−1.33]
$\beta^{y*tenant}$	0.029 [15.34]	0.028 [13.09]	0.011 [7.35]	0.018 [20.69]	−0.129 [−39.25]	−0.003 [−1.59]	0.008 [4.86]	0.001 [1.61]	0.018 [8.06]
$\beta^{y*carown}$	0.009 [3.98]	0.007 [2.94]	0.002 [1.11]	−0.002 [−1.65]	−0.007 [−1.98]	−0.001 [−0.48]	−0.007 [−3.99]	−0.001 [−1.28]	0.005 [1.94]
$\beta^{y*NumKids}$	0 [−0.07]	0 [0.05]	−0.003 [−1.03]	0 [−0.34]	0.012 [2.19]	0.001 [0.45]	0.002 [0.76]	0.001 [0.92]	−0.006 [−1.66]
$\beta^{y*single}$	−0.005 [−0.21]	0.034 [1.16]	0.074 [3.59]	−0.012 [−1.06]	−0.113 [−2.54]	0 [−0.01]	0.005 [0.22]	−0.014 [−1.31]	0.07 [2.29]
$\beta^{y*Families}$	0.028 [3.32]	−0.004 [−0.46]	−0.017 [−2.47]	0.005 [1.25]	−0.028 [−1.9]	0.005 [0.51]	0.004 [0.52]	0 [−0.02]	−0.019 [−1.82]
β^{y*MPHH}	0.013 [1.54]	−0.003 [−0.27]	−0.018 [−2.71]	0.002 [0.55]	−0.006 [−0.44]	−0.004 [−0.48]	0.008 [1.11]	0 [−0.1]	−0.013 [−1.3]
$\beta^{y*oldHH}$	−0.012 [−5.11]	−0.016 [−5.7]	−0.013 [−6.75]	0.002 [1.76]	0.01 [2.28]	−0.004 [−1.56]	0.001 [0.55]	0.009 [8.6]	−0.005 [−1.72]
$\beta^{y*youngHH}$	0.012 [4.23]	−0.014 [−4.37]	−0.003 [−1.49]	0.002 [1.64]	−0.001 [−0.2]	0.019 [6.42]	0 [−0.05]	−0.011 [−9.34]	0.004 [1.2]
β^{y*Q2}	−0.002 [−0.77]	0 [0]	0.004 [2.13]	0.004 [3.33]	−0.006 [−1.37]	0.003 [1.19]	0.003 [1.31]	0.001 [0.79]	−0.006 [−2.29]
β^{y*Q3}	−0.004 [−1.87]	0.002 [0.78]	0 [0.16]	0.003 [2.93]	−0.001 [−0.27]	0.003 [1.15]	−0.001 [−0.3]	0 [−0.44]	−0.001 [−0.35]
β^{y*Q4}	−0.004 [−1.91]	−0.002 [−0.8]	0.006 [3.22]	0.002 [1.94]	0.002 [0.48]	0 [−0.13]	0 [−0.1]	0 [−0.15]	−0.003 [−0.9]
$\beta^{pfoodin}$	0.004 [0.11]	−0.036 [−0.87]	−0.03 [−3.21]	0.013 [1.38]	0.033 [0.92]	0.1 [2.67]	−0.035 [−4.11]	0.032 [3.86]	0.058 [1.59]
$\beta^{pfoodout}$	−0.036 [−0.87]	−0.216 [−2.31]	0.004 [0.34]	−0.013 [−0.94]	0.132 [1.87]	−0.006 [−0.08]	0.023 [1.9]	0.003 [0.25]	−0.006 [−0.1]
$\beta^{pclothing}$	−0.03 [−3.21]	0.004 [0.34]	0.01 [1.31]	0.004 [0.88]	−0.005 [−0.32]	0.015 [1.29]	−0.015 [−3.31]	−0.008 [−2.27]	0.026 [2.51]
$\beta^{penergy}$	0.013 [1.38]	−0.013 [−0.94]	0.004 [0.88]	0 [0.03]	0.002 [0.13]	−0.004 [−0.29]	−0.001 [−0.28]	−0.002 [−0.73]	−0.01 [−0.83]
$\beta^{phousing}$	0.033 [0.92]	0.132 [1.87]	−0.005 [−0.32]	0.002 [0.13]	−0.071 [−0.94]	−0.065 [−1.04]	−0.036 [−2.72]	0.008 [0.6]	0.006 [0.12]
β^{poper}	0.1 [2.67]	−0.006 [−0.08]	0.015 [1.29]	−0.004 [−0.29]	−0.065 [−1.04]	−0.003 [−0.03]	0.003 [0.21]	−0.024 [−2.01]	−0.107 [−1.68]
β^{ptrans}	−0.035 [−4.11]	0.023 [1.9]	−0.015 [−3.31]	−0.001 [−0.28]	−0.036 [−2.72]	0.003 [0.21]	0.06 [11.31]	−0.004 [−1.23]	0.019 [1.79]
$\beta^{pcommunic}$	0.032 [3.86]	0.003 [0.25]	−0.008 [−2.27]	−0.002 [−0.73]	0.008 [0.6]	−0.024 [−2.01]	−0.004 [−1.23]	−0.004 [−0.9]	−0.042 [−4.02]
β^{precr}	0.058 [1.59]	−0.006 [−0.1]	0.026 [2.51]	−0.01 [−0.83]	0.006 [0.12]	−0.107 [−1.68]	0.019 [1.79]	−0.042 [−4.02]	−0.042 [−0.67]

Table 12: Parameter Estimates of the EASI Model from Pseudo Panel

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
$\beta^{Constante}$	18.957 [3.82]	7.716 [1.39]	5.657 [1.47]	11.084 [4.51]	−37.049 [−4.13]	−0.664 [−0.12]	3.762 [0.86]	−4.303 [−1.72]	1.36 [0.2]
β^{y^1}	−6.496 [−3.66]	−3.033 [−1.53]	−2.081 [−1.51]	−3.779 [−4.3]	13.083 [4.08]	0.409 [0.21]	−1.368 [−0.88]	1.573 [1.76]	−0.328 [−0.14]
β^{y^2}	0.754 [3.57]	0.396 [1.67]	0.253 [1.54]	0.431 [4.12]	−1.515 [−3.97]	−0.073 [−0.31]	0.168 [0.91]	−0.188 [−1.76]	0.02 [0.07]
β^{y^3}	−0.03 [−3.53]	−0.017 [−1.81]	−0.01 [−1.56]	−0.016 [−3.97]	0.058 [3.85]	0.004 [0.44]	−0.007 [−0.93]	0.007 [1.75]	0 [0.02]
β^{Q2}	0.011 [4.79]	−0.001 [−0.24]	0.005 [3.03]	−0.002 [−1.9]	−0.001 [−0.27]	−0.003 [−1.19]	0.001 [0.63]	−0.001 [−0.88]	−0.01 [−3.4]
β^{Q3}	0.005 [3.5]	0.009 [5.94]	−0.001 [−0.8]	−0.002 [−2.38]	−0.001 [−0.4]	−0.003 [−1.95]	0 [0.18]	0 [0.33]	−0.008 [−4.62]
β^{Q4}	0.013 [6.33]	−0.002 [−0.96]	0.009 [5.91]	−0.003 [−2.59]	−0.009 [−2.78]	−0.001 [−0.29]	0 [0.19]	−0.001 [−0.61]	−0.003 [−1.19]
$\beta^{num.pers}$	0.205 [4.92]	−0.09 [−1.92]	0.018 [0.55]	0.05 [2.43]	−0.168 [−2.23]	0.074 [1.58]	−0.009 [−0.25]	−0.002 [−0.08]	−0.054 [−0.94]
$\beta^{sq.num.pers}$	−0.052 [−1.38]	0.06 [1.42]	−0.004 [−0.12]	−0.034 [−1.81]	0.101 [1.48]	−0.1 [−2.38]	−0.021 [−0.63]	0.006 [0.33]	0.032 [0.61]
$\beta^{pfoodin}$	−0.064 [−1.51]	0.062 [1.02]	−0.031 [−2.45]	0.005 [0.39]	0.009 [0.18]	0.146 [2.56]	−0.027 [−2.24]	0.032 [2.88]	0.093 [1.75]
$\beta^{pfoodout}$	0.062 [1.02]	−0.336 [−2.48]	0.009 [0.57]	−0.007 [−0.33]	0.176 [1.74]	−0.17 [−1.53]	0.01 [0.57]	−0.01 [−0.62]	−0.041 [−0.43]
$\beta^{pclothing}$	−0.031 [−2.45]	0.009 [0.57]	0.002 [0.21]	0.003 [0.51]	−0.01 [−0.5]	0.024 [1.38]	−0.009 [−1.55]	0 [0]	0.017 [1.08]
$\beta^{penergy}$	0.005 [0.39]	−0.007 [−0.33]	0.003 [0.51]	−0.003 [−0.34]	0.02 [0.94]	−0.053 [−2.5]	0.002 [0.35]	−0.001 [−0.17]	−0.002 [−0.13]
$\beta^{phousing}$	0.009 [0.18]	0.176 [1.74]	−0.01 [−0.5]	0.02 [0.94]	−0.169 [−1.52]	0.132 [1.33]	−0.046 [−2.31]	0.013 [0.67]	0.023 [0.31]
β^{poper}	0.146 [2.56]	−0.17 [−1.53]	0.024 [1.38]	−0.053 [−2.5]	0.132 [1.33]	−0.116 [−0.63]	0.037 [1.95]	−0.019 [−1.07]	−0.146 [−1.4]
β^{ptrans}	−0.027 [−2.24]	0.01 [0.57]	−0.009 [−1.55]	0.002 [0.35]	−0.046 [−2.31]	0.037 [1.95]	0.068 [8.99]	−0.008 [−1.73]	0.015 [0.9]
$\beta^{pcommunic}$	0.032 [2.88]	−0.01 [−0.62]	0 [0]	−0.001 [−0.17]	0.013 [0.67]	−0.019 [−1.07]	−0.008 [−1.73]	−0.004 [−0.68]	−0.034 [−2.27]
β^{precr}	0.093 [1.75]	−0.041 [−0.43]	0.017 [1.08]	−0.002 [−0.13]	0.023 [0.31]	−0.146 [−1.4]	0.015 [0.9]	−0.034 [−2.27]	−0.098 [−1.02]

B.1 Semi-elasticities of Demographic Factors

Table 13 displays the parameter estimates, so called semi-elasticities for the demographic variables in the cross-section model as well as quarterly dummies accounting for seasonality. As can be seen, although the magnitude is in general relatively small, the majority of estimates is significant at the one percent level of significance.

