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Long term fuel price elasticity: Effects on mobility tool ownership and residential location choice

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Contents

1 Abstract

The study analyzes how mobility tool usage and ownership as well as residence location choice are affected by rising fuel costs. Based on econometric models, long-term fuel price elasticities are derived.

Based on data collected in *stated choice* and *stated adaptation* experiments that were conducted as computer-based face-to-face surveys, a structural equation model was estimated. The resulting fuel price elasticities are primarily dependent on fuel type and fuel price level, but sociodemographic variables, such as income, also have significant effects on elasticity. theprice elasticity of gasoline for a prices of 1.5 CHF/l and 5 CH/l ranges between -0.31 and -0.60. For diesel and natural gas, the elasticities range between 0.32 and -0.67 and 2.74 and -0.93 whereas the positive elasticity values are caused by substitution effects. The mainly observed demand reactions given higher fuel prices are the reduction of mileage and the consideration of smaller engine and diesel cars. As natural gas and electric engined cars were hardly considered in the survey, the results of the natural gas model can only serve as trend whereas no stable model could be estimated for the demand and usage of electric cars. Although the results presented herein are based on the for this topic novel stated adaption approach, the results are comparable to other studies, namely to the recent time series based fuel price elasticity study of Baranzini *et al.* (2009). They report a long term price elasticity of -0.27 for all fuels and -0.34 for gasoline.

In terms of a possible impact of fuel prices on residence location choice, the results suggest a high aversion to moving away from the current type of residence location. The willingness to pay more before moving to a more central location that has lower mobility costs is dependent on income and the spatial types of both the old and envisaged residence location. For an average income, mobility costs range between 463 CHF/month in the case of a residence location change from an agglomeration to an urban area and 2040 CHF/month when moving from a rural area to the city center. In addition, differences in the valuations of housing, car and public transport costs are identified, in which car costs are generally the least negatively valued.

2 Kurzfassung

2.1 Zielsetzung und Datenerhebung

Die vorliegende Studie untersucht die langfristigen Wirkungen steigender Treibstoffpreise. Dabei mitberücksichtigt werden mögliche Auswirkungen bezüglich der Wahl und des Besitzes von Mobilitätswerkzeugen, also Personenwagen und Abonnementen des Öffentlichen Verkehrs (ÖV), und deren Nutzung. Zusätzlich wird der Einfluss der Mobilitätskosten auf die Wohnstandortwahl untersucht.

Zu diesem Zweck wurden in einer persönlichen, computer-unterstützten Befragung 409 Haushalte in einem ersten Teil über ihren derzeitigen Besitz von Mobilitätswerkzeugen sowie deren Benutzung befragt und die Beschreibung ihrer soziodemografischen Eigenschaften aufgenommen. Im zweiten, zentralen Teil der Befragung wurde mit verschiedenen *stated preference* Methoden die Wirkung von steigenden Treibstoffpreisen bezüglich des Besitzes und der Nutzung von Mobilitätswerkzeugen sowie der Wahl des Wohnstandortes untersucht. Zunächst wurden in sechs Situationen Treibstoff- und ÖV-Preise im Bereich zwischen 1.5 CHF/l und 5 CHF/l, respektive 90-120 % des heutigen Preisniveaus verändert (SP1). Daneben wurde der Einfluss von verschiedenen CO_2-Anreizsystemen untersucht. Gemäss der Methodik der *stated adaptation* waren die Befragten dazu aufgefordert ihre Mobilitätswerkzeugwahl und deren Nutzung anzugeben. Personenwagen konnten nach Fahrzeug- und Motorentyp sowie Hubraum ausgewählt werden. Als ÖV-Abonnemente standen die drei gängigsten Varianten Halbtax, Tarifverbund und GA zur Wahl. In sechs weiteren Situationen (SP2) sollten sich die Befragten vorstellen, wie sich ihr Mobilitätswerkzeugbesitz und -nutzung für einen gegebenen Wohnort an anderer räumlicher Lage als der heutigen ändern würde. Zusätzlich wurde, wie bereits bei den ersten sechs Entscheidungssituationen, auch die Ausgestaltung der Mobilitätskosten verändert. Der letzte Teil (SP3) der Befragung kombinierte aus diesen zwölf Situationen (mitsamt der präferierten Zusammensetzung von Mobilitätswerkzeugen und deren Nutzung) je zwei zu sechs *stated choice* Entscheidungssituationen. Mit diesem Teil der Befragung wurde untersucht, inwiefern steigende Mobilitätskosten auf die Wohnstandortwahl einen Einfluss ausüben.

2.2 Resultate

2.2.1 Preiselastizität des Treibstoffs

Aus dem ersten Teil der *stated preference* Experimente (SP1) wurde klar, dass die befragten Haushalte bei steigenden Mobilitätskosten sowohl über die veränderte Wahl der vorgehaltenen Personenwagen und deren Nutzung als auch über stärkere ÖV-Nutzung reagieren. Die dabei am häufigsten beobachteten Handlungsmuster waren Wechsel von grösseren und/oder stärker motorisierten zu kleineren und/oder schwächer motorisierten Modellen, von Benzin zu Dieselmotoren, sowie die Reduktion der Jahresfahrleistung. Zusätzlich konnte ein Trend zur vermehrten Nutzung des ÖV ausgemacht werden.

Basierend auf diesen Verhaltensdaten wurden mittels eines Strukturgleichungsmodells (*structural equations model*) ökonometrische Modelle geschätzt. Als abhängige Variablen wurden auf Haushaltsebene der jährliche Treibstoffverbrauch, aufgeteilt nach Treibstofftypen, sowie die jährlich mit dem ÖV zurückgelegte Distanz modelliert. Als unabhängige Variablen wurden neben den Treibstoffkosten auch der heutige Treibstoffverbrauch und die ÖV-Nutzung berücksichtigt. Die Interaktion der Treibstoffkosten mit verschiedenen sozio-demografischen Variablen ermöglichte es Abhängigkeiten der Preiswahrnehmung herauszuarbeiten. Dabei zeigte sich, dass insbesondere ein überdurchschnittliches Einkommen und der Besitz eines grossen Fahrzeuges die Preissensitivität verringern. Besitzer von ÖV-Abonnementen, Personen in der zweiten Lebenshälfte sowie Personen, welche in peripheren Orten wohnen, zeigen hingegen bei steigenden Benzinpreisen eine grössere Veränderungsbereitschaft. In Tabelle 1 sind die aus den Modellen abgeleiteten und bezüglich der Repräsentativität der Stichprobe umgewichteten Preiselastizitäten zusammengefasst. Aufgrund der linear-quadratischen Modellformulierung sind die Elastizitätswerte abhängig vom Treibstoffpreis. Aufgrund des Befragungsansatzes, der sowohl eine Reduktion der Fahrleistung als auch den Wechsel der benutzten Fahrzeuge respektive deren Verzicht umfasste, sind die berichteten Preiselastizitäten als langfristig zu interpretieren.

Table 1: Langfristige Treibstoffpreiselastizitäten, basierend auf den Daten des ersten *stated adaptation* Experiments, modelliert mit dem Strukturgleichsmodell gemäss Gleichung 1 und bezüglich Repräsentativität umgewichtet (siehe Abschnitt 8.3.2).
‡Der totale Treibstoffverbrauch umfasst Benzin, Diesel und Gas

Treibstoffpreise [CHF/l]	Totaler Treibstoffverbrauch‡	Benzin	Diesel	ÖV
1.5	-0.14	-0.31	0.32	0.09
2	-0.19	-0.41	0.30	0.12
3	-0.29	-0.56	0.15	0.17
4	-0.51	-0.60	-0.15	0.22
5	-0.54	-0.43	-0.67	0.26

Die angegebenen Elastizitätwerte sind folgendermassen zu interpretieren: Beispielsweise wird bei einem Treibstoffpreis von 3 CHF/l erwartet, dass bei einer Preiserhöhung um 10% der totale Treibstoffkonsum um -2.9% zurückgeht (Benzinkonsum -5.6%, Dieselkonsum +1.5%).

Mit steigenden Treibstoffkosten steigen auch die Elastizitätswerte an.

Die Dieselelastizität ist bis zu einem Treibstoffpreis von 3.5 CHF positiv. Bis zu diesem Preisniveau übersteigt die auf Substitution von Benzin- durch Dieselfahrzeuge zurückzuführende Nachfragezunahme den Nachfragerückgang, der für die bereits vorhanden Dieselfahrzeuge beobachtet wurde.

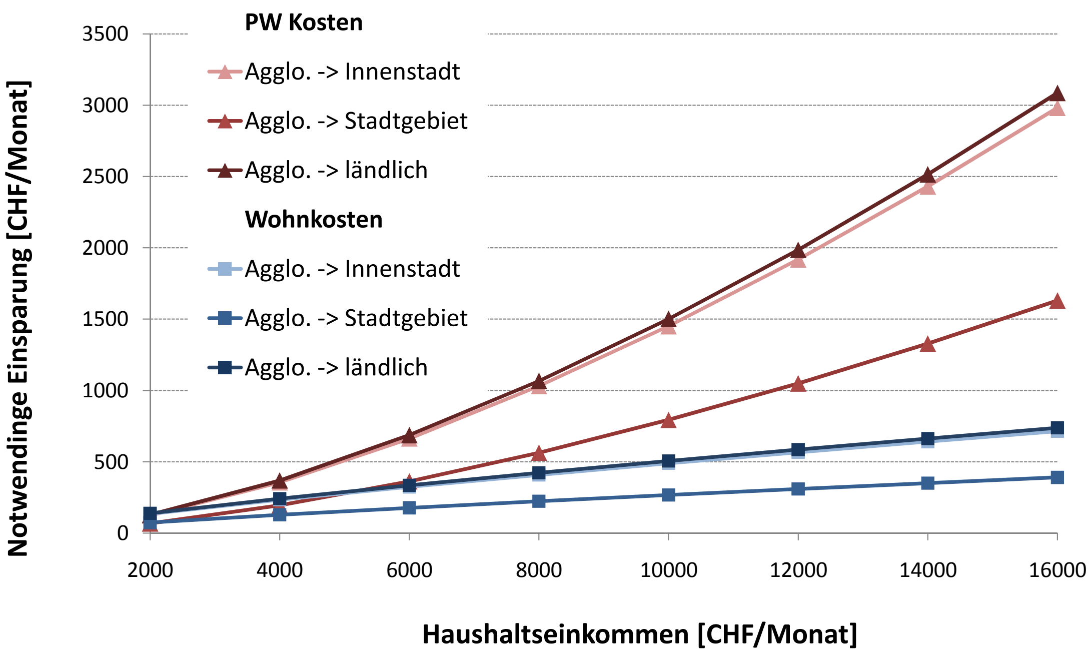
Die Benzinpreiselastizität entspricht im vergleichbaren, unteren Preisbereich den in Baranzini *et al.* (2009) berichteten Werten, die auf einer Zeitreihenanalyse basieren, sehr gut. So beträgt die Preiselastizität bei einem Benzinpreis von 1.65 CHF/l (wie zum Zeitpunkt der Befragung) -0.34, also genau dem Wert, der auch von Baranzini *et al.* (2009) berichtet wird. Die Elastizität des totalen Treibstoffverbrauchs liegt in diesem Bereich allerdings unter dem ebenda berichteten Wert (-0.15 vs. -0.27). Dies dürfte, zumindest teilweise, auf die unterschiedlichen zugrunde liegenden Methodiken zurückzuführen sein: In Baranzini *et al.* (2009) wird die Anzahl der Fahrzeuge einer Treibstoffklasse als exogen angenommen, wogegen in der vorliegenden Studie der von der Höhe des Treibstoffpreises abhängige Wechsel von Benzin zu Diesel mitberücksichtigt wird. Daneben berücksichtigt die vorliegende Studie nur den Treibstoffverbrauch der privaten Haushalte, während in Baranzini *et al.* (2009) der Gesamtverbrauch des gesamten Transportsektors (mit Ausnahme Aviatik) modelliert wurde. Weiter kann nicht ganz ausgeschlossen werden, dass aufgrund des hypothetischen Charakters der Befragung die mit einem Autowechsel verbundenen Kosten und Anstrengungen von den Befragten teilweise unterschätzt wurden.