Concerning the indicated long-term effects, tenancy has a negative influence on the consumed amount for the most of good categories. Solely for communication and housing the estimated semi-elasticities are positive. Furthermore, for households with a female reference person, the budget shares for food-in as well as food-out and for transportation are significantly lower, while on the contrary more budget is spent on clothing, health, recreation, communication and energy (in this order). As one would expect, households with children spend more budget on food in and less for food out, while the opposite is true for single member households. Young households tend to spend relatively more money on food out, clothing, transportation, communication and housing and less for food in, health and energy. Hence, leaving aside the category of recreation, young and old households exhibit inverse patterns with the most distinct difference for the category of health.

Table 13: Semi-elasticities of Demographic Factors

	food in	food out	clothing	energy	housing	oper	trans	communic	recr
$\zeta^{num.pers}$	0.089 [3.55]	0.032 [1.13]	−0.045 [−2.2]	−0.001 [−0.08]	0.178 [4.07]	−0.059 [−2.23]	−0.025 [−1.13]	−0.037 [−3.61]	−0.047 [−1.58]
$\zeta^{sq.num.pers}$	0.017 [1.73]	−0.004 [−0.34]	0.018 [2.2]	0.001 [0.27]	−0.092 [−5.36]	0.002 [0.18]	0.01 [1.2]	0.02 [4.97]	−0.004 [−0.35]
ζ^{tenant}	−0.011 [−11.23]	−0.007 [−6.18]	−0.005 [−6.52]	−0.026 [−60.03]	0.112 [65.69]	−0.027 [−26.98]	−0.004 [−4.25]	0.002 [5.06]	−0.035 [−29.86]
ζ^{carown}	0.006 [4.58]	−0.001 [−0.88]	−0.005 [−4.8]	0.001 [1.93]	−0.002 [−0.76]	−0.006 [−4.7]	0.021 [19.71]	0 [0.25]	−0.013 [−8.93]
$\zeta^{NumKids}$	0 [0.15]	−0.007 [−3.8]	−0.001 [−0.94]	−0.001 [−1.93]	0.017 [6.2]	0.004 [2.4]	−0.006 [−4.23]	−0.009 [−14.82]	0 [−0.01]
ζ^{single}	0.004 [0.34]	0.032 [2.17]	−0.017 [−1.66]	−0.004 [−0.65]	0.1 [4.44]	−0.029 [−2.19]	−0.004 [−0.34]	−0.018 [−3.37]	−0.018 [−1.17]
$\zeta^{Families}$	−0.006 [−1.53]	−0.021 [−4.39]	0.011 [3.36]	0 [0.01]	0.001 [0.15]	0.006 [1.26]	−0.002 [−0.56]	0.011 [6.44]	−0.014 [−2.82]
ζ^{MPHH}	0.001 [0.25]	−0.013 [−2.84]	0.006 [1.68]	0.002 [1.03]	−0.013 [−1.85]	0.008 [1.94]	−0.001 [−0.37]	0.011 [6.48]	−0.01 [−2.1]
ζ^{oldHH}	0.023 [17.23]	−0.023 [−14.93]	−0.007 [−6.55]	0.007 [11.06]	−0.023 [−9.73]	0 [0.02]	−0.011 [−9.08]	−0.012 [−21.77]	−0.007 [−4.14]
$\zeta^{youngHH}$	−0.02 [−14.82]	0.025 [16.36]	0.006 [5.38]	−0.004 [−6.81]	−0.004 [−1.6]	0.002 [1.66]	0.004 [3.35]	0.006 [11.01]	−0.009 [−5.32]
ζ^{Q2}	0.019 [10.65]	0.003 [1.35]	0.004 [3.06]	−0.002 [−2.35]	−0.001 [−0.44]	−0.006 [−2.71]	0.001 [1.07]	−0.001 [−1.79]	−0.02 [−9.45]
ζ^{Q3}	0.013 [10.33]	0.012 [7.94]	0 [−0.33]	−0.002 [−2.94]	0 [0]	−0.006 [−4.44]	0 [0.37]	−0.001 [−2.49]	−0.018 [−11.64]
ζ^{Q4}	0.021 [12.59]	0.001 [0.3]	0.008 [5.85]	−0.003 [−3.76]	−0.009 [−3.26]	−0.004 [−2.25]	0.001 [1.08]	0 [−0.46]	−0.013 [−6.77]

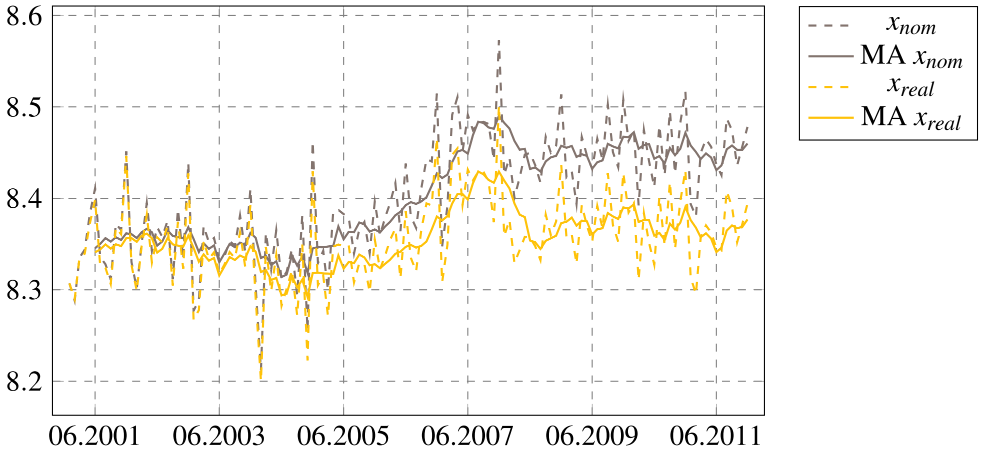
	food in	food out	clothing	energy	housing	oper	trans	communic	recr
$\zeta^{num.pers}$	−0.023 [−0.23]	−1.325 [−5.87]	−0.172 [−2.16]	0.036 [2.17]	0.341 [1.91]	−0.037 [−0.13]	−0.116 [−1.35]	−0.047 [−1.43]	0.158 [0.52]
$\zeta^{sq.num.pers}$	0.45 [4.12]	1.188 [4.77]	0.274 [3.12]	−0.013 [−0.69]	−0.578 [−2.93]	0.038 [0.12]	0.176 [1.84]	0.065 [1.77]	−0.273 [−0.81]
ζ^{Q2}	0.006 [1.09]	−0.002 [−0.2]	0.003 [0.67]	0 [−0.17]	0.005 [0.49]	−0.001 [−0.08]	−0.003 [−1]	0.001 [0.7]	−0.01 [−0.72]
ζ^{Q3}	0.001 [0.4]	0.007 [0.88]	0 [0.13]	0 [−0.67]	0.002 [0.32]	0.001 [0.12]	0 [−0.07]	0.001 [0.87]	−0.005 [−0.49]
ζ^{Q4}	0.009 [1.83]	−0.005 [−0.49]	0.006 [1.67]	0 [−0.2]	0.005 [0.55]	0.002 [0.16]	−0.005 [−1.5]	0.001 [0.73]	−0.011 [−0.85]

Notes: Parameter estimates from cross section (upper panel) and pseudo panel (lower panel).

B.2 Nominal and Real Expenditures

Figure 6 shows the average total expenditures. Specifically, we present the logs of nominal and real expenditures and the respective moving averages. After a slight decrease until 2004, expenditures increased subsequently until 2007. The consequences of the increase in energy prices and the economic crisis after 2008, caused another slight decrease of total expenditures in Switzerland.

Figure 6: Nominal and Real Household Expenditures



Notes: Average household expenditures reported in logs, with and without 6 month moving averages.

B.3 Energy Consumption by Energy Sources, Household Type and Region

Table 14: Distribution of Electricity Expenses at Home

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household type										
Singles	3.99	51.03	2.21	42.99	1.90	45.70	1.55	46.55	1.20	54.23
Couples	3.65	70.68	2.56	74.60	2.08	75.02	1.70	76.29	1.27	85.00
Families	2.87	85.66	2.14	88.72	1.75	88.19	1.47	90.58	1.30	112.60
Other	3.27	93.91	2.35	102.72	2.06	109.84	1.67	110.27	1.39	125.74
Age										
Young	2.46	62.86	1.81	58.69	1.47	54.24	1.21	51.41	0.86	50.15
Middle Aged	3.23	84.89	2.33	85.84	1.99	84.67	1.65	82.34	1.31	89.66
Old	4.00	69.37	2.70	72.48	2.18	71.65	1.86	75.39	1.42	86.42
Housing Situation										
Owner	3.98	90.41	2.84	101.08	2.40	101.98	2.01	101.74	1.60	113.58
Tenant	2.38	61.47	1.80	58.22	1.51	55.75	1.26	54.44	0.94	54.84
Transport Type										
Carowner	3.33	80.04	2.34	81.39	1.95	79.25	1.62	77.44	1.28	84.98
Non-Carowner	3.17	68.99	2.15	68.27	1.81	67.58	1.50	68.11	1.18	74.06
Average	3.30	78.13	2.31	79.08	1.93	77.35	1.60	75.91	1.26	83.13

Notes: The average households' electricity expenditures at home by household type and income quintile.

Table 15: Distribution of Fuel Expenses at Home

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household Type										
Singles	2.51	32.15	1.03	20.33	1.21	29.19	1.08	32.52	0.92	43.28
Couples	2.54	50.08	1.76	51.13	1.52	54.99	1.35	60.72	1.29	91.02
Families	1.05	32.87	1.05	44.66	1.09	55.78	1.12	69.49	0.94	82.28
Other	1.56	44.87	1.46	63.17	1.30	69.48	1.25	83.36	1.46	134.40
Age										
Young	0.83	22.25	0.60	20.46	0.49	20.23	0.41	19.40	0.37	23.26
Middle Aged	1.49	38.28	1.27	47.54	1.28	55.13	1.20	61.37	1.07	76.34
Old	3.06	54.90	2.21	60.38	2.17	70.64	2.25	91.02	2.10	136.18
Housing Situation										
Owner	2.64	58.77	2.24	77.31	2.22	90.86	2.10	103.39	1.89	132.92
Tenant	0.57	14.36	0.45	14.95	0.46	17.06	0.47	20.55	0.43	26.99
Transport Type										
Carowner	1.80	41.27	1.36	47.05	1.34	54.00	1.24	59.95	1.18	81.55
Non-Carowner	1.61	33.48	1.17	37.13	1.02	38.91	1.08	49.01	0.91	60.60
Average	1.76	39.92	1.32	45.31	1.28	51.55	1.21	58.15	1.13	77.99

Notes: The average households' fuel expenditures at home by household type and income quintile. Fuel expenses include all expenses for fossil fuels and district heating at home.

Table 16: Distribution of Expenses for Gasoline and Diesel

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household type										
Singles	5.30	71.74	4.58	89.52	4.69	112.84	4.52	135.74	3.68	163.17
Couples	5.32	107.39	4.91	142.96	4.46	161.06	4.23	190.60	3.41	229.81
Families	5.01	153.16	4.31	178.75	4.05	201.15	3.53	214.43	3.02	252.18
Other	5.70	172.97	4.83	212.82	4.74	252.76	4.05	265.59	3.34	305.57
Age										
Young	5.53	142.61	5.04	157.95	4.91	178.07	4.57	190.51	3.78	216.77
Middle Aged	5.32	146.25	4.64	171.00	4.40	185.78	4.11	200.41	3.48	229.57
Old	4.84	88.63	4.05	109.17	3.85	126.28	3.48	142.36	2.86	173.56
Housing Situation										
Owner	5.61	137.26	4.79	173.88	4.51	194.66	4.10	209.05	3.43	241.89
Tenant	4.74	125.33	4.43	143.33	4.31	157.85	4.11	175.05	3.42	196.84
Transport Type										
Carowner	5.48	139.96	4.86	169.29	4.63	185.96	4.35	203.50	3.59	230.60
Non-Carowner	4.08	95.11	3.38	106.17	3.21	118.71	2.86	124.36	2.60	159.64
Average	5.24	132.20	4.60	158.20	4.40	175.05	4.10	190.48	3.42	218.53

Notes: The average households' gasoline and diesel expenditures by household type and income quintile.

Table 17: Distribution of Transport Expenses for Accessories, Spare Parts and Services

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Household type										
Singles	1.70	23.65	2.46	48.59	2.78	67.10	3.72	112.84	4.44	204.79
Couples	1.86	38.77	2.22	65.01	2.76	99.83	3.39	153.71	3.91	274.42
Families	1.64	53.27	2.25	94.24	2.96	150.14	3.55	220.15	3.91	334.63
Others	1.60	51.94	2.48	111.71	3.20	174.80	3.78	250.44	4.41	407.66
Age										
Young	1.66	46.54	2.18	71.44	2.73	102.83	3.65	154.61	4.42	260.29
Middle Aged	1.67	48.19	2.24	85.00	2.88	126.99	3.51	179.11	4.12	283.59
Old	1.86	35.99	2.64	70.65	3.04	100.24	3.63	147.76	3.69	236.48
Housing Situation										
Owner	1.78	46.04	2.29	84.38	2.81	126.65	3.35	177.41	3.84	284.33
Tenant	1.62	43.81	2.31	76.43	2.94	111.51	3.72	164.51	4.34	261.32
Transport Type										
Carowner	1.78	47.74	2.47	87.24	3.05	126.04	3.76	182.36	4.31	287.91
Non-Carowner	1.38	32.43	1.50	47.74	2.00	80.08	2.48	109.45	3.08	196.74
Average	1.71	45.09	2.30	80.30	2.88	118.59	3.55	170.37	4.10	272.40

Notes: The average households' expenditures by household type and income quintile.

Table 18: Distribution of Energy Shares by Region and Quintile

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Lake Geneva Region	6.57	134.58	4.32	140.32	4.00	154.07	3.39	157.29	2.93	196.95
Espace Mittelland	5.17	110.14	3.68	119.97	3.42	129.80	3.05	139.80	2.68	176.29
NW Switzerland	4.86	105.46	3.55	111.97	3.05	116.18	2.62	118.54	2.50	163.61
Zurich	3.92	83.53	2.73	83.44	2.39	89.23	2.32	105.23	1.77	116.14
E Switzerland	5.21	110.92	3.63	118.70	3.18	122.50	2.84	134.41	2.66	166.40
C Switzerland	4.73	104.07	3.24	109.78	2.78	111.99	2.54	116.60	1.93	131.76
Ticino	7.23	145.96	4.67	148.37	3.99	150.97	3.85	177.08	3.11	199.57
Average	5.44	114.56	3.69	119.09	3.26	124.79	2.90	133.13	2.41	158.64

Notes: Households' energy consumption at home by region and income quintile.

Table 19: Distribution of Transport Shares by Region and Quintile

Income Quintiles	Bottom		2nd		3rd		4th		Top	
	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF	% Inc	CHF
Lake Geneva Region	7.51	190.54	7.53	263.85	7.94	326.31	8.07	386.04	8.00	538.35
Espace Mittelland	6.94	175.48	6.79	235.33	7.29	292.26	7.74	361.49	7.40	478.29
NW Switzerland	6.11	159.23	6.53	220.02	6.86	273.12	6.96	327.20	7.15	473.11
Zurich	6.32	160.31	5.89	203.20	6.44	261.87	6.69	315.63	7.20	472.17
E Switzerland	7.03	181.08	6.90	237.85	7.21	286.89	8.07	379.96	7.90	486.56
C Switzerland	6.64	173.90	6.42	229.72	7.05	291.29	7.71	362.17	7.41	498.79
Ticino	7.70	192.14	8.27	278.46	8.36	331.67	9.23	436.07	8.22	515.74
Average	6.95	177.29	6.91	238.51	7.28	293.64	7.66	360.85	7.52	490.93

Notes: Households' expenses for private transportation by region and income quintile.

Chapter 3: The Direct Rebound Effect of Private Transportation in Switzerland

1 Introduction

During the last years, many countries have adopted binding energy efficiency policies. For instance, the EU member states agreed in 2014 to improve energy efficiency by 30% by 2030. In Switzerland, energy efficiency improvements are one of the main pillars to achieve the reduction objectives in energy consumption and CO2 emissions. There are multiple measures in place, ranging from the buildings program with the objective to support renovations and investments in renewable energy sources, emissions standards and regulations for new cars, to efficiency requirements and labels for residential appliances and equipment, respectively.

In practice, technical energy saving potentials from efficiency improvements are hardly ever fully realized due to behavioral changes of consumers and producers. These effects are often summarized under the broad term "rebound effects". For example, more fuel-efficient cars make driving long distances cheaper and therefore the efficiency improvement is at least partially compensated by economic substitution and income effects directly affecting the use of cars. In addition to this direct rebound effect, energy savings in one service such as transportation can affect the demand for entirely other services. This process is is known as the indirect rebound effect. The overall rebound effect is composed of the direct rebound effect and the indirect rebound effect.

The magnitude of rebound effect yields important implications since policy objectives in the reduction of energy consumption are harder to attain if rebound effects turn out to be large. If these effects are disregarded, expected energy demand reductions may not realize in practice. Furthermore, rebound effects may have far-reaching implications on other policy areas. For example, knowledge of rebound effects in private transportation may allow to better forecast future traffic volumes influencing transport and environmental policy. It is therefore no surprise that in the last decades many empirical studies have tried to pin down rebound effects for different energy services.[1]

Despite the relatively large literature about rebound effects, with empirical estimations for different energy services, regions and countries, evidence for rebound effects covering important production or consumption areas in Switzerland is still scarce. One exception is the paper by Weber and Farsi (2014), which estimates the direct rebound effect in private transportation. Weber and Farsi use cross-section data of Swiss households in 2010. They find relatively high rebound effects for private transportation, ranging between 75% and 81%. Further evidence on the rebound effect for Switzerland is available from several case studies, considering rebound effects of high-speed transportation (Spielmann et al., 2008) and hybrid cars (de Haan et al., 2006). Furthermore, Madlener and Alcott (2009) review the literature on the relationship between energy rebound effects and economic growth. Somewhat related to that is the paper by Baranzini et al. (2013) on the relation between energy use and GDP growth

---

[1] For a literature review on the rebound effect, see Greening et al. (2000) and more recently Sorrell et al. (2009) which review the estimates of direct rebound effects for different energy services.

in Switzerland. Finally, Jenny et al. (2013) analyze how behavioral and socio-psychological factors, as well as rebound effects, affect selected energy-saving measures stipulated in the energy strategy 2050 in Switzerland. The study focuses on the consequences and the specific mode of operation of these measures.