Basierend auf den Daten der Befragung können bezüglich des Einflusses verschiedener CO_2-Anreizschemata keine gesicherten Aussagen gemacht werden. Zwar wurden entsprechende Variablen in der Befragung berücksichtigt, deren Einfluss erwies sich aber in keinem der angewendeten Modelle als signifikant. Dies steht im Gegensatz zu bisherigen Studien (Iten *et al.* (2005), de Haan *et al.* (2009)), welche aber klar auf die Wirkungsabschätzung solcher Schemata abzielten und daher dafür geeignetere Methoden verwendeten. Es ist daher davon auszugehen, dass sich die Befragten aufgrund der hohen Komplexität der Befragung vor allem auf den angegebenen Treibstoffpreis konzentriert haben und andere Variablen bei ihren Entscheiden nicht genügend berücksichtigen konnten.

2.2.2 Einfluss des Treibstoffspreises auf die Wohnstandortwahl

Mit den Daten des *stated choice* Experiments (SP3) wurden diskrete Logit-Entscheidungsmodelle zur Wohnstandortwahl unter spezieller Berücksichtigung der Mobilitätskosten geschätzt. Dabei zeigte sich einerseits, dass Mobilitätskosten weniger stark wahrgenommen werden als Wohnkosten. Andererseits, erwies sich die Veränderungswilligkeit bezüglich des Wohnstandorts als sehr gering. Dies äusserte sich darin, dass die Befragten Alternativen, deren räumlicher Funktionstyp dem heutigen entsprach, systematisch bevorzugten. Basierend auf den Modellresultaten lassen sich Zahlungsbereitschaften des Verbleibens am ursprünglichen Wohnort berechnen. Aufgrund des statistisch signifikanten Einflusses des Einkommens und des heutigen Wohnorts der Befragten, ergeben sich die in Abbildung 1, hier für den heutigen Wohnstandort Agglomeration, dargestellten Zahlungsbereitschaftskurven. Ein Vergleich mit den durch einen Wohnstandortwechsel möglichen Mobilitätskosteneinsparungen, die je nach Treibstoffpreis und Jahresfahrleistung bis rund 150 CHF/Monat betragen, zeigt, dass auch Treibstoffpreise bis 5 CHF/l eine sehr geringe Auswirkung auf die Wohnstandortwahl hätten.

Figure 1: Zahlungsbereitschaften (berechnet nach Gleichung 4) des Verbleibens am heutigen Wohnstandort Agglomeration gemäss den Resultaten des Wohnstandortwahlmodells SP3 (Gleichung 3)



2.3 Fazit

Die hier ausgewiesenen, auf *stated adaptation*-Daten basierenden Treibstoffpreiselastizitäten stimmen gut mit vergleichbaren, auf Zeitreihenanalyse basierenden Resultaten (Baranzini *et al.* (2009)) überein, was die Validität der angewendeten Methodik bestätigt. Allerdings konnte der Einfluss verschiedener CO_2-Anreizsysteme nicht quantifiziert werden. Daher wird für zukünftige Studien, die den Effekt unterschiedlicher CO_2-Anreizsystem untersuchen, empfohlen auf für den Befragten einfachere Befragungsmethodiken, wie beispielsweise stated choice, zurückzugreifen.

Weiter sind die ausgewiesenen Marktanteile und Elastizitäten alternativer Treibstoffe wie Gas und Strom mit Unsicherheiten behaftet, die teilweise auf den Befragungsansatz zurückzuführen sind. Einerseits dürfte ein Teil der Befragten mit den Eigenschaften alternativer Treibstoffe nur wenig vertraut sein, weshalb derart angetriebene Fahrzeuge nicht als valable Alternative wahrgenommen werden. Andererseits hängt die Attraktivität solcher Fahrzeuge stark von der Verbreitung entsprechender Tankstellen (Gas) und der Reichweite der Fahrzeuge (Strom) ab. Da beide Punkte in der Befragung nicht explizit beschrieben wurden, ist davon auszugehen, dass die Befragten die heutigen Verhältnisse als Grundlage für ihre Entscheidung heranzogen. Es ist aber zu erwarten, dass sich bei Treibstoffpreisen bis 5 CHF/l sowohl die Gastankstellendichte als auch die Reichweite von elektrisch betriebenen Fahrzeugen gegenüber heute positiv entwickelt haben dürfte.

In dieser Studie wurde nur der Einfluss von Treibstoffpreisen auf die Wohnstandortwahl berücksichtigt. Dabei zeigten sich grosse Trägheitseffekte; die Befragten tendieren trotz hoher Mobilitätskosten also dazu in der ihnen bekannten Umgebung zu verbleiben. In früheren Studien konnte gezeigt werden, dass Haushalte in der Schweiz im Schnitt alle 7 Jahre umziehen (Beige (2008)). Für langfristige Prognosen wäre daher die besondere Berücksichtigung von Haushalten, die kurz vor oder nach einem Umzug stehen, sinnvoll.

Neben der Lage des Haushalts bestimmt auch die Lage der Arbeit, zumindest relativ zum Haushalt, in grossem Masse den Mobilitätsbedarf. Im Hinblick auf das stetige Wachstum der Pendlerdistanzen (Fröhlich (2008)) wäre eine Untersuchung, die den Einfluss höherer Mobilitätskosten hinsichtlich der Wahl des Arbeitsortes untersucht, sowohl energiepolitisch als auch raumplanerisch relevant.

3 Résumé

3.1 Objectifs et collecte de données

La présente étude analyse les effets à long terme de la hausse du prix des carburants, notamment les conséquences possibles sur le choix, sur la possession et sur l'utilisation des outils de mobilité que sont les voitures et les abonnements de transports publics (TP). De plus, elle examine l'influence des coûts de la mobilité sur le choix du lieu d'habitation.

A cette fin, on a effectué un entretien individuel assisté par ordinateur auprès de 409 ménages. Dans la première partie, on les a interrogés pour savoir quels outils de mobilité ils possédaient, comment ils les utilisaient et quelles étaient leurs données sociodémographiques. Dans

la deuxième partie de l'entretien, la plus importante, on a étudié à l'aide de diverses méthodes de préférence déclarée (stated preference) l'effet de la hausse du prix des carburants sur la possession et sur l'utilisation des outils de mobilité ainsi que sur le choix du lieu d'habitation. On a d'abord présenté six situations dans lesquelles le prix des carburants variait dans une fourchette allant de 1,5 CHF/l à 5,0 CHF/l et celui des TP dans une fourchette comprise entre 90 à 120% du niveau actuel des prix (PD1). On a en outre examiné l'influence de différents systèmes d'incitation visant à réduire les émissions de CO_2. Conformément à la méthode de l'adaptation déclarée (*stated adaptation*), on a demandé aux personnes interrogées d'indiquer quel outil de mobilité elles choisiraient et quelle utilisation elles en feraient. Pour les voitures, elles pouvaient choisir le type de véhicule, la motorisation et la cylindrée. Pour les abonnements de TP, elles avaient le choix entre les trois variantes les plus courantes: le demi-tarif, la communauté tarifaire et l'abonnement général (AG). Elles devaient aussi se représenter dans six autres situations (PD2) comment changeraient leur possession et leur utilisation des outils de mobilité dans un lieu d'habitation donné situé dans une autre configuration spatiale que l'actuelle. De surcroît, comme pour les six premières situations de décision, on a aussi modifié la structure des coûts de la mobilité. A partir de ces douze situations (avec la combinaison préférée des outils de mobilité et de leur utilisation), la dernière partie (PD3) du sondage proposait de deux à six situations de choix déclaré (*stated choice*) afin d'étudier dans quelle mesure la hausse des coûts de la mobilité exercent une influence sur le choix du lieu d'habitation.

3.2 Résultats

3.2.1 Elasticité-prix des carburants

Il ressort clairement de la première partie des expériences de préférence déclarée (PD1) que les ménages interrogés réagissent à la hausse des coûts de la mobilité à la fois en portant leur choix sur un autre modèle de voiture et en modifiant l'utilisation qu'ils en font mais aussi en recourant plus aux TP. Les modèles d'action les plus souvent observés sont le changement d'un modèle de plus grande et/ou forte cylindrée à un modèle de plus petite et/ou faible cylindrée, l'abandon du moteur à essence au profit du moteur diesel et la réduction du kilométrage annuel.

Sur la base de ces données comportementales, on a établi des modèles économétriques à l'aide d'un modèle d'équations structurelles (*structural equations model*). Au niveau des ménages, on a modélisé comme variables dépendantes la consommation annuelle selon les différents types de carburants et la distance annuelle parcourue en TP. On a pris en considération comme variables indépendantes non seulement le coût des carburants mais aussi la consommation actuelle de carburant et l'utilisation des TP. L'interaction du coût des carburants avec diverses variables sociodémographiques a permis de trouver des interdépendances dans la perception des prix. Il ressort entre autres qu'un revenu supérieur à la moyenne et la possession d'un grand véhicule diminuent la sensibilité au prix. Les détenteurs d'abonnements de TP, les personnes de plus de 40 ans et les habitants des zones périphériques sont en revanche plus disposés à changer en cas de hausse du prix de l'essence. Le tableau 2 résume les élasticités-prix déduites des modèles et repondérées en fonction de la représentativité de l'échantillon. En raison de la formulation linéo-quadratique des modèles, les valeurs d'élasticité dépendent du prix des carburants. Etant donné le mode de sondage, qui envisage aussi bien de réduire le kilométrage que de changer de voiture, voire d'y renoncer, les élasticités-prix constatées doivent être interprétées sur le long terme.

Table 2: Elasticités-prix à long terme du prix des carburants sur la base des données recueillies lors des premières expériences d'adaptation déclarée, modélisées au moyen du modèle d'équations structurelles selon l'équation 1 et repondérées en fonction de la représentativité (cf. section 8.3.2).
‡La consommation totale de carburants comprend l'essence, le diesel et le gaz.