In this chapter, we estimate the rebound effect of private transportation in Switzerland by applying two different approaches and focusing on the direct rebound effect. In the first approach, the rebound effect is directly estimated by using efficiency measures. In the second approach, the rebound effect is derived from the price elasticities from Chapter 2, which reveals a moderate effect of about 20%. For the first approach, we apply two different indicators for useful work: the annual and the daily distance traveled by car and person. Our estimation approach is similar to that used in Weber and Farsi (2014). We use a multivariate system of equations with distance (daily and annual), fuel intensity and vehicles' weight as endogenous and personal/household specific characteristics as well as technical details on the vehicle as control variables. For a comparison with other findings in the literature we apply both OLS as well as 3SLS to account for endogeneity issues. We find comparable, but slightly lower rebound effects than Weber and Farsi (2014) at around 60%, which is partly due to a different set of control variables and a more restricted dataset.

In addition, we extend the analysis of Weber and Farsi (2014) by two important ways. We estimate rebound effects for different household types and for different driving purposes. The results of the first extension show that the rebound effect is decreasing with income and increasing with the driver's age. Moreover, the data about households' daily distances traveled offers additional information to distinguish between different driving purposes such as work, shopping and leisure. We estimate rebound effects of 48% for the driving purpose work and 24% for recreational activities.

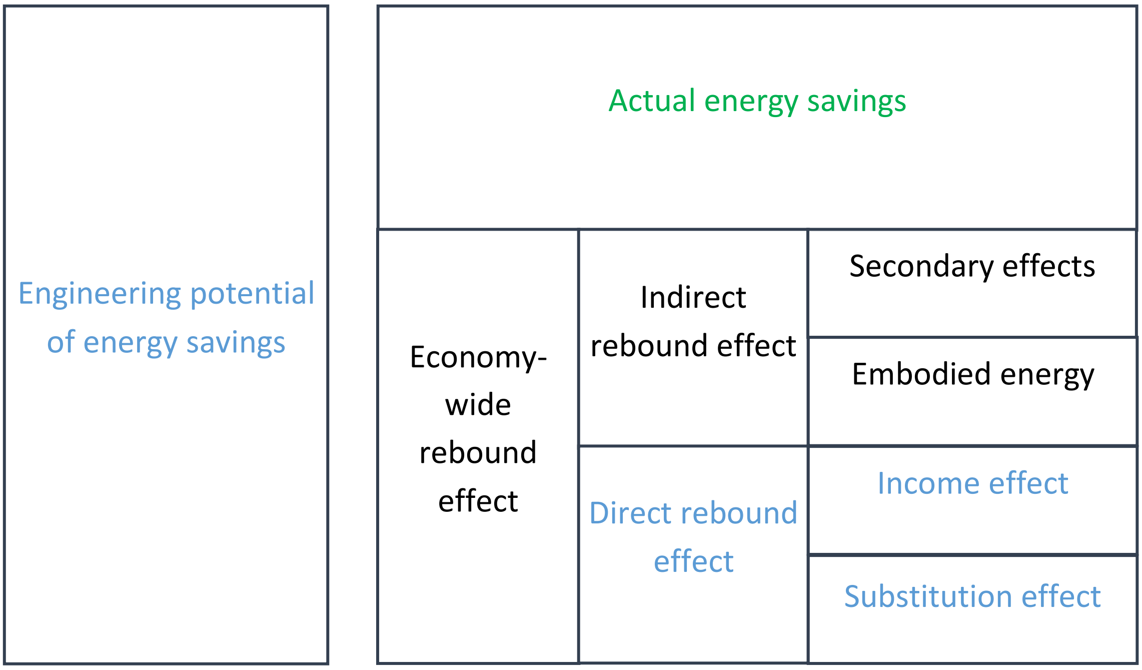
The remainder of the paper is organized as follows: Section 2 defines the rebound effect and compares two different approaches to estimate the rebound effect. Section 3 describes the employed data in detail and outlines the estimation approach. Section 4 presents the estimation results. Finally, Section 5 contains the conclusion.

2 Defining the Rebound Effect

The rebound effect is usually expressed as a percentage of the possible reduction of energy use from an energy efficiency improvement. For example, assume that a new technology reduces energy consumption by 10% based on engineering estimates holding demand constant (potential energy savings). If the actual energy consumption declines by only 2 percent, this would imply that the rebound effect is 80%. On the other hand, if the actual energy consumption declines by the potential 10%, the size of the rebound effect is zero. Note that the size of the rebound effect does not provide any information about the costs of the underlying energy efficiency improvement.

Figure 1 displays the decomposition of the rebound effect, following the definition of Sorrell et al. (2009). On the left, the potential energy savings from an energy efficiency improvement, based on the engineering estimates, are shown. The potential energy savings are partly offset by direct and indirect rebound effects. The direct rebound effect is restricted to the effect of an efficiency improvement of one defined service on the consumption of this service. An efficiency improvement makes the affected service cheaper. This increases the demand for this service and, at the same time, real income of households rises.The first effect is labeled *substitution effect*. The latter effect is labeled *income effect* and affects households' demand for the affected service and the demand for other goods and services. As a consequence, energy efficiency improvements also affect the consumption of other goods and services that require energy via the income effect. The higher demand for other goods and services, the embodied energy of the energy efficiency improvements and further secondary effects combined represent the so-called *indirect rebound effect*. Finally, the difference between the engineering potential of energy savings and the economy-wide rebound effect is the actual energy savings.

Figure 1: Classification of the Rebound Effect



Source: Prepared by the authors and based on the classification of the rebound effect for consumers by Sorrell and Dimitropoulos (2008).

Unfortunately, existing international evidence for rebound effects is still somewhat inconclusive and only comparable to a certain degree between different countries. The comparison of results from empirical studies can be difficult as there is no standard approach to estimate these effects and alternative definitions of the rebound effect coexist.[2] Adding to these difficulties is the fact that energy efficiency gains often come along with productivity improvements that are not directly related to energy consumption but affects the demand for energy from households and firms. These reasons make it difficult to estimate the overall (or economy-wide) rebound effect of an energy efficiency improvement. An illustrative example are private cars. For instance, private cars in the US have undergone considerable improvements of the transmission in the last 30 years. However, the demand for larger and heavier cars and at the same time the demand shift of consumers during the period has diminished the possible energy savings to relatively small 8% (Knittel, 2011).

---

[2] Turner (2013) discusses the problems of the current debate due to the different assumptions made in the rebound literature and the key issues for policymakers. Turner also highlights the difference between final consumers and producers in the rebound literature.

The measurement of the long-run rebound effect is especially difficult. Energy efficiency improvements are usually linked with other changes in productivity. Moreover, other factors such as changing consumer preferences, households' income levels or the general economic environment affect the energy consumption. Knittel (2011) analyses the efficiency gains in private transportation for the US. He shows that if weight, horsepower and torque were held at their 1980 levels, fuel economy could have increased by 60 percent. The actual fuel economy increased by only 18.5% until 2006. The reason is that today US households drive on average heavier and more powerful cars. Similar trends towards larger, stronger and more comfortable cars are observed in various OECD countries, including Switzerland.

In addition, the driving behavior of car owners might change if driving becomes cheaper and Swiss households might drive more often and longer distances. This is also true for other appliances. Hence, increasing the degree of energy efficiency might be less effective in reducing the energy consumption as theses efficiency gains make these services cheaper and might lead to an increased demand and offset the gains partly. Further information about the actual mode of operations of several energy-saving measures can be found in Jenny et al. (2013).

In this chapter, we are interested in the magnitude of the rebound effect in Switzerland. There are several different formal definitions of the direct rebound effect, mostly depending on data availability.[3] We consider two definitions tailored to the data availability regarding private transportation services of Swiss households. Note first, that energy efficiency (μ) is defined as

$$\mu = \frac{s}{e}, \tag{1}$$

where s denotes the consumption level of energy services and e denotes the energy used to provide these services. All else equal, the price for energy services becomes $p_s = p_e/\mu$. The most immediate definition of the rebound effect (*Definition 1*) is based on the elasticity of service demand with respect to efficiency (Frondel et al., 2008a), i.e.,

$$\eta_\mu(s) = \frac{\partial \ln s}{\partial \ln \mu}. \tag{2}$$

If this elasticity equals zero, the rebound effect is zero. While this is the preferred definition of the rebound effect, it also is the most demanding regarding data requirements.

The second definition of the rebound effect makes use of the relationship between the elasticity of the energy price and the elasticity of μ. The energy price elasticity is defined by

$$\eta_{p_e}(e) = \frac{\partial \ln e}{\partial \ln p_e}. \tag{3}$$

If demand only depends on service prices p_s and energy efficiency μ is constant over time then it is the case that $\eta_{p_e}(e) = -\eta_\mu(s)$. This assumption does not hold if we are considering a longer period of time. Obvious advances in energy efficiency are for instance improvements in the insulation of buildings or the realized efficiency gains of heating appliances in the past decades. Sorrell et al. (2009) argue, that by using energy efficiency proxies as control variables in the estimation of the price elasticity of energy demand it can be accounted for these efficiency improvements. This results in a measure comparable to $-\eta_\mu(s)$.

---

[3] See for example Berkhout et al. (2000), Frondel et al. (2008a) or Sorrell et al. (2009).

Hence, we use two different approaches to estimate the rebound effect. Under the first approach (*Definition 1*), the rebound effect is directly estimated by using efficiency measures. Under the second approach, the rebound effect is derived from the price elasticity of private transportation computed in Chapter 2. Both approaches have their pros and cons and the best strategy to estimate the magnitude of the rebound effect is generally dependent on data availability.

Estimating the rebound effect from price elasticities has the advantage that data consisting of energy consumption and energy prices exist for a wide range of energy services. Moreover, the rebound effect can directly be computed by using results of existing studies that have estimated own-price elasticities of such energy services. Another advantage is the greater variability of price data compared to the variability of energy efficiency. Finally, longitudinal data allows to estimate short-run and long-run rebound effects.

The drawbacks of the second approach is that the rebound estimates are only consistent with theory if energy prices are independent of energy efficiency. In reality, energy efficiency increases faster in environments of high energy prices than in environments of low prices, where the pressure on innovation is lower. Rebound estimates based on price elasticities are more reliable when data of energy prices and consumption exist for a single energy service. As soon as the energy consumption is more aggregated such as household appliances, rebound estimates becomes biased, as other factors, not directly observable in the data, affect the elasticity estimate. Another criticism is the notion that households react differently toward energy price increases than to price decreases. For example, Haas and Schipper (1998) find that households in OECD countries adjust their residential oil and gas demand stronger under rising energy prices than under falling energy prices.

In an world with perfect information about the energy efficiency of a service, the first approach, where the rebound effect is directly estimated by using efficiency measures, yield better rebound estimates. However, good measures or instruments for energy efficiency are only rarely available. Furthermore, there are services where the used technology only changes every five to ten years. Under such circumstances, the direct estimation of the rebound effect proves to be difficult or at least costly, since larger data sets are needed that do not exist for all energy services.

In summary, it depends on the availability and the variability of the existing data which approach should be favored to estimate the rebound effect of a specific energy service (Sorrell et al., 2009). While the use of own-price elasticities tends to overestimate the rebound effect, it has been argued by several authors that they provide an upper bound of the rebound effect. Moreover, considering energy services where the energy efficiency is not directly observable, it is—under certain conditions—favorable to rely on more accurate price data than on biased efficiency estimates. To our knowledge, this is the first study, that compares the estimation results of the two approaches for the same energy service—private transportation in Switzerland—to see how large the differences in the estimates of the rebound effect are.

3 Empirical Evidence

3.1 Data

Two comprehensive surveys of the Swiss Federal Statistical Office of Statistics (SFSO) allow us to estimate the rebound effect in private transportation. The first survey gathers data on the driving behavior in Switzerland with detailed information about the driver and the vehicle. The second survey has already been used in Chapter 2 and collects detailed information on household expenditures for private transportation, food and beverages, clothing and footwear, energy and further categories. These two surveys allow us to calculate the rebound effect either directly from energy efficiency measures or indirectly by using substitution elasticities.

To estimate the rebound effect using substitution elasticities of private transportation, we rely on the elasticity estimates from Chapter 2 of this report. The detailed information on households' expenses for private transportation and the underlying demographic characteristics in the Swiss Household Budget Survey (HBS) have led to reliable elasticity estimates. The rebound effect based on the price elasticity of private transportation is equal to $-\eta_{p_e}(e)$. Sorrell et al. (2009) notes that $\eta_{p_e}(e)$ is often interpreted as an upper bound of the rebound effect.

The other approach estimates the rebound effect directly from energy efficiency measures of cars in Switzerland. Detailed data on the energy efficiency for transportation is available from the survey "Swiss Microcensus on Mobility and Transport (MCMT) 2010" conducted by the SFOS and the Federal Office for Spatial Development (ARE). We use detailed information about the driver, the vehicle and the distances traveled by car. The dataset provides two different measures for the distance traveled by cars in Switzerland. First, the annual distance driven over the last 12 months.[4] Second, the daily distance traveled by car, recorded in the MCMT 2010 using GIS (Geographical Information System) software. Moreover we restrict the dataset to contain only observations for cars where technical details on the vehicle are available. These include the number of cylinders, the transmission system, the weight, the fuel type as well as the vehicles' energy label. Following Weber and Farsi (2014), the latter is used to estimate the vehicles' fuel intensity, which is not directly available in the MCMT 2010.[5] Furthermore, the survey also contains information on gender, age, the family and housing situation, as well as the drivers' income level and education to control for demographic factors.

Table 1 provides an overview of the sample used to estimate the rebound effect in private transportation. The average distance driven per day is approximately 44 kilometers, while the yearly distance is almost 14,000 kilometers. The fuel intensity, measured as l/100kg, ranges from 4.8 to 16.3 with an average of 8.9. The mean weight of cars is approximately 1861 kg, the percentage of diesel cars is 22 and a manual transmission system is observed for three out of four vehicles in our dataset. The average vehicle age is 5.85 years with a relatively high standard deviation of 3.71. The number of cylinders is around four. Considering drivers' characteristics, 33% (35%) live in a two (three) persons household. A medium household income (monthly income between 4,000 and 10,000 CHF) is achieved by six persons out of

---

[4] All positive observations up to 200,000 km are included. No relevant differences were detected when the maximum of annual distance was set to 100,000 and 50,000 respectively.

[5] We follow the approach of (Weber and Farsi, 2014, p.10) and recover the vehicles' fuel intensity from the 2007 energy labels (A to G) used in the MCMT 2010. The fuel intensity can be computed with the aid of the vehicle weight and the efficiency index I ($FI = (600 + W^{0.9}) * I/7,267$. More information about index I and the computation can be found in Weber and Farsi (2014).

ten, a high household income (above 10,000 CHF) by 28%. We find 40% female drivers, 37% persons with children and 23% to live in an urban region. Moreover the drivers' age ranges from 20 to 92 years with a mean of approximately 52 years. Over 50% have a medium educational level and around 40% a high educational level.

Table 1: Descriptive Statistics

Variable	Mean	SD	Min	Max
Distance				
Annual distance	43.95	54.62	0.024	704.55
Daily distance	13,889.88	10,065.41	4	200,000
Vehicle characteristics				
Fuel Intensity	8.87	1.9	4.83	16.3
Weight	1861.35	358.51	980	3500
Vehicle Age	5.85	3.71	0	17
Cylinder	4.31	0.88	3	12
Dummies				
Diesel	0.22	0.41		
Manual	0.76	0.43		
Household characteristics				
Drivers Age	52.1	13.8	20	92
Dummies				
Two Person HH	0.33	0.47		
Three Person HH	0.35	0.48		
Medium Income	0.60	0.49		
High Income	0.28	0.45		
Women	0.39	0.49		
Children	0.37	0.48		
Urban Region	0.23	0.42		
Medium Education	0.52	0.50		
High Education	0.42	0.49		

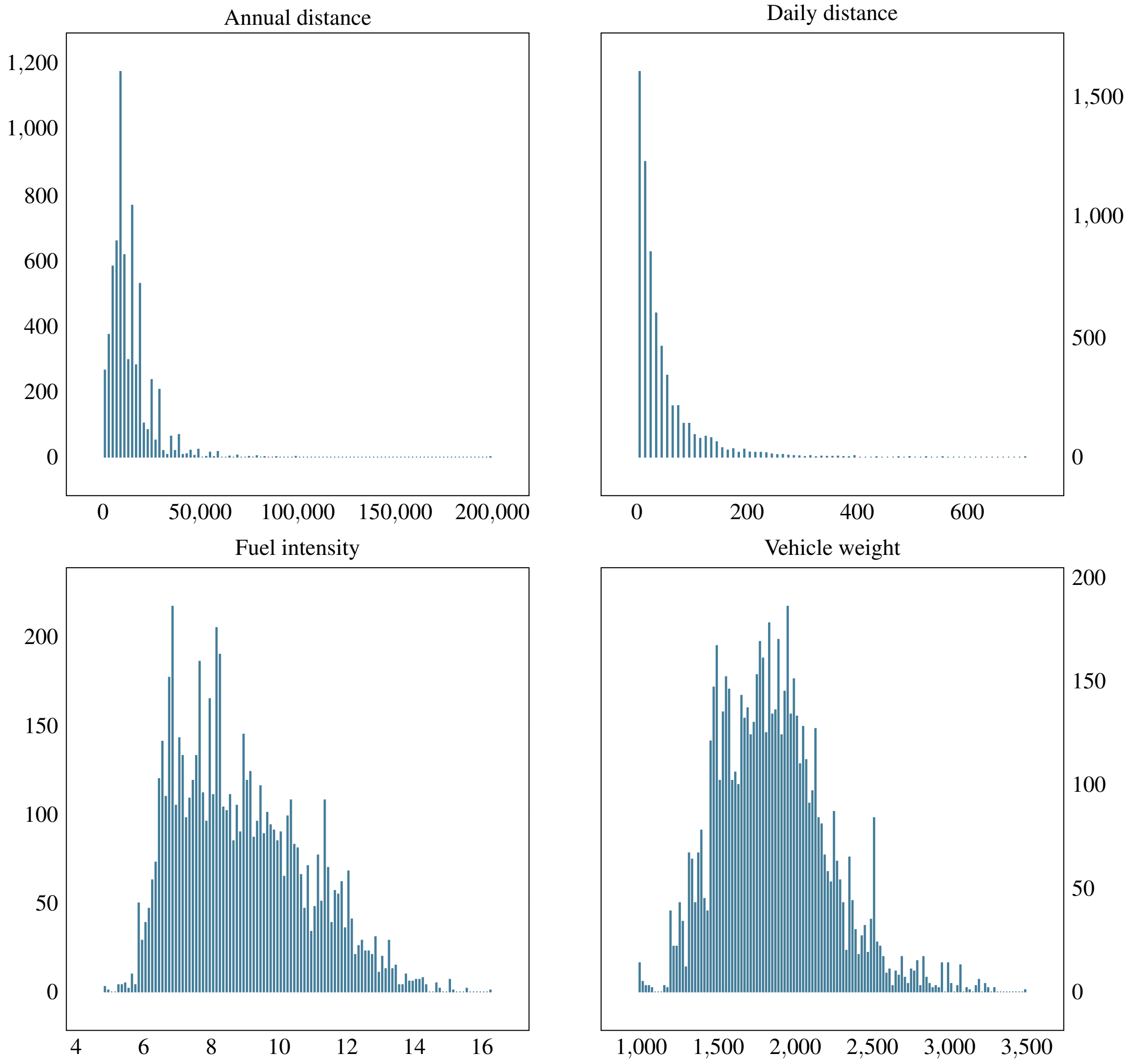
Notes: The estimation sample consists of 6,553 observations with positive distances reported in the MCMT 2010.