Prix des carburants [CHF/l]	Consommation totale de carburants‡	Essence	Diesel	TP
1.5	-0.14	-0.31	0.32	0.09
2	-0.19	-0.41	0.30	0.12
3	-0.29	-0.56	0.15	0.17
4	-0.51	-0.60	-0.15	0.22
5	-0.54	-0.43	-0.67	0.26

Il faut interpréter les valeurs d'élasticités indiquées comme suit: p. ex. lorsque le carburant coûte 3 CHF/l, on s'attend en cas de hausse de prix de 10% à ce que la consommation totale de carburants baisse de -2,9% (consommation d'essence -5,6%, consommation de diesel +1,5%).

L'élasticité de prix du gazole est positive jusqu'au prix de 3.5 CHF par litre de carburant. Jusqu'à ce plateau, la croissance de la demande suite à la substitution de véhicules à essence par ceux à gazole excède la baisse de la demande observée pour les véhicules à gazole existants.

Dans une fourchette comparable de prix bas, l'élasticité-prix de l'essence recoupe très bien les valeurs figurant in Baranzini *et al.* (2009) qui reposent sur une analyse de série temporelle. Ainsi, l'élasticité-prix pour de l'essence coûtant 1,65 CHF/l (prix de l'essence au moment du sondage) est de -0,34, soit exactement la valeur mentionnée par Baranzini *et al.* (2009). Toutefois, l'élasticité de la consommation totale de carburants se situe dans cette fourchette au-dessous de la valeur citée ibidem (-0,15 vs. -0,27).

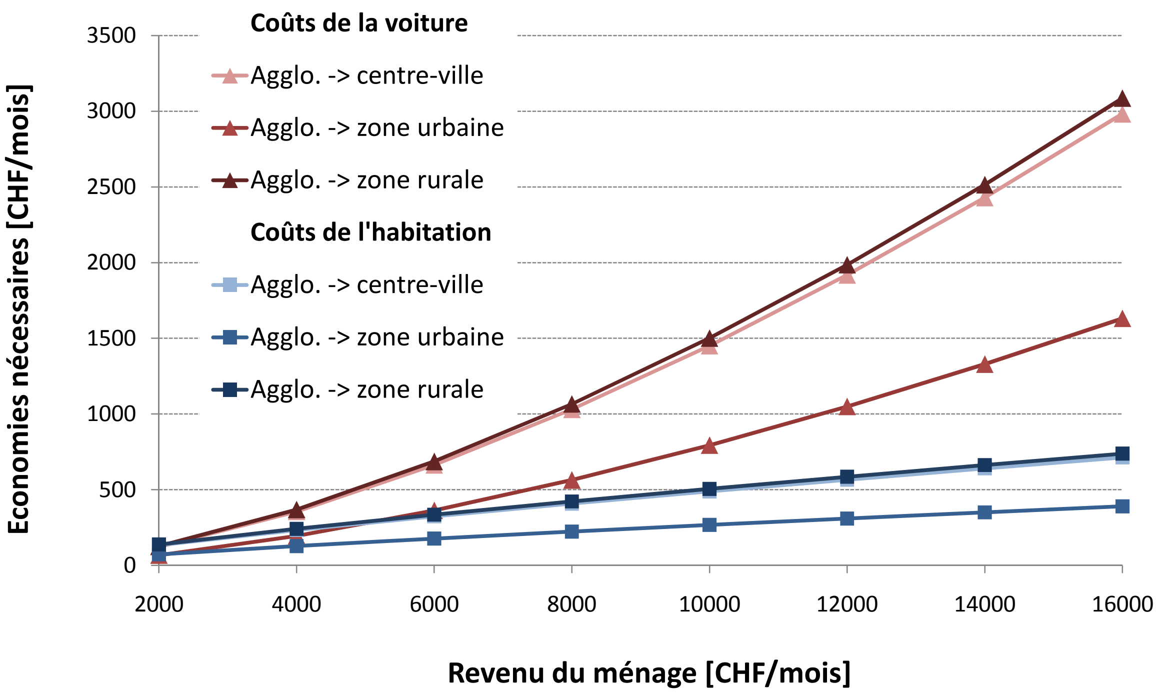
Cette différence est probablement due (au moins en partie) aux différentes méthodologies: Baranzini et al. (2009) assument que le nombre de véhicules d'une classe de carburant est exogène au système, tandis que dans l'étude présente, on tient compte de la transition de véhicules à essence à ceux à diesel en fonction des prix des carburants. En outre, l'étude présente ne considère que la consommation de carburant des ménages privés, tandis que la consommation totale de tous les secteurs (à l'exception de l'aviatique) a été modélée dans Baranzini et al. (2009). En plus, on ne peut pas exclure que, suite au caractère hypothétique du sondage, les interviewés sous-estiment, des coûts et efforts liés à un changement de véhicule.

Les données recueillies lors des entretiens ne permettent pas de se prononcer de manière sûre sur l'influence de différents systèmes d'incitation visant à réduire les émissions de CO_2. Le sondage prend certes en considération des variables ad hoc mais leur influence ne s'est révélée significative dans aucun des modèles utilisés, alors qu'elle l'était dans des études antérieures (Iten *et al.* (2005), de Haan *et al.* (2009)), qui avaient clairement pour objectif d'évaluer les effets des systèmes d'incitation et qui avaient utilisé des méthodes mieux adaptées à cette fin. Il faut donc partir de l'idée qu'en raison de la complexité élevée du sondage, les personnes interrogées se sont surtout concentrées sur le prix des carburants indiqué et qu'elles n'ont pas été en mesure de tenir suffisamment compte des autres variables dans leur prise de décision.

3.2.2 Influence du prix des carburants sur le choix du lieu d'habitation

Avec les données collectées lors des expériences de choix déclaré (PD3), on a testé des modèles de choix discret de type Logit sur le choix du lieu d'habitation en accordant une attention particulière aux coûts de la mobilité. On a constaté, d'une part, que les coûts de la mobilité sont moins bien identifiés que les coûts d'habitation et, d'autre part, que la volonté de changer de lieu d'habitation est très faible, ce qui c'est traduit comme suit: les personnes interrogées ont systématiquement préféré les propositions présentant un type de configuration spatiale correspondant au leur. Les résultats de la modélisation permettent de calculer la propension à payer pour conserver le lieu de domicile initial. Les courbes présentées à l'illustration 2 relatives à la propension à payer pour conserver son lieu d'habitation dans l'agglomération tiennent comptent de l'influence statistiquement significative du revenu et du lieu de domicile actuel des personnes interrogées. Une comparaison avec des économies allant jusqu'à 150 CHF/mois (selon le prix du carburant et le kilométrage annuel) qui pourraient être réalisées sur les coûts de mobilité en changeant de lieu de domicile, montre que le prix des carburant, tant qu'il reste inférieur à 5 CHF/l, n'a qu'une très faible influence sur le choix du lieu d'habitation.

Figure 2: Propension à payer (calculées selon l'équation 4) pour conserver son actuel lieu de domicile dans l'agglomération selon les résultats de la modélisation du choix du lieu d'habitation PD3 (équation 3)



3.3 Synthèse

Les élasticités-prix des carburants présentées ici sur la base des données d'adaptation déclarée recoupent bien des résultats comparables obtenus avec une analyse de série temporelle (Baranzini *et al.* (2009)), ce qui confirme la validité de la méthode utilisée. Cependant, cette méthode n'a pas permis de quantifier l'influence de différents systèmes d'incitation visant à réduire les émissions de CO_2. C'est la raison pour laquelle les auteurs de la présente étude recommandent d'utiliser à l'avenir des modes de sondage plus simples pour les personnes interrogées tels que celui du choix déclaré quand il s'agit d'analyser les effets de différents systèmes de réduction des émissions de CO_2.

De plus, les parts de marché et les élasticités mentionnées pour les carburants alternatifs tels que le gaz et l'électricité sont entachées d'incertitudes en partie dues au mode de sondage. D'une part, il est possible que certaines personnes interrogées connaissent mal les caractéristiques des carburants alternatifs et, par conséquent, ne considèrent pas les véhicules alternatifs comme une solution valable. D'autre part, l'attrait de ces véhicules dépend fortement de la densité du réseau de stations-services ad hoc (gaz) et de l'autonomie des véhicules (électricité).

Comme ces deux points n'étaient pas explicitement précisés dans le sondage, il faut partir du principe que les personnes interrogées se sont fondées sur la situation actuelle pour prendre leurs décisions, même si l'on peut s'attendre à ce que la densité du réseau de stations-services de gaz et l'autonomie des véhicules électriques augmentent à l'avenir, même avec un prix des carburants inférieur à 5 CHF/l.

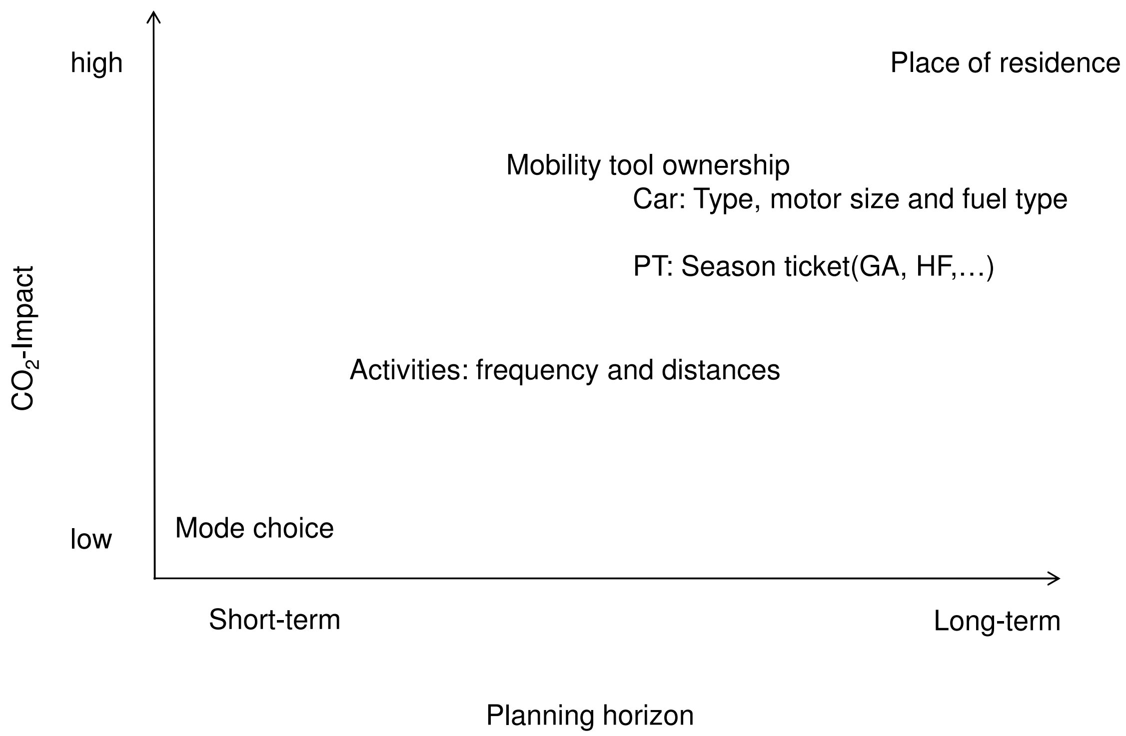
La présente étude porte uniquement sur l'influence du prix des carburants sur le choix du lieu d'habitation. Elle a révélé d'importants effets d'inertie: les personnes interrogées tendent à rester dans l'environnement qui leur est familier malgré les coûts élevés de la mobilité. Des études antérieures ont montré qu'en Suisse, les ménages déménagent en moyenne tous les sept ans (Beige (2008)). Il conviendrait donc d'accorder une attention particulière aux ménages qui vont déménager ou à ceux qui viennent de déménager pour faire des prévisions à long terme.