To estimate the aggregate rebound effect, we use both, the distance traveled over one year as well as the daily distance. While the former serves as a general indicator for demand response after an increase in energy efficiency, the latter allows to distinguish between the various travel purposes (work, shopping, leisure and others). Figure 2 illustrates the distribution of the endogenous variables. While the vehicle weight is almost normally distributed, the fuel intensity is right-skewed with a median (mean) of 8.56 (8.87). Both distance measures are distinctly right-skewed, especially the daily distance measure with 50% of observations below 24.6 km compared to 12,000 km in case of the annual distance.

3.2 Estimation Method

Having defined two metrics of the rebound effects in Section 2, we now consider the model used for estimating the corresponding rebound effect in private transportation. Data on energy service consumption and on energy efficiency is readily available for private transportation.

Figure 2: Histogram of the Endogenous Variables



Notes: The histograms display the descriptive statistic of the three endogenous variables, whereas distance is measured as daily and yearly distance. Data source: MCMT survey of 2010.

This allows us derive the rebound effect from the price elasticity in Chapter 2 and to use a more sophisticated model based on the energy efficiency of vehicles. Specifically, we use a structural simultaneous equation model, where average distance driven (D), fuel intensity

(FI) and the vehicles' weight (W) are determined simultaneously:

$$\begin{aligned} D_i &= \alpha_0^D + \alpha_{FI}^D FI_i + \alpha_W^D W_i + \beta^D X_i + \gamma^D Z_i^D + \varepsilon_i^D \\ FI_i &= \alpha_0^{FI} + \alpha_D^{FI} D_i + \beta^{FI} X_i + \gamma^{FI} Z_i^{FI} + \varepsilon_i^{FI} \\ W_i &= \alpha_0^W + \alpha_D^W D_i + \beta^W X_i + \gamma^W Z_i^W + \varepsilon_i^W, \end{aligned} \tag{4}$$

where D_i is the average distance traveled by person i in kilometers, FI_i and W_i are the fuel intensity and weight of the person's vehicle respectively. All endogenous variables are transformed to logarithms. Driver and vehicle specific characteristics are included in the matrices X_i and Z_i^j(with $j \in \{D, FI, W\}$) respectively. Note that the variables contained in the Z matrices can indeed vary by endogenous variable. We also include an equation-specific constant denoted by α_0. The residuals are captured in ε_i. From the explicit form stated in Equation (4), the rebound effect is defined as $-\alpha_{FI}^D$.

Using cross-sectional data from 2010, we estimate the rebound effect of private transportation by using both, simple OLS as well as a three stage least square (3SLS) estimator to account for potential endogeneity in the system of equations. Endogeneity may occur if the expected amount of useful work consumed (i.e. the distance driven) is taken into account when the technology (fuel efficiency of the car) is chosen. The rebound estimates based on OLS are presented in Appendix B. OLS is applied for comparability of our results with estimates from the early literature on rebound effects which often relied on OLS techniques. Moreover, it allows for an inspection of the endogeneity problem in our specific dataset by contrasting them to estimates gained from a 3SLS regression.

4 Results

4.1 The Average Rebound Effect

Table 2 displays the rebound effect based on the price elasticities from Chapter 2. We find a rebound effect of 18%, which implies that the energy savings from the energy efficiency improvement are reduced by 18%. Hence, an energy efficiency improvement of one percent leads to actual energy savings of 0.82%, 0.18 percentage points are lost due to the rebound effect. The upper limit of the confidence interval (UL) lies at 32% and is consistent with the results of Sorrell et al. (2009). Since the substitution elasticities from Chapter 2 are short-run to medium-run elasticities, these results can be interpreted as a short-term rebound effect.

Table 2: Rebound Effect based on Elasticity Measures

Category	η_p	RE	t-value	LL	UL
Private transportation	-0.18	0.18	2.48	0.04	0.32

Notes: The rebound effect is based on the own-price elasticity of private transportation from Chapter 2 of the report. These elasticities are a short-run to medium-run elasticities.

Table 3 displays the rebound effect based on the efficiency measure for private transportation. Considering 3SLS estimation, we obtain a rebound effect of 59% using the annual distance and 63% using the daily distance. The size of the rebound effect is slightly lower than in Weber and Farsi (2014).[6] It is close to the value that Frondel et al. (2008b) obtain

---

[6] In accordance to Weber and Farsi (2014), we find OLS estimates to be smaller than those obtained from applying 3SLS.

from household panel data from Germany, with values between 57% and 67%. Nonetheless, we find relatively high rebound effects compared to other international studies.

Table 3: Rebound Effect based on Efficiency Measures

Distance	RE	SE	t-value	95% CI	
				LL	UL
Annual distance	0.59	0.07	8.14	0.45	0.73
Daily distance	0.63	0.12	5.27	0.40	0.86

Notes: The 3SLS estimates of the rebound effect are based on the fuel efficiency of driven cars in Switzerland. The number of observations is 6,553.

The comparison of the rebound estimates from price elasticities with the estimates from efficiency measures shows that the latter lead to a considerably higher rebound effect in private transportation. At first glance, this result contradicts the claim that rebound estimates based on price elasticities can be interpreted as an upper bound of the rebound effect. A plausible explanation for this contradiction in our study is that the price elasticity estimates of Chapter 2 are short to medium-run elasticities, whereas the rebound estimates from efficiency measures are based on cross-sectional data. Elasticity or rebound estimates based on cross-sectional data rather provide long-run estimates because these estimates exploit the differences between the different subjects and such differences can be much larger and therefore can rather be interpreted as long-run as opposed to the changing behavior of individual subjects over a short time period. In general, long-run elasticities are expected to be higher in magnitude since a higher time span allows for a higher degree of individual adjustment to the new conditions.

4.2 Rebound Effects by Driver Characteristics

Empirical evidence from existing price elasticity studies and our results in Chapter 2 show that the magnitude of price and income elasticities highly depends on demographic and socioeconomic factors such as income, education and further factors. This section analyzes whether the same is true for the rebound effect. Specifically, we investigate how driver characteristics affect the rebound of private transportation in Switzerland. To our best knowledge, this is the first study that investigates the impact of household characteristics on the magnitude of the rebound for Switzerland.

Table 4 displays the magnitude of the rebound effect for different household types, when the annual distance is considered. On the one hand, we are investigating how household size and income level affect the rebound effect. We find no impact of household size on the magnitude of the rebound effect. The results show that the estimates are between 55% and 63% and not significantly different from the average value. In contrast, the income level of households fundamentally affects the magnitude of the rebound effect. We find considerably higher rebound effects for low income households than for medium or high income households. Note, however, that the confidence interval of the rebound for low income households is relatively large.

We also compute the rebound effect for different driver characteristics. Interestingly, the rebound effect is considerably higher for older and less educated drivers, where we find rebound effects of 82% and 79%, respectively. A possible explanation for the high rebound effect for car drivers with a low level of education is the fact that education and the income

Table 4: Rebound by Household Types, Annual Distance

Annual distance	RE	SE	t-value	95% CI	
				LL	UL
Household size					
Single	0.60	0.15	3.92	0.30	0.90
Two persons	0.58	0.13	4.61	0.33	0.83
Three persons	0.55	0.18	3.13	0.21	0.89
More persons	0.63	0.14	4.66	0.37	0.89
Income					
Low income	0.87	0.27	3.17	0.33	1.41
Medium income	0.67	0.10	7.01	0.48	0.86
High income	0.33	0.11	2.89	0.11	0.55
Age					
Young	0.53	0.19	2.84	0.16	0.90
Middle-age	0.60	0.09	6.93	0.43	0.77
Old	0.82	0.19	4.34	0.45	1.19
Sex					
Male	0.51	0.09	6.00	0.34	0.68
Female	0.71	0.13	5.35	0.45	0.97
Education					
Low education	0.79	0.31	2.53	0.18	1.40
Medium eduction	0.56	0.10	5.43	0.36	0.76
High education	0.61	0.11	5.61	0.40	0.82
Average	0.59	0.07	8.14	0.45	0.73

Notes: The 3SLS rebound estimates are computed for annually driven distances. The number of observations is 6,553.

category are positively correlated in our data sample. Similar to low income households, the confidence intervals are relatively large for older and less educated drivers.

In Table 5, we also present the rebound effects based on households' daily driven distances. The main reason for showing both tables is to see whether it matters what distance measure is employed. The average rebound effect for private transportation in Switzerland lies at 63% using the daily distance (59% using the annual distance). We also find the same pattern for income and education. The rebound effect is significantly higher for low income households and drivers with a lower level of education. Different to the yearly distance measure, the rebound effect for single households is considerably higher with a value of 99% (compared to 60%). Overall, the rebound results are very similar and suggest that the rebound based on daily distances is a good proxy for the rebound based on annual distance.

In summary, we find the typical pattern, well-known from other studies, that the rebound effect is higher for low-income households. The standard argument is that the demand for private transportation is not saturated for low-income households. Efficiency improvements make private transportation cheaper and their real income increases. The remaining income is over-proportionally used for driving more often and therefore energy efficiency improvements result in increased demand for private transportation, especially for low-income households. Interestingly, Frondel et al. (2010) find no differences in the rebound effect for different income groups in Germany.

Table 5: Rebound by Household Types, Daily Distance

Daily distance	RE	SE	t-value	95% CI	
				LL	UL
Household size					
Single	0.99	0.23	4.26	0.53	1.45
Two persons	0.48	0.21	2.24	0.06	0.90
Three persons	0.75	0.33	2.26	0.10	1.40
More persons	0.71	0.22	3.23	0.28	1.14
Income					
Low income	1.06	0.40	2.66	0.28	1.84
Medium income	0.71	0.15	4.62	0.41	1.01
High income	0.39	0.21	1.82	-0.03	0.81
Age					
Young	0.07	0.32	0.22	-0.55	0.69
Middle-age	0.71	0.14	5.00	0.43	0.99
Old	0.99	0.30	3.26	0.39	1.59
Sex					
Male	0.66	0.15	4.53	0.37	0.95
Female	0.52	0.21	2.53	0.12	0.92
Education					
Low education	0.48	0.43	1.12	-0.36	1.32
Medium eduction	0.77	0.17	4.47	0.43	1.11
High education	0.58	0.18	3.17	0.22	0.94
Average	0.63	0.12	5.27	0.40	0.86

Notes: The 3SLS rebound estimates are computed for daily driven distances. The number of observations is 6,553.

4.3 Rebound Effects by Driving Purpose

Empirical studies on the rebound effect clearly show that the driving behavior of households is affected by multiple factors such as the price of gasoline, household characteristics, vehicle type, taxes on transport fuels and further fiscal incentives by the government. Another important factor is the structure and quality of public transport services in the country or region of concern. A factor that has been neglected so far is the driving purpose. In this section, we investigate how the driving purpose affects the magnitude of the rebound effect.

Table 6: Rebound Effects by Driving Purpose

Purpose	RE	SE	t-value	95% CI	
				LL	UL
Work	0.48	0.09	5.16	0.30	0.66
Shopping	0.42	0.12	3.46	0.18	0.66
Leisure	0.24	0.10	2.47	0.05	0.43
Others	0.50	0.15	3.34	0.21	0.79

Notes: The 3SLS rebound estimates are computed for daily distances with the detailed purpose information from the GIS software. The number of observations is 6,553.

Table 6 displays the rebound effect for different transportation purposes. The magnitude of the rebound effect lies between 40% and 50% for the majority of driving purposes. The only exception is the lower rebound effect for leisure activities with a value of 24%. In comparison to the previous rebound estimates, the differences between the 3SLS estimates differ to a larger extent from the OLS estimates. Unfortunately, we could only differentiate between the driving purposes for the daily distances, since only the daily distance measure is based on the geo-routing system. Further research is needed to better understand the relationship between driving purpose and the magnitude of the rebound effect.

5 Conclusion

In this chapter, we compare two different approaches to estimate the rebound effect of private transportation in Switzerland. Under the first approach, we estimate the rebound effect using detailed data of the Swiss microcensus on mobility and transport for the year 2010. Under the second approach, we derive the rebound effect from the price elasticities from Chapter 2.

The energy service private transportation has the advantage, that there are two different surveys that conduct information about the driving behavior of Swiss households. We find a rebound of about 20% based on price elasticities and a rebound of approximately 60% based on the efficiency measure. Hence, the rebound estimates from the two approaches reveal considerable differences. Moreover, the result contradicts the notion that rebound effects based on price-elasticities can be considered as an upper-bound of the true rebound effect. One explanation of the relatively large differences is that under the former approach we employ short-run elasticities while the latter approach estimates long-run rebound effects. Hence, in Switzerland the rebound effect seems to be considerably higher in the long-run, at least for private transportation.

In addition to the comparison of the two approaches, we also compute rebound effects for specific household groups. We find large differences between certain groups with the income level as the main driver. Considering the annual distance measure, we find a relatively high rebound effect of 87% for low-income households and rather low values of 33% for high-income households. A similar effect is also observed for the level of education. Furthermore, we find the rebound effect to increase in the drivers' age. Comparable results are found using the daily distance measure. For the latter, we investigated how the driving purpose affects the magnitude of the rebound effect. Considering 3SLS estimates, we find a rebound effect of 48% for work and of 24% for leisure. In summary and compared to other studies, we find relatively high rebound effect for private transportation in Switzerland.

References

Baranzini, A., S. Weber, M. Bareit, and N. A. Mathys (2013). The causal relationship between energy use and economic growth in Switzerland. *Energy Economics 36*(C), 464–470.

Berkhout, P. H. G., J. C. Muskens, and J. W. Velthuijsen (2000). Defining the rebound effect. *Energy Policy 28*(6-7), 425–432.

de Haan, P., M. G. Mueller, and A. Peters (2006). Does the hybrid Toyota Prius lead to rebound effects? Analysis of size and number of cars previously owned by Swiss Prius buyers. *Ecological Economics 58*, 592–605.

Frondel, M., J. Peters, and C. Vance (2008a). Identifying the rebound: Evidence from a German household panel. *Energy Journal 29*, 154–163.

Frondel, M., J. Peters, and C. Vance (2008b). Identifying the Rebound: Evidence from a German Household Panel. *The Energy Journal 0*(Number 4), 145–164.

Frondel, M., N. Ritter, and C. Vance (2010, November). Heterogeneity in the Rebound Eff ect Further Evidence for Germany. Ruhr Economic Papers 0227, Rheinisch-Westflisches Institut fr Wirtschaftsforschung, Ruhr-Universitt Bochum, Universitt Dortmund, Universitt Duisburg-Essen.

Greening, L. A., D. L. Greene, and C. Difiglio (2000). Energy efficiency and consumption – the rebound effect – a survey. *Energy Policy 28*, 389–401.

Haas, R. and L. Schipper (1998, September). Residential energy demand in OECD-countries and the role of irreversible efficiency improvements. *Energy Economics 20*(4), 421–442.

Jenny, A., A. Karlegger, D. Montanari, W. Ott, and R. Madlener (2013). Massnahmen der Energiestrategie 2050: Begleitende verhaltensökonomische und sozialpsychologische Handlungsempfehlungen. Technical report, Swiss Federal Office of Energy (SFOE).

Knittel, C. R. (2011, December). Automobiles on Steroids: Product Attribute Trade-Offs and Technological Progress in the Automobile Sector. *American Economic Review 101*(7), 3368–99.

Madlener, R. and B. Alcott (2009). Energy rebound and economic growth: A review of the main issues and research needs. *Energy 34*(3), 370–376.

Sorrell, S. and J. Dimitropoulos (2008). The rebound effect: Microeconomic definitions, limitations and extensions. *Ecological Economics 65*(3), 636–649.

Sorrell, S., J. Dimitropoulos, and M. Sommerville (2009). Empirical estimates of the direct rebound effect: A review. *Energy Policy 37*, 1356–1371.

Spielmann, M., P. de Haan, and R. W. Scholz (2008). Environmental rebound effects of high-speed transport technologies: A case study of climate change rebound effects of a future underground maglev train system. *Journal of Cleaner Production 16*(13), 1388 – 1398.

Turner, K. (2013). "Rebound" Effects from Increased Energy Efficiency: A Time to Pause and Reflect. *The Energy Journal 0*(Number 4).

Weber, S. and M. Farsi (2014, September). Travel Distance and Fuel Efficiency: An Estimation of the Rebound Effect using Micro-Data in Switzerland. IRENE Working Papers 14-03, IRENE Institute of Economic Research.