L'emplacement du ménage mais aussi l'emplacement du travail, à tout le moins par rapport à celui du ménage, détermine dans une large mesure le besoin de mobilité. Dans la perspective de la croissance continue de la distance pendulaire (Fröhlich (2008)), il serait pertinent, à la fois pour la politique énergétique et pour l'aménagement du territoire, de réaliser une étude sur l'influence de la hausse des coûts de la mobilité sur le choix du lieu de travail.

4 Introduction

Changing travel costs influence travel behavior on several levels (Figure 3). In the short run, individuals react by varying mileage (trip frequency, average trip length) and travel mode for certain trips. Given that individuals and households fix the marginal costs of their mileage by acquiring a set of mobility tools - vehicles and public transport season and discount cards - it is clear, that mobility tool ownership is also affected by fuel price changes. While daily travel decisions are already subject to inertia, mobility tool ownership is even more rarely reconsidered which makes it more difficult to study in a survey context.

Figure 3: Possible reactions to higher fuel prices



However, the recent price shock of crude oil - doubling between June 2005 and June 2008 - and later the economic slow-down have not only influenced daily travel decisions but might have also broken the inertia of not reconsidering mobility tool ownership: on the one hand, individuals changed their travel behaviour in terms of mode choice, as the following statistics indicate: while the nominal income (+2.0%, BfS (2009a)) and population (+1.4%, BfS (2009b)) grew in 2008 in Switzerland at comparable rates to the years before, analysis of the motorway traffic counts reveals a drop in the annual traffic increase from 1.2% during the years 2000-2007 to 0.65%. At the same time, however, the Swiss Federal Railways reports an increase in passenger mileage by +6.7% (Swiss Railways (2009)). On the other hand, also changes in car purchase behavior became visible: market analysis both from Switzerland (Auto Schweiz, Association of Swiss car importers (2009)) and the U.S. Autoobserver (2008) reveal demand shifts towards smaller and more energy efficient cars.

Although fuel prices are currently back to the level before the price shock, it is widely expected that they will start increasing again, especially when the global economy recovers. As we will see in this paper, most studies analyzing mobility tool ownership use either aggregated or disaggregated revealed preference data. As public transport costs and fuel prices - except the fuel price shocks in 2008, 1981 and 1973 - varied only moderately, any results are only viable for a restricted cost range. This is especially true for countries where taxes make up a substantial share of the fuel price, like Switzerland. We therefore see a lack of research examining the effects of substantial changes in transport costs on long term transport decisions such as mobility tool ownership. Last, it is still very unclear how significantly higher transport costs might affect residential location choice behavior.

Transportation is, among the industrial, commercial, residential, agriculture and waste sectors, not only the sector causing the highest CO_2-emissions (32%) in Switzerland, but also the only one that shows a clearing increasing trend over the last decade (Filliger (2009)) . The same applies for the United States(Conti and Sweetnam (2008)). Meanwhile, most OECD countries are behind their CO_2-emission reduction targets (UNFCC (2008)). Despite the observed transport related demand reactions to higher fuel prices, it is still widely accepted that further measures are needed to reach the global targets. Therefore, the need of having mobility tool ownership models that also deliver reliable forecasts of the impact of substantially higher cost regimes and policy measures is obvious.

The Swiss Federal Office of Energy (SFOE) together with the Swiss Federal Office of the Environment (FOEN) commissioned the Institute for Transport Planning and Systems (IVT) with a study to analyze the long term reactions of Swiss households to substantial increases in fuel prices and different transport related energy-efficiency measures. The objectives are twofold: First, modeling price elasticity of different fuel types based on demand reactions such as changes in the mileage by car and public transport, changes in car ownership (including car type) and public transport season card ownership. Second, modeling of possible reactions concerning residential location choice in reponse to substantially higher fuel prices.

The remainder of this report is structured as follows: Based on a extensive literature review of both mobility tool ownership and residential location choice modeling, the survey design is developed employing a *stated adaption* approach for mobility tool ownership and a *stated choice* approach for residential location choice. After summarizing the data collection, both the modeling process and the results are presented in the following chapters. The report ends by stating possible limitations of the employed approach and indicating possible directions of further research. The appendix contains on the one hand additional information on the employed methodologies and on the other hand a summary of a recent study commissioned by the SBB focusing on mode choice and mobility tool ownership whose results were reweighted for this study in order to be representative for the Swiss population.

5 Literature overview

5.1 Mobility tools ownership

5.1.1 Car ownership and usage

A good overview of different car ownership models for public sector planning is provided by de Jong *et al.* (2004). They identify nine types of car ownership models. Depending on the model's purpose, the models differ from each other mainly by level of aggregation, theoretical and methodological background, data requirements, car-type segmentation and inclusion of variables such as income, car type, sociodemographic and attitudinal variables. However, as they state that only disaggregated type choice models can fulfill the requirement of assessing the influence of cost changes on the choice of car type and mileage, only studies involving such models are presented here.

While early studies (Mannering and Winston (1985); Train (2003)) analyzed vehicle choice in terms of numbers of vehicles and type, the focus of research has shifted recently. Motivated by energy and environmental concerns, the models were specified to examine the effectiveness of different policy measures on fuel consumption and emission reduction and thus included vehicle types and consumption. Mattew *et al.* (2000) developed a model for new car sales for incorporation in the Vehicle Market Model (VMM) using both revealed (RP) and stated preference (SP) data. The revealed preference data set was obtained by pooling all vehicles less than one year old from the national travel survey. Due to the character of the UK's vehicle ownership structure, two types of stated preference surveys were constructed, one for company cars and one for private cars. Only persons who were either planning to buy or had just bought a new car were surveyed. With the engine size as the choice alternative, they found that for private car ownership people were sensitive to purchase price, running costs and standing charges.

Brownstone *et al.* (2000) and Hensher and Greene (2001) combined RP and SP data to evaluate preferences for both conventional and alternative fuel/electric vehicles. Brownstone *et al.* (2000) found SP data critical for obtaining information about attributes not available in the marketplace, while RP data was critical for obtaining realistic body-type choice and scaling information. Since they modeled make, vintage and size categories, a key issue with RP data analysis was the large number of vehicle type alternatives, which was approached by importance sampling.

Birkeland and Jordal-Jørgensen (2001) developed a car-type choice model for new cars in order to analyze different policy measures intended to obtain a more efficient car fleet. Based on a vast database that included more than 150,000 individuals and companies that bought a car in 1997 in Denmark, they were able to use detailed make and model combinations as the universal choice set, from which 49 alternatives were randomly chosen. To clarify buyers' preferences for different types of taxes and changing fuel prices, a SP survey of 200 car buyers was also conducted. The model was validated by forecasting the 1997 car sales and did reasonably well. Concerning the effectiveness of different policy measures, their conclusion was that controlling the choice of new cars is most effective through taxes on purchase prices, whereas fuel prices have a significantly lower impact. Similar findings can also be derived from the models presented by Mattew *et al.* (2000) and Brownstone *et al.* (2000).

Iten *et al.* (2005) conducted a stated preference survey of new car purchasing behavior in Switzerland. Persons who had recently purchased either a small or mid-sized car (the most important market segment in Switzerland) had to choose between three different cars of the same type that they had purchased. The cars in the experiment were described by make and type, engine size, fuel consumption, fuel type and fuel efficiency class. In a second series, incentives of 1,800 CHF and 1,200 CHF, respectively, were added for particularly fuel efficient cars (measured by the European Union energy label, including levels A and B). They found that the mere presence of energy efficiency already influenced purchase behavior by augmenting the share of class "A" cars by 2% for small cars and 0.5% for mid-sized cars. Coupled with an incentive, the share was augmented by 5%. Interestingly, it could also be shown that the consideration of incentives also increased overall purchase price awareness.

Müller and de Haan (2009) implemented the parameter estimates of Birkeland and Jordal-Jørgensen (2001) in their agent-based model of consumer choice of new cars, which was successfully validated for Switzerland. Using this particular model, de Haan *et al.* (2009) simulated the effects of different energy-efficiency feebates systems: For the partial feebate system, an incentive is foreseen for newly purchased Class A energy-efficient cars ($\frac{1}{7}$% of all cars, either within their class or overall) whereas the purchase tax for all other cars was augmented by 3%. To ensure revenue neutrality, the amount of this incentive depended upon sales volume. The classification of fuel efficiency is either relative to the car class or absolute, and the feebate system is named accordingly. For the so-called full feebate system, the 15.3% of newly purchased cars with the lowest fuel efficiency have to pay a tax of 3,000 CHF, which is transferred to the 14.7% of new registrations with the highest fuel efficiency (the in-betweens are used for administration and debit losses). They recognize the absolute full feebate system as the most efficient in terms of CO_2 reduction, but point out that public acceptance and transparency of the system also have to be kept in mind. For the more realistic relative full feebate system, they see changes in market share of +0.6% - +1.5% for micro and subcompact cars, while the share of SUV/luxury and sports cars drops by 1.8% and 0.7%, respectively.

While the models presented above are able to forecast car market reaction to different fuel economy policies, the modeling of future fuel consumption, and hence of CO_2 emissions, is only feasible under the assumption of negligible rebound effects. Rebound effects are commonly defined as increases in demand induced by efficiency gains (Sanders (2000)). While de Haan *et al.* (2009) lists several reasons why feebate systems might not lead to rebound effects, some of these are not applicable to shifts in car purchase behavior induced by fuel price change. While all of the models presented above find that the effect of fuel prices on car choice is significantly lower than purchase price, only the development of discrete-continuous models made it possible to jointly model vehicle type choice and usage. Examples of the use of such models to evaluate different policies can be found in Feng *et al.* (2005) or Goldberg (1998).

However, in OECD countries, a substantial number of households own more than one car. As it is clear that the choice of several vehicles is interdependent, Bhat (2005) extended these models to the so-called multiple discrete-continuous model, which is able to cover car choice and usage on a household level that includes several cars. Recently, such models were used to estimate the impact of gasoline prices, vehicle characteristics, demographics and the built environment on household vehicle holdings and use (Bhat *et al.* (2009), Fang (2008), Bhat and Sen (2006)). Based on census data, they all find that residence density enhances the propensity of holding a more fuel efficient (smaller) car. Using the parameter estimate of vehicle operating costs, it is also possible to assess the effect of different fuel price scenarios: Bhat and Sen (2006) evaluates the increase in fuel prices from $1.40 to $2.00 and predicts drops in vehicle holdings between -0.1% for passenger cars to -5.9% for SUVs. Only the use of passenger cars is augmented by +0.5%, while all other types are reduced by -3.0% (SUV) to -6.5% (Van). In response to a fuel price increase of + 25%, Bhat *et al.* (2009) see the share of compact cars rising but overall use for all car types declining. Spissu *et al.* (2009) evaluate the effect of a fuel price level of 5$ using Frank Copula's model, which predicts a higher share (+1.25%/0.28%) and use (0.98%/0.23%) for compact and large sedans and a smaller share (+1.57%/0.88%) and use (1.33%/0.82%) for compact and sedans.

5.1.2 Public transport season card ownership and usage

Compared to the large number of studies analyzing car ownership, very few studies covering public transport season card ownership and usage can be found. Again, the literature can be separated according to the methodology employed, namely time series analysis and discrete choice models.

García-Ferrer *et al.* (2006) use monthly data from the Madrid Transport Consortium (Consorcio de Transportes de Madrid) for the years 1987-2000 to estimate price elasticities of single and 10-trip bus and metro tickets, as well as season cards. While the individual elasticities for single bus and metro tickets are very similar (-1.03 and -1.07), the respective values of 10-trip tickets differ substantially (-2.17 and -0.52). In addition, statistically significant cross-price elasticities were also obtained between single and 10-trip tickets (0.6 for metro, 0.2/0.3 for bus tickets).

The season card elasticity turned out to be insignificant, although the values of cross-price elasticity of 2.4 (metro) and 0.9 (bus) with respect to 10-trip tickets are quite high. However, the authors also point to the instability of the results due to collinearity problems, which arise in particular with the introduction of the season card variable.

More reliable results for the same study area were obtained by Matas (2005), who analyzed annual data on the number of public transport trips over the years 1979-2001. Here, the prices of different public transport ticket schemes are pooled into two price indices (one each for bus and metro). Given the high share of trips made with season tickets, the derived elasticity can be interpreted as season ticket elasticity: -0.21 for bus and -0.37 for metro fares. To cover mode substitution effects, the model also includes the fuel price cross-elasticity of season tickets, which is estimated to be 0.15.

Although it should be intuitively obvious that public transport season cards can serve as a good substitute for car ownership, especially when fuel prices increase strongly, studies considering this effect by jointly modeling car and public transport season cards ownership are rare. Based on Dutch and German panel data, Simma and Axhausen (2003) study the choice between the commitment to one or the other mode and its impact on travel behavior as well as the temporal dimension. Using structural equation modeling, a high degree of stability for both car and season card ownership was identified. Additionally, it revealed that the commitment to one mode also strongly influences mode usage, which emphasizes the substitutive relationship between car and public transport season card ownership. However, the data employed does not include any information on price levels, making the estimation of any price-related influence impossible.

With a primary objective of understanding moving behavior, the German Mobiplan project (Beckmann *et al.* (2002)) included an Internet-based stated preference survey (König and Axhausen (2001)) with respondents who had recently moved. The experiment was formulated as an open stated-response survey. Given information on accommodation (type and price), travel time to work and for shopping by car and public transport, public transport service frequency at the nearest stop and its distance from home, respondents had to state choice and usage of mobility tools. The survey software recalculated the costs associated with the current choice in real time. Scott and Axhausen (2006) modeled the collected data using bivariate ordered probit models, designed to capture interaction effects between alternatives, namely, car and season card ownership. The correlation parameter capturing substitution effects being clearly significant, it is argued that the neglect of such interactions may produce biased results both for car and public transport season card ownership models. However, having no monetary variables included in the analysis (except income), no conclusion about price elasticities could be derived.

In a study examining possible effects of the introduction of mobility pricing in Switzerland, a stated adaption experiment similar to that of Mobiplan Beckmann *et al.* (2002) was conducted in Switzerland to evaluate possible long-term effects, namely changes of mobility tool ownership (Vrtic *et al.* (2007)). In this survey, the respondents had to state their choice of mobility tools considering changes in both car and public transport costs. Running costs of cars were altered up to twice the actual value at that time, while prices for public transport ranged by factors between 0.8-1.2. The results suggest a price elasticity of -0.14 for car ownership (number of cars owned), but no significant influence of public transport cost on any type of season card was recognized. As car ownership was modeled on an aggregate level, no conclusions on changes between car types could be derived.

Given the increase in fuel prices in 2008 and 2009, the Swiss Federal Railways (SBB) commissioned the Institute for Transport Planning and Systems of ETH Zurich to conduct a study to analyze short- and long-term demand reactions to substantial transport price changes (fuel prices up to a level of 5 CHF/l, public transport costs up 50%). The analysis of short-term reactions is based on a mode choice experiment with the alternatives of car and public transport, and long-term reactions are covered by a mobility tool ownership experiment; both designed as stated choice experiments. The results suggest a rather low price elasticity between -0.1 and -0.3 depending on fuel price, trip distance and income. The second experiment focused on season ticket ownership. Depending on the price level, price elasticity ranges between -0.9 and -1.4 for the General All-Switzerland ticket and -0.03 and -0.06 for the Half-Fare card, while the cross-price elasticities range between 0.04 and 0.15, and 0.2 and 0.6, respectively, depending on the fuel price level. A detailed summary of the results, which were re-weighted to be representative for the Swiss population, can be found in the Appendix G.

5.2 Residence location choice and travel costs

In contrast to the extensive literature discussing travel cost reactions on mode choice, mobility tool ownership and usage, the influence on residence location choice has received limited attention. However, residence location choice itself is a widely studied topic. Three different types of data are usually employed: longitudinal (time series or panel data), revealed and stated preference data. In addition, there is a large volume of research focusing on the influence of one's lifestyle on the choice of residence location.

5.2.1 Longitudinal data

Since residence location choice decisions are taken relatively seldom and are often dependent on the stage of one's life, the decision to analyze longitudinal data describing changes over the course of a person's life is obvious. Beige (2008) found a strong relationship between residential locations choice and mobility tool ownership over the course of a person's life. Interestingly, changes in residence, education and employment occur noticeably more frequently than changes in mobility tool ownership. Persons between the ages of 15 and 35 years are the most mobile, i.e., moving and changing occupations as well as varying ownership of mobility tools most frequently. Later, they become relatively more settled.

However, due to data constraints, the influence of travel costs on residential location choice decisions usually cannot be included in the analysis when modeling longitudinal data.

5.2.2 Revealed preference data

The literature review on earlier studies (Zondag and Pieters (2005)) already stated that the number of empirical studies of the impact of transport on land use is quite limited. This is especially true when compared with the large body of empirical studies on the reverse impact of land use on transport.

Generally, in revealed preference studies the mobility costs cannot be directly included in the analysis: when analyzing revealed preference data, non-chosen alternatives usually have to be sampled in order to estimate the models. Thereby, the indication of one household's mobility costs is related to many uncertainties. Therefore, when analyzing the mobility aspects of residential location using revealed preference data, the mobility offer is described rather than the mobility costs themselves. This is usually done by employing accessibility measures. Since places with high accessibility tend to bring lower mobility costs (more opportunities are available at less distance), it can be considered a proxy for mobility costs.

In an early study, Weisbrod *et al.* (1978) emphasized that the transportation level-of-service has only a marginal influence on residential preferences. Factors beyond the scope of public policy at that time, such as the desire for single-family, detached homes among families with children and reduced moving rates for older persons and families with several children, affect mobility and location patterns more than other factors related to public expenditures (e.g., mobility costs and quality of public transport). Bürgle (2006) found that of all the mobility-related variables tested, only those directly related to the individual, such as travel time to work, have a strong influence on residential location choice.

Löchl (2007) analyzed the supply side of the residence market by applying the hedonic pricing method to estimate property and rent prices. Interestingly, of all the accessibility measures, the variable describing travel time to the city center showed the best explanation power. However, the proximity of the nearest rail station also positively influenced price levels.

5.2.3 Stated preference data

There are several constraints on analyzing revealed preference data when studying residential location choice. Besides data issues (effective sampling strategies, multi-collinearity, high data requirements), the main constraint is that the impact of new measures and policies, such as road pricing or substantially higher mobility costs, can only hardly be evaluated. To overcome these constraints, several researchers used stated preference techniques to analyze residential location choice.

Hunt (2001) concluded, based on a stated preference survey with respondents from Edmonton, Canada, that dramatic improvements in travel times to work would be required to compensate a typical household for a move into higher density dwelling forms. A stated preference study conducted in six communities in Belgium and the Netherlands, Molin and Timmermans (2003) confirmed these findings. They concluded that, regardless of the study area and the model specifications, accessibility attributes are significantly less important than attributes that describe the housing and neighborhood.

5.2.4 Residential location choice as a lifestyle decision

It is widely accepted that the place of residence is chosen that best fulfills the needs of the household members and, therefore, reflects the household's lifestyle (see e.g., Kitamura and Mokhtarian (1997), Krizek and Waddell (2003), Schwanen and Mokhtarian (2005)). Results of stated preference data collected in the Portland, Oregon metropolitan area presented by Walker and Li (2007) suggests the presence of three household lifestyle segments: suburban and car-oriented, suburban and transit-oriented and urban and car-oriented. However, Cao *et al.* (2006) have also noted that policies aimed at influencing behavior may have limited impact because of the large proportion of households that have strong preferences towards car-oriented lifestyles.

5.3 Conclusions of literature analysis

While there is a significant amount of research analyzing car purchase behavior on an individual level, very little research can be found that analyzes car purchase behavior on the household level and even fewer combine car choice and car usage. In addition, most studies only cover a rather restricted range of fuel prices, leaving the expected consumer reaction to high fuel prices unclear. The neglect of the substitution effect of public transport season cards might not only cause bias when modeling car and season car ownership, it might also bias the estimation of the CO_2 effect of different policy measures: mode shifts from cars to public transport usually reduce emissions but do not eliminate them.

Concerning residential location choice, most studies found that other, lifestyle related factors are more relevant than mobility costs and that monetary policy measures may have a limited impact on residential location choices.

6 Survey design

The goal of this project is to gain insight into the long-term reactions to transport price changes. Three types of reactions are expected and therefore need to be covered by the survey:

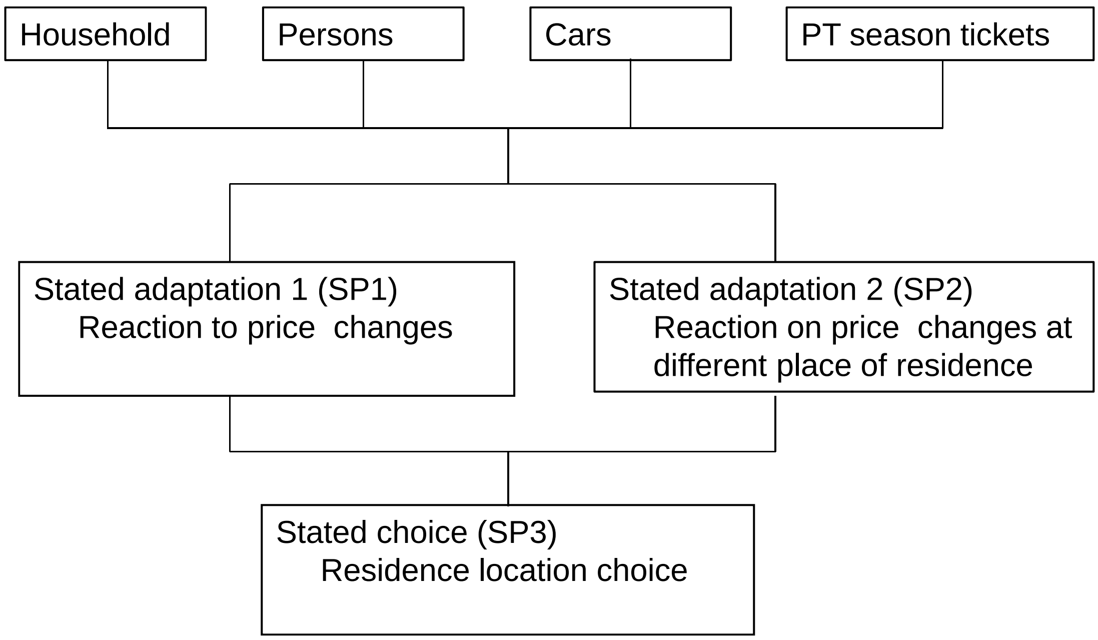
- Adaptation of the yearly mileage on two levels: changes in overall mileage driven and its modal split,
- Adaptation of mobility tools ownership: type of car and motorization; type of public transport season ticket,
- Adaptation of the residence location.

Due to the multitude of expected demand reactions and their characteristics, but also due to the complexity of the decision, the survey is designed as a combination of two stated adaptation experiments and one stated choice experiment carried out in face-to-face interviews. To be able to give the respondents direct feedback on the costs associated with the envisaged mobility tool bundle, the survey needs to be software-based.

In multi-person households, cars tend to be commonly used and the residence location is also expected to be the result of a collective decision-making process. Therefore, the survey considers mobility tool ownership and its usage on a household level. Due to organizational constraints, however, only the interviewee states the preferences for all household members. This approach has already been satisfactorily implemented in similar experiments (Beckmann *et al.* (2002), Vrtic *et al.* (2007)).

The survey consists of four parts (4. In the sociodemographic part, the respondent has to indicate information about all household members, the present choice of mobility tools and the present residence. This is followed by two stated adaptation experiments in which the interviewee has to choose the preferred bundle of mobility tools and indicate its usage (mileage). Whereas in the first experiment only the price regime differs from the present state, in the second experiment, the place of residence is also altered. In the third experiment, the respondent has to choose one of two earlier specified alternatives.

Figure 4: Survey design: overview



6.1 Sociodemographic variables

6.1.1 Residence

Together with the indication of his address, the respondent had to specify his residence concerning the type of housing (apartment, terrace house, detached house), number of rooms, (notional) rent and surroundings (old town/city center, urban area, agglomeration, rural area). In addition, information about the availability of parking facilities and their cost was collected.

6.1.2 Transport-related attributes of the residence

Since the transport-related attributes of the residence influence mobility tool ownership (see Bhat *et al.* (2009)), the respondents were asked to indicate travel time and distance for both car and public transport, as well as the preferred mode to the next public transport stop, railway station and large shopping area.

6.1.3 Cars

The following information was requested for all regularly used cars belonging to the household:

- Make, model and vintage (based on a EurotaxGlass's database)
- Motorization (capacity and fuel type)
- Year and type of purchase (new/used)
- Yearly mileage
- Actual mileage
- Degree of cost transfer in the case of a company car
- If the purchase of a new car is intended in the next 3 years: type and motorization

Earlier studies revealed that respondents have difficulties correctly specifying motorization, consumption and type of car(s). Since reliable information on this variable is crucial for the construction of the stated preference experiment, and also for later analysis of the data, the indication of make, model, engine type and choice of vintage is supported by the Eurotaxglass database. This database comprises a comprehensive array of information on every car type that was available for sale in Switzerland over the last few decades. Especially important for the experiment is the correct indication of the car type (body), since the car choice in the stated adaptation experiments are specified on this level rather than by make and model. In addition, the Eurotaxglass's database contains information referring to the Swiss energy efficiency labeling scheme, which is used later in the stated preference experiment to indicate whether a certain car is eligible for an incentive.

Also from experience, people have difficulties to indicate yearly mileage. Therefore, they are supported by a calculation tool, were they had to indicate the frequency, the average distance and mode share of typical trips to work, shopping, leisure and holidays.

6.1.4 Persons and public transport season tickets

For every person above the age of 18, the following information is collected:

- Age
- Sex
- Highest education degree
- Organizational function and type of employment (shift work/field work)
- On-going education
- Travel time to work / education
- Parking availability at work /education
- Season ticket ownership
- Cost of season ticket
- Yearly mileage by public transport
- Drivers license
- Car availability
- Most frequently used car
- Yearly car mileage (with any car)

While the sociodemographic variables are only used in the later analysis, the information of season ticket ownership will be used in the choice experiments to indicate the cost of the present fleet under a new cost regime.

6.1.5 Income and propensity to change mobility

The income is asked on a separate screen to give the interviewee the possibility to privately indicate its monthly gross household income.

The questions about the propensity to change the mobility tool ownership follows different objectives: First, the interviewee should be leaded to the concept of the following stated choice experiments. Second, the respondent has always to indicate the propensity to change mobility for himself but also for its household fellows, which give the possibility to analyze motivation for changing/not changing mutually used cars or residence location. However, the relevance of these questions for later scenario analysis and forecasting is restricted, since representative surveys of the Swiss population do not cover this information.

6.1.6 Exemplary computation of car costs

From experience, people are only vaguely aware of the fixed and variable costs of their car(s). Since these variable are crucial in the stated preference experiments, it was decided to give them an opportunity to verify the assumptions that are employed when constructing the alternative sets (choice of car types) of the stated preference experiments. For one car (the first reported), the following components of the fixed and variable cost were presented, based on the respondents indication of purchase price and mileage:

Fixed Costs

- Yearly depreciation (for new cars 12%, used cars 7%)
- Taxes (depending on car type)
- Insurance (depending on car type)
- Parking costs (1500/year)
- Miscellaneous (316 CHF/year)

Variable Costs

- Operational depreciation (2% of the purchase price for every 10,000 km)
- Fuel costs (based on the actual fuel price during the survey of 1.55 CHF/l)
- Tire abrasion (depending on car type and yearly mileage)
- Service and Maintenance (670 CHF/year)

The costs listed above are all based on cost manual of the Swiss Touring Club Touring Club Schweiz (2009), Switzerland's largest car drivers association. However small adaptations concerning the depreciation rates (distinction between new and used cars) and the interest rates (lower, reflecting current rates) were applied. In addition, costs associated to tyre abrasion, car tax and insurance were formulated depending on the car type.

6.1.7 Experimental design

All stated preference experiment plans were once changed during the survey to cover a broader spectrum of combinations of public transport and fuel price levels along with different incentives when purchasing energy efficient vehicles and levels of travel times. The complete experiment plans can be found in Appendix B while the construction of the individual plans is presented in the following sections.

6.2 SP1: Effect of price changes on mobility tool ownership

6.2.1 Construction of the experiment plan

The first of three stated preference experiments is designed as a stated adaption experiment. Given today's residence, but a new price regime of mobility costs, the respondent has to indicate the respective choice and usage of mobility tools for all household members. Each respondent is confronted with six such situations, which are predefined by the experiment plan.

The experiment plan is constructed by orthogonal design and combines three variables with different levels according to Table 3. For each situation, only one incentive type is considered.

Table 3: Attribute characteristics of the first stated adaptation experiment
†applicable to all cars of energy efficiency class F/G
‡applicable to cars of energy efficiency class A

Variable	Definition	Levels
Car costs	Fuel price [CHF/l]	1.5 2, 3, 4, 5
Public transport costs	Price level in relation to today's prices	-10%, +20%, +50%
Incentives	Car tax surcharge(†)/reduction(‡) [CHF/year]	+/-432, +/-864
	Buyer's premium [CHF](‡)	1,500, 3,000
	CO_2 tax on fuel [CHF/l]	0.2, 0.5

6.2.2 Construction of the choice alternatives

To give the respondent direct feedback on his choice, the software is programmed to indicate the costs associated with any combination of mobility tools and mileage. Therefore, the fixed and variable costs needed to be predefined for all the mobility tools that were offered.

Car choice In the case of car choice, the respondents had to specify their car choice with three variables as stated in Table 4. In addition to cars owned by the household, the respondent could also select the option "Mobility" which stands for a membership in Switzerland's largest car sharing community.

Table 4: SP1: Car choice characteristics

Car type	Price	Capacity	Engine type and consumption factor	
Micro	18,000 CHF	< 1500ccm	Fuel	1.0
Subcompact	25,000 CHF	< 2000ccm	Diesel	0.75
Minivan	30,000 CHF	< 2500ccm	Natural gas	0.9
Lower middle class	45,000 CHF	< 3000ccm	Hybrid	0.7
Middle class	45,000 CHF	> 3,000ccm	Electric car	0.6
Upper middle class	70,000 CHF			
SUV/Luxury car	90,000 CHF			
Sportscar	75,000 CHF			
Mobility	-			

To make realistic assumptions on consumption and the consumption factors of different engine types, data of all new cars available in Switzerland, provided by the Swiss Federal Office of Energy (SFOE) (2009), was analyzed. The purchase price for each category of car type was set according to market research conducted by the author. Combinations of car types and engine sizes not available on the market were excluded as choice options in the experiment. Table 31 in Appendix C lists all considered combinations of car type and capacity and indicates the respective consumption.

Additionally, the respondent had to indicate whether the chosen car was purchased as a new or used car, which defines eligibility for the buyer's premium incentive, depreciation rate, and also consumption: It is assumed that the average age of a used car when resold is four years. According to Blessing and Burgener (2008), the average consumption of new cars declined by 10% between 2004 and 2008, which gives an additional consumption factor of 1.1 for used cars. The calculation of fixed and variable costs is again based on the cost manual of the Swiss Touring Club Touring Club Schweiz (2009) as stated in Section 6.1.6. The cost structure of the car option "Mobility" is characterized by a membership fee of 20 CHF/month as fixed cost and variable costs of 0.8 CHF/km.

For every chosen car, the respondent has to indicate the vehicle mileage traveled according to the stated price regime. To get reliable information the respondent is urged to use the yearly mileage calculation tool.

The software features a function that can import the present car fleet, which was highly recommended to the respondents. The software is programmed to give direct feedback to the respondent according to his choice: Besides the actual cost of the selected car fleet and usage, the cost difference to today's fleet and usage, given the stated price regime, is also indicated.

Public transport season ticket choice Table 5 lists all offered options of public transport season ticket choice. To capture budget constraints, it is important to indicate the public transport costs as accurately as possible, whereby the offer provided is rather diversified. However, it is expected that for later analysis certain types need to be combined into meta-types.

Table 5: Seasontickets: range of choice

Season ticket type	1st option	2nd option
Half Fare card	-	-
Season ticket of a public transport association	Monthly	local
Season ticket of a public transport association	Yearly	regional
GA	Standard	1st class
	Student	2nd class
	Partner	
	Senior	
	Disabled	

While the yearly costs of the GA options are fixed costs, for all other options variable cost components also need to be considered. The unit costs [CHF/km] of the variable component again depend on the usage, since short trips in the local network tend to be more expensive than trips in the interregional network. To keep the cost calculation as realistic as possible, average fixed and variable costs are predefined for eight distance categories (see Table 32 in Appendix C).

Housing costs In this first experiment, the place of residence is not altered. However, with higher fuel prices, heating costs also tend to increase and the effects on the budget need to be represented when modeling mobility tool ownership. Therefore, heating costs were coupled with fuel costs, assuming that the product prices (price of fuel minus taxes and distribution costs) remain equal.

In Switzerland, oil taxes for car consumption amount to 0.7447 CHF/l for unleaded gasoline and 0.7587 CHF/l for diesel with an additional tax of 1.5 Rp/l (Klimarappen/climate tax) and 0.33 Rp/l (import tax), respectively. Distribution costs are estimated at 0.17 CHF/l (Löhrer and Schwizer (2008)), while the VAT augments the price for consumers by another 7.6%. To establish the market price of heating oil, one has to add distribution costs of 0.1 CHF/l (Erdöl Vereinigung Schweiz (2005)) to the product price and augment this by 7.6% VAT. Given different fuel price levels, Table 6 summarizes the expected costs of heating oil. The calculation of average heating costs, depending on floor space, is based on the assumptions of the Swiss Homeowners Association Guidelines (Swiss Homeowners Assocation (2008)). The values indicated in Table 6 are calculated for an apartment with 80 m^2 floor space.

Table 6: Dependency of heating costs on fuel price

Fuel Price [CHF/l]	Product price [CHF/l]	Heating oil price [CHF/l]	Heating cost [CHF/month]
1.5	0.5	0.6	80
2.0	0.9	1.1	147
3.0	1.8	2.1	279
4.0	2.8	3.1	412
5.0	3.7	4.1	544

6.3 SP2: Effect of price and residence place changes on mobility tool ownership

In addition to the variation of the price regime, in the second series of the six stated adaptation situations, the place of residence and hence travel times to work and major shopping centers are also varied. Therefore, both travel times and housing costs needed to be defined.

Fuel and public transport prices are altered in the same range as in SP1 (see Table 3). By requisition of the SP3's experiment plan, two cost regimes need to be equal for each respondent. Again, because of methodological reasons concerning the construction of the third stated preference experiment, the housing costs needed to be altered as well. The experiment plan was again constructed by orthogonal design combining travel time, travel costs and housing costs levels.

Travel times Depending on the newly defined residence location, the ranges of considered travel time are listed in Table 7. When defining these ranges, special attention was given to ensure that the travel times were not only realistic, but also broad enough to cover potential situations with sufficient variation.

Table 7: Experiment plan SP2: Variation of travel times and housing costs

Location of new residence	Travel time to work [min]		Travel time to city center [min]	
	Public transport	Car	Public transport	Car
City center	5/10/15	8/12/15/20	5/8/10/15	5/8/10/15
Urban area	10/15/20/25	10/15/20/25	5/10/15/20/25	5/10/15/20
Agglomeration	15/25/35/40	10/20/30	15/20/25/30/35	10/20/30
Rural Area	30/40/60	20/30/40	30/40/60	20/30/40
Housing costs [factors of current rent]			0.9/1.1/1.1	

Travel distances As in SP1, in addition to the mobility tools, the respective yearly mileage can also be adapted by the respondent. It is clear that the respondents would find it very hard to freely indicate reliable information on the yearly travel demand based on the new residence location. Therefore, it was decided to indicate the estimated yearly travel demand based on statistical data, which the respondent could then adapt.

According to the Swiss Federal Statistical Office (2006), car travel demand changes substantially for people living in areas with different types of spatial structures. Levels of average yearly mileage on a household level are summarized in Table 8. The categorization of types of spatial structures of the *Mikrozenus Verkehr* does not differentiate between "City center" and "Urban area", which meant that the values for city center had to be estimated. For each combination of reported and new residence location, the conversion factor of yearly mileage is given by dividing the average mileage of the new residence location with the respective value of the corresponding present residence location.

Table 8: Experiment plan SP2: Variation of travel times

Residence location	Average yearly mileage [km]	Relative to city center
City center	12,000 (est.)	1
Urban area	14,344	1.2
Agglomeration	17,587	1.47
Rural area	20,022	1.67

Housing costs Depending on the new residence location, housing costs are also adapted. Table 9 lists the underlying assumptions. The number of rooms is kept constant. The total surface area equals the number of rooms multiplied by 25 m^2 and is corrected by a factor depending on the residential area. The information on average rents per surface area is based on Switzerland's most comprehensive rent survey (Wüest & Partner AG (2008)). To represent the quality standard of the respondent's flat, an additional factor is employed which is given by dividing the actual rent by the rent that would be expected given the assumptions stated above.

Table 9: Assumptions of price of residence calculation

Residence location	Price per m^2	Space factor
City center / Old town	22.0	0.9
Urban area	18.3	1
Agglomeration	15.8	1.05
Rural area	14.2	1.1

Again, heating costs are dependent on fuel prices. The dependency is implemented in the same way as in SP1.

In the last stated preference experiment, SP3, the respondent had to choose between two situations of SP1 and SP2. In order to get additional variation into the housing costs data, the newly calculated housing costs were altered by multiplication with one factor out of three predefined levels (90%/100%/110% of today's value) given by the experiment plan.

6.4 SP3: Choice between two residential locations with optimized sets of mobility tools

The last series of six choice situations is formulated as a stated choice experiment. Each situation combines two alternatives from the SP1 and SP2 experiments, where only alternatives with the same cost regime but different residential locations were combined. Thereby, trade-offs between the following variables resulted: residential location and costs, sets of mobility tools, and travel times. For the first three situations, both alternatives were taken from SP2, where all residential locations differ from the reported location. For the remaining three situations, one alternative is taken from SP1 and hence consistent with today's residential location. The complete experiment plan can be found in Appendix B.

7 Data collection

7.1 Software

The survey software is programmed as a Java application to run on a Windows XP/Vista platform. Usability was highly emphasized when developing the software: Each interview, for example, consists of two specific data files with an automatic Save function, which makes it possible to restart the interview in case of a program crash without losing already surveyed data. Screenshots of the survey software can be found in Appendix A.

The program flow follows the structure of the survey as presented in this report. The software is programmed to run in three languages since interviews were conducted in the German-, French- and Italian- speaking parts of Switzerland. To guarantee a clearly arranged screen design, despite the extensiveness of the survey, up to two tab layers are employed. During the interview, additional data on the survey process, such as overall survey time and number of changes to find the optimal mobility tool set, is saved so it can be used later for additional analyses, if needed.

During the fieldwork, no problems were encountered with the software. However, software updates, such as the implementation of the second stage experiment plans, as well as the data collection and monitoring of the survey, required substantial organizational efforts. For similar future projects, a Web-based solution where interviewers would use mobile broadband communication devices is suggested.

7.2 Recruiting

The realization of the fieldwork was commissioned to Interdata Forschung, a market research institute based in Lucerne that specializes in face-to-face interviews. Before the fieldwork began, all interviewers attended a workshop where they were introduced to the survey and learned to handle the software.

The interviewees were directly recruited by the interviewers. Due to the survey focus, only persons living in a household with at least one car were considered. As an incentive, each interviewee was paid 20 CHF.

All interviews are conducted between June and July 2009. During the realization of the interviews, the interviewers were coached by the fieldwork supervisor of Interdata. The quality of the data was monitored by the research team through the analysis of interim data deliveries.

A total of 409 interviews were conducted by 13 interviewers, with two interviewers for the

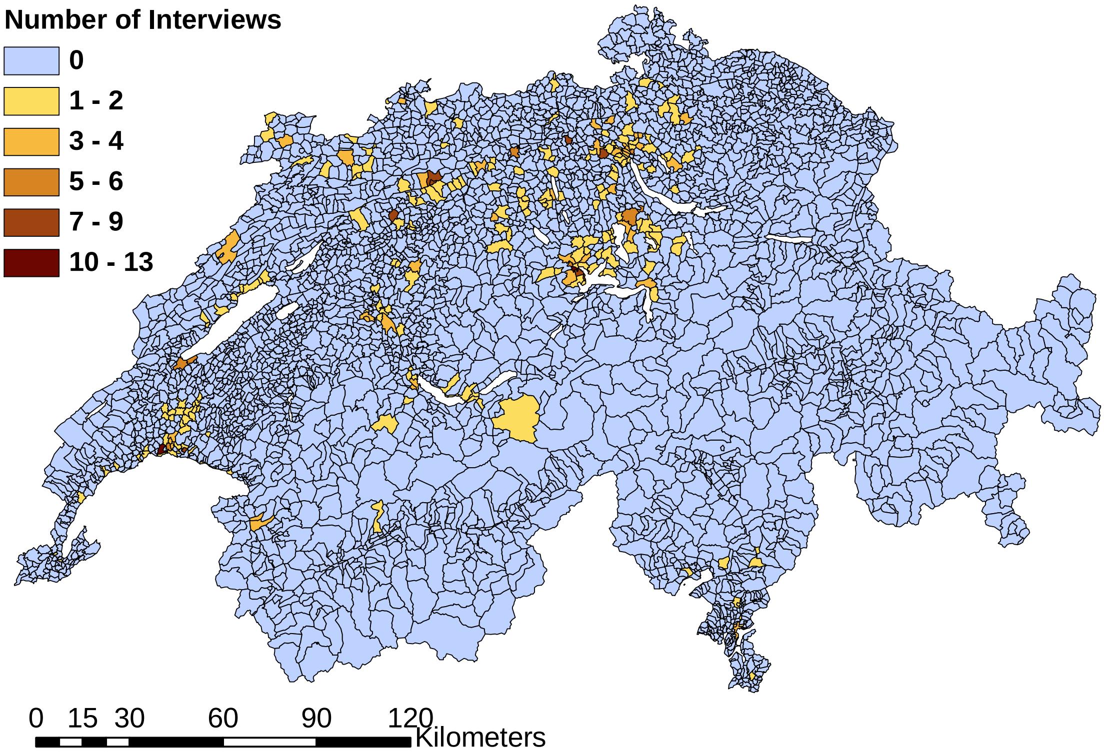
French-speaking area and one for the Italian-speaking areas. The interviewers reported that the survey was well understood. However, it was reported that some respondents found it very unlikely that they would change their residence location and therefore had problems imagining their mobility needs in SP2.

7.3 Quotas and Representativeness

The overall quotas to achieve a representative sample are listed in Tables 10 and 11. These quotas were segmented proportionally to all interviewers and every interviewer was supposed to fill his quotas as well as possible. However, in consideration for the interviewers' residential locations, they were allowed to exchange certain quotas with each other, but the overall quotas must not be affected by the exchange.

The quotas are representative for the Swiss population over 18 years of age and living in a household with at least one car. Except for the car types market shares, which are based on market observations in Switzerland as stated in de Haan *et al.* (2009), all values are derived from the Mikrozensus Verkehr Swiss Federal Statistical Office (2006).

Figure 5: Spatial distribution of the respondents' residence municipalities



Overall, the quotas were fulfilled satisfactorily and the sample can be considered representative of the Swiss population except for public transport season ticket ownership. While the GA and local and regional network passes are represented according to the expected shares, too few Half Fare card owners are covered by the sample (16.1% instead of 29.9%). In addition, households owning two and more cars are underrepresented in the sample.

Table 10: Quotas: Part I

Variable	Characteristic	Quota [%]	Tolerance [%]	Effective [%]
Sex	Male	48.3	1	55.0
	Female	51.7	1	45.0
Age	18 - 35	27.2	2	25.0
(years)	36 - 50	32.0	2	38.0
	51 - 65	24.5	2	25.5
	> 65	16.4	2	11.5
Highest education level	Compulsory education	18.4	3	20.6
	Apprentice, Prof. School	55.6	3	57.6
	Tertiary education	26.0	3	21.8
Persons per household	1	20.5	3	34.5
	2	38.9	3	39.1
	3	14.7	3	11.0
	4	18.0	3	12.0
	> 4	7.9	3	3.4
Household income	< 2,000	1.8	3	2.4
(CHF / month)	2,000 - 4,000	14.6	3	12.5
	4,000 - 6,000	28.6	3	25.7
	6,000 - 8,000	23.6	3	17.6
	8,000 - 10,000	14.3	3	15.4
	10,000-12,000	7.8	3	10.3
	>12,000	9.3	3	9.0
	n.a.	-	-	6.8
PT season ticket	none	63.2	3	73.8
	Half-Fare	29.9	3	16.1
	GA	6.9	3	4.1

Table 11: Quotas: Part II

Variable	Characteristic	Quota [%]	Tolerance [%]	Effective [%]
Car availability	always	83.5	3	84.0
	occasional	16.5	3	12.8
Cars in the household	1	62.4	3	72.4
	2	31.0	3	16.1
	> 2	6.6	3	4.1
Engine capacity	<1500	30.3	3	32.8
(ccm)	<2000	31.9	3	43.7
	<2500	23.9	3	11.8
	<3000	7.2	3	6.8
	>3000	6.7	3	4.8
Car type	Sports car	2.6	2	8.1
	Luxury /SUV	6.3	2	6.3
	Upper middle class	8.9	2	7.9
	Middle class	22.3	2	17.9
	Minivan / Van	14.1	2	13.3
	Compact	23.1	2	20.3
	Subcompact	19.0	2	18.1
	Micro	3.7	2	8.1
Spatial structure	Centers (CEN)	30.0	2	35.5
(ARE classification)	Suburban(SUB)	28.9	2	31.5
	High income (RE)	4.4	2	4.2
	Periurban (PERI)	10.1	2	7.8
	Tourist (TOUR)	3.4	2	1.7
	Industrial (IND)	9.9	2	9.0
	Rural commuter (PEND)	6.3	2	5.4
	Mixed agrarian (MIX)	5.9	2	4.4
	Agrarian (AGR)	1.1	2	0.2

As the observed variations between the quotas and the representative values are satisfying overall and some of the applied statistical software (e.g., Amos) were not designed to handle weighted samples, reweighting was omitted at this stage. However, when modeling, special attention was paid to possible dependencies of the model's dependent variables with the above sociodemographic variables and reweighting of the model results will be realized where needed.

8 Mobility tool ownership and usage (SP1 and SP2)

8.1 Descriptive Analysis

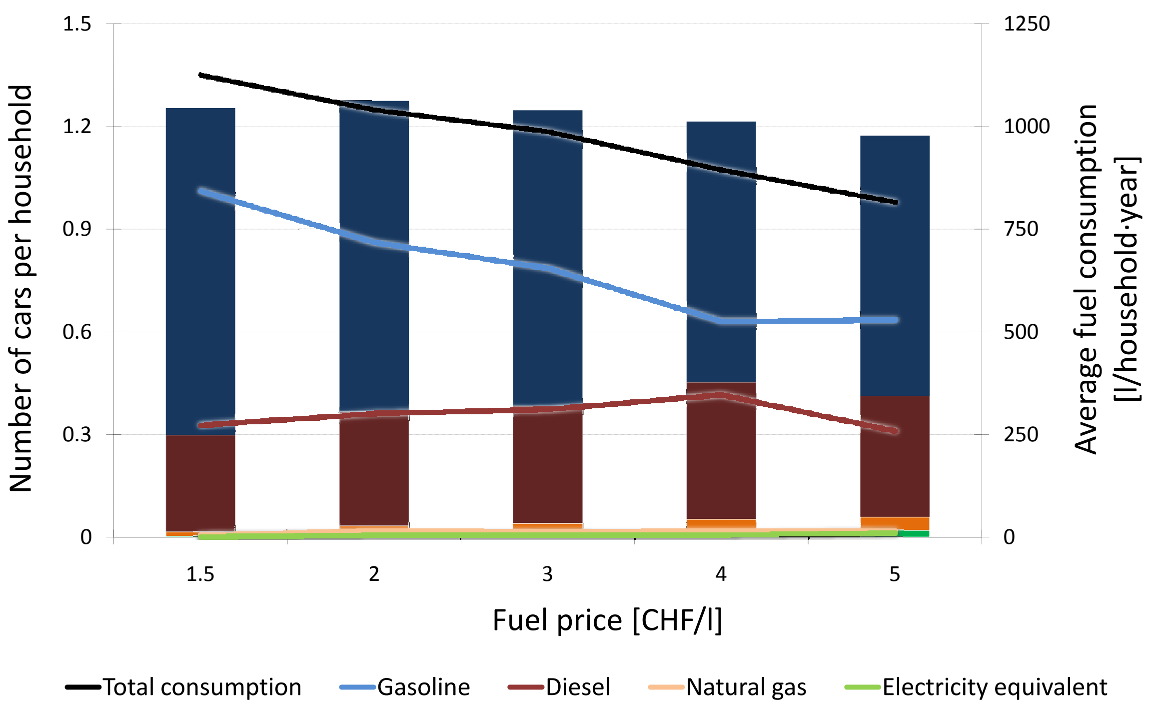
In this section, the response to changing transport costs is presented. The respondents, confronted with increasing mobility costs, had different options for behavior change, namely the change of the type of car, engine (fuel type), engine size and public transport season tickets as well as the use of the selected mobility tools.

To cancel out possible effects resulting from changes of residential area occurring in the SP2 experiment, only data of the SP1 is considered in the following analysis of respondents' reaction to cost variations. SP2 and SP3 data is considered when analyzing substitution effects and the influence of residence location choice. The analysis is based on 409 interviews resulting in 7,362 choice situations or 2,454 in each case of SP1, SP2 and SP3. After the elimination of obviously erroneous entries, 2,436 cases of SP1 and SP2 and 2,402 of SP3 remained for analysis.

8.1.1 Fuel consumption and engine type

The change of total consumption, along with the number of cars owned and their engine types, depending on fuel price is analyzed first. Figure 6 shows a quasi-linear drop of both total and gasoline consumption with increasing fuel prices. Interestingly, the total number of cars declines at a much slower rate, suggesting that the respondents switched to more fuel efficient cars (as the diesel data shows) or reduced the mileage per car. However, between fuel costs of 4 and 5 CHF/l, this trend discontinues and the ownership rate of both diesel and gasoline cars declines. Only a small number of diesel or gasoline cars are substituted with natural gas or electric cars. Generally, natural gas and electric cars are seldom chosen in spite of their substantially higher fuel efficiency. However, whether the respondents were unaware/unfamiliar or deprecate these car types cannot be stated satisfactorily and leaves an open question for further research.

Figure 6: Fuel consumption, car ownership and engine types depending on fuel price: bars indicate the number of cars per household, lines the fuel consumption



8.1.2 Annual mileage

Adjustment of yearly mileage is probably the most likely demand reaction as only the usage of the currently owned car(s) is affected. As presented in Table 12, the respondents reacted to fuel price changes by adjusting their mileage. While the impact for higher income classes is less distinct, in lower income classes the average mileage as much as 22%.

Table 12: i

n SP1]Influence of fuel price on annual car mileage [km] in SP1

Price Gaz [CHF/l]		Monthly household Income CHF/year										
		<2000	<4000	<6000	<8000	<10000	< 13000	<16000	>16000	n.a.	Average	Total share
	1.5	7750	8686	10046	10595	12741	10669	12643	11371	15869	11193	16.6%
	2	7731	8454	9690	10460	12326	9962	12583	10609	15815	10854	21.8%
	3	6533	7132	9457	9843	11871	9775	12010	11488	16173	10499	22.4%
	4	6433	6722	8884	8843	11408	9758	10977	11467	14070	9854	20.8%
	5	6657	6989	8613	8762	10989	10571	11229	9878	14287	9782	18.3%
	Total share	2.0%	9.5%	21.0%	17.5%	16.1%	13.2%	6.5%	6.5%	7.8%	100.0%	100.0%

8.1.3 Car type

Given the increasing fuel costs in the experiment, one can also expect that people would prefer owning smaller, more fuel-efficient car types. Figure 7 shows how the respondents adjusted their current car types in the experiment, including all levels of fuel cost offered.

While only the car types micro and subcompact become more popular, the shares of all other types decrease. Interestingly, the intensity of the relative drop within each of these categories is quite stable, ranging from -16% for compact cars to -25% for full-size cars, only sport cars owners tend to stick more to their current car types (-13%). The relative gain for the two categories with increasing market shares are also very similar: +37% for micro cars and +35% for subcompact cars.

Figure 7: Propensity to change car type in SP1

Car type chosen	Actual car type: Micro	Subcompact	Compact	Mini MPV	Mid-size car	Full-size car	SUV/Luxury	Sports car	Total Share
Micro	74.6%	14.0%	6.7%	4.6%	2.7%		.5%	1.5%	11.2%
Subcompact	12.1%	79.0%	22.1%	10.9%	14.8%	1.2%	1.0%	2.3%	24.1%
Compact	3.4%	1.0%	61.8%	7.0%	11.7%	4.7%	3.5%	4.2%	17.0%
Mini MPV				72.6%	4.8%	1.6%	1.5%		10.8%
Mid-size car			6.4%	.5%	61.7%	16.3%	5.5%	3.0%	14.4%
Minivan				1.6%	.2%	10.5%	2.0%		1.2%
Full-size car			.6%	.9%	1.4%	60.9%	9.5%	.8%	6.0%
SUV/Luxury					.2%	2.7%	75.4%	1.9%	5.0%
Sports car			.2%			1.6%		85.6%	7.1%
Car sharing				.7%					0.1%
no car	9.8%	6.0%	2.1%	1.2%	2.6%	.8%	1.0%	.8%	3.1%
Total Share	8.2%	17.9%	20.3%	13.3%	18.0%	8.0%	6.2%	8.2%	

The bars and the respective values in Figure 7 indicate the interrelationship of car type changes. As expected, respondents currently owning micro or subcompact cars still tend to prefer those types, but also show the strongest inclination to discard their cars. When reconsidering car type, owners of compact, mid-sized cars and mini MPV prefer subcompacts, while full-size car owners would largely change to mid-sized cars. Sports and SUV/luxury vehicle owners exhibit a less clear switching pattern. In addition, those people also have lower propensity to change car type at all. This is an interesting finding, especially because the running costs of those cars are not only the most affected