A Parameter Estimates

A.1 Estimates from Annual Distance

Table 7: Parameter Estimates from Annual Distance

	3SLS			OLS		
	Distance	Fuel intensity	Weight	Distance	Fuel intensity	Weight
(Intercept)	2.151*** (0.7521)	1.399*** (0.3376)	6.269*** (0.3704)	4.409*** (0.416)	1.872*** (0.0272)	6.995*** (0.0291)
log(FI)	−0.591*** (0.0726)			−0.409*** (0.0547)		
log(W)	1.194*** (0.1115)			0.841*** (0.063)		
med.income	0.148*** (0.0306)	0.017* (0.0093)	0.016 (0.0103)	0.165*** (0.0301)	0.022*** (0.0055)	0.03*** (0.006)
high.income	0.194*** (0.0357)	0.022* (0.0128)	0.014 (0.0142)	0.224*** (0.0345)	0.03*** (0.0062)	0.033*** (0.0069)
women	−0.204*** (0.0203)	−0.039*** (0.0099)	−0.024** (0.0109)	−0.223*** (0.0193)	−0.041*** (0.0035)	−0.041*** (0.004)
children	−0.077*** (0.021)	0.038*** (0.0039)	0.033*** (0.0075)	−0.062*** (0.0205)	0.029*** (0.0037)	−0.002 (0.0098)
drivage	−0.124*** (0.0072)	0 (0.0048)	0.008 (0.0052)	−0.127*** (0.0072)	−0.007*** (0.0014)	−0.002 (0.0015)
urbreg	−0.123*** (0.0216)	−0.007 (0.006)	−0.001 (0.0066)	−0.127*** (0.0215)	−0.011*** (0.0039)	−0.011** (0.0043)
mid.educ	0.055 (0.0372)			0.055 (0.0372)		
high.educ	0.137*** (0.0387)			0.133*** (0.0386)		
log(dist)		0.053 (0.034)	0.094** (0.0373)		0.009*** (0.0023)	0.021*** (0.0025)
vehage		0.008*** ($5e{-}04$)	−0.01*** ($5e{-}04$)		0.011*** ($5e{-}04$)	−0.009*** ($5e{-}04$)
manual		−0.075*** (0.0032)			−0.135*** (0.0046)	
diesel		−0.259*** (0.0029)			−0.167*** (0.0042)	
zylinder4		0.289*** (0.0112)	0.32*** (0.0122)		0.271*** (0.0112)	0.314*** (0.0122)
zylinder5		0.517*** (0.0152)	0.503*** (0.0165)		0.464*** (0.0153)	0.496*** (0.0165)
zylinder6		0.533*** (0.0124)	0.536*** (0.0133)		0.483*** (0.0126)	0.529*** (0.0133)
zylinder8		0.625*** (0.017)	0.656*** (0.0184)		0.58*** (0.0173)	0.652*** (0.0184)
zylinder10		0.777*** (0.0403)	0.75*** (0.0439)		0.691*** (0.0404)	0.738*** (0.0439)
zylinder12		0.66*** (0.0779)	0.726*** (0.085)		0.619*** (0.078)	0.723*** (0.0849)
hhsize2			0.012*** (0.0034)			0.025*** (0.0049)
hhsize3			0.04*** (0.0074)			0.083*** (0.0107)

Notes: Distance = distCH_last12m; ***,** and * denote significance at the 1, 5 and 10 per cent level.

A.2 Estimates from Daily Distance

Table 8: Parameter Estimates from Daily Distance

	3SLS			**OLS**		
	Distance	Fuel intensity	Weight	Distance	Fuel intensity	Weight
(Intercept)	-1.33 (1.2366)	1.816^{***} (0.0702)	7.01^{***} (0.0769)	0.64 (0.6857)	1.969^{***} (0.0169)	7.188^{***} (0.0175)
log(FI)	-0.628^{***} (0.1196)			-0.52^{***} (0.0901)		
log(W)	0.848^{***} (0.1833)			0.554^{***} (0.1038)		
med.income	0.137^{***} (0.0503)	0.023^{***} (0.0066)	0.027^{***} (0.0073)	0.152^{***} (0.0497)	0.024^{***} (0.0055)	0.034^{***} (0.0061)
high.income	0.282^{***} (0.0587)	0.028^{***} (0.0096)	0.024^{**} (0.0107)	0.309^{***} (0.0568)	0.033^{***} (0.0062)	0.038^{***} (0.007)
women	-0.156^{***} (0.0334)	-0.048^{***} (0.0049)	-0.04^{***} (0.0055)	-0.174^{***} (0.0318)	-0.043^{***} (0.0035)	-0.046^{***} (0.004)
children	-0.144^{***} (0.0345)	0.04^{***} (0.0043)	0.036^{***} (0.0077)	-0.132^{***} (0.0338)	0.029^{***} (0.0037)	-0.004 (0.0098)
drivage	-0.149^{***} (0.0119)	-0.002 (0.0031)	0.004 (0.0034)	-0.151^{***} (0.0118)	-0.008^{***} (0.0014)	-0.004^{***} (0.0015)
urbreg	-0.186^{***} (0.0355)	-0.009^{*} (0.0051)	-0.005 (0.0056)	-0.19^{***} (0.0354)	-0.012^{***} (0.0039)	-0.013^{***} (0.0043)
mid.educ	0.146^{**} (0.0613)			0.148^{**} (0.0613)		
high.educ	0.308^{***} (0.0636)			0.309^{***} (0.0636)		
log(dist)		0.027 (0.0175)	0.049^{**} (0.0192)		-0.002 (0.0014)	0.003^{*} (0.0015)
vehage		0.008^{***} ($5e-04$)	-0.01^{***} ($5e-04$)		0.011^{***} ($5e-04$)	-0.01^{***} ($5e-04$)
manual		-0.075^{***} (0.0032)			-0.135^{***} (0.0046)	
diesel		-0.259^{***} (0.0029)			-0.165^{***} (0.0042)	
zylinder4		0.289^{***} (0.0112)	0.32^{***} (0.0123)		0.272^{***} (0.0112)	0.318^{***} (0.0123)
zylinder5		0.518^{***} (0.0152)	0.503^{***} (0.0165)		0.467^{***} (0.0153)	0.502^{***} (0.0165)
zylinder6		0.534^{***} (0.0124)	0.536^{***} (0.0134)		0.486^{***} (0.0126)	0.535^{***} (0.0134)
zylinder8		0.624^{***} (0.0171)	0.655^{***} (0.0184)		0.582^{***} (0.0173)	0.657^{***} (0.0184)
zylinder10		0.781^{***} (0.0403)	0.759^{***} (0.044)		0.699^{***} (0.0404)	0.757^{***} (0.044)
zylinder12		0.653^{***} (0.078)	0.718^{***} (0.0853)		0.616^{***} (0.0781)	0.722^{***} (0.0854)
hhsize2			0.012^{***} (0.0034)			0.025^{***} (0.0049)
hhsize3			0.041^{***} (0.0074)			0.085^{***} (0.0108)

Notes: Distance = distCH_GIS; ***,** and * denote significance at the 1, 5 and 10 per cent level.

B Rebound Effect from OLS Estimation

For the sake of completeness, we present in this section the rebound estimates, based on standard OLS.

Table 9: Rebound Effect based on Efficiency Measures

Distance	RE	SE	t-value	95% CI	
				LL	UL
Annual distance	0.41	0.05	7.49	0.30	0.52
Daily distance	0.52	0.09	5.78	0.34	0.70

Notes: The OLS estimates of the rebound effect are based on the fuel efficiency of driven cars in Switzerland. The number of observations is 6,553.

Table 10: Rebound by Household Types, Annual Distance

Annual distance	RE	SE	t-value	95% CI	
				LL	UL
Household size					
Single	0.46	0.11	4.10	0.24	0.68
Two persons	0.36	0.09	3.85	0.18	0.54
Three persons	0.34	0.14	2.46	0.07	0.61
More persons	0.47	0.10	4.48	0.26	0.68
Income					
Low income	0.83	0.20	4.19	0.44	1.22
Medium income	0.49	0.07	6.82	0.35	0.63
High income	0.12	0.09	1.31	-0.06	0.30
Age					
Young	0.37	0.14	2.68	0.10	0.64
Middle-age	0.41	0.06	6.31	0.28	0.54
Old	0.58	0.14	4.07	0.30	0.86
Sex					
Male	0.35	0.06	5.42	0.22	0.48
Female	0.52	0.10	5.16	0.32	0.72
Education					
Low education	0.51	0.25	2.04	0.02	1.00
Medium eduction	0.38	0.08	4.93	0.23	0.53
High education	0.43	0.08	5.30	0.27	0.59
Average	0.41	0.05	7.49	0.30	0.52

Notes: The OLS rebound estimates are computed for annually driven distances. The number of observations is 6,553.

Table 11: Rebound by Household Types, Daily Distance

Daily distance	RE	SE	t-value	95% CI	
				LL	UL
Household size					
Single	0.73	0.17	4.34	0.40	1.06
Two persons	0.27	0.16	1.67	-0.05	0.59
Three persons	0.61	0.26	2.34	0.10	1.12
More persons	0.58	0.17	3.40	0.25	0.91
Income					
Low income	0.92	0.29	3.18	0.35	1.49
Medium income	0.67	0.12	5.81	0.44	0.90
High income	0.14	0.16	0.86	-0.18	0.46
Age					
Young	0.26	0.25	1.04	-0.23	0.75
Middle-age	0.53	0.11	4.98	0.32	0.74
Old	0.77	0.23	3.39	0.32	1.22
Sex					
Male	0.47	0.11	4.29	0.26	0.68
Female	0.57	0.16	3.60	0.26	0.88
Education					
Low education	0.57	0.33	1.72	-0.08	1.22
Medium eduction	0.69	0.13	5.32	0.44	0.94
High education	0.33	0.14	2.43	0.06	0.60
Average	0.52	0.09	5.78	0.34	0.70

Notes: The OLS rebound estimates are computed for daily driven distances. The number of observations is 6,553.

Table 12: Rebound Effects by Driving Purpose

Purpose	RE	SE	t-value	95% CI	
				LL	UL
Work	0.58	0.12	4.72	0.34	0.82
Shopping	0.35	0.15	2.32	0.05	0.65
Leisure	0.44	0.13	3.35	0.18	0.70
Others	0.31	0.11	2.78	0.09	0.53

Notes: The OLS rebound estimates are computed for daily distances with the detailed purpose information from the GIS software. The number of observations is 6,553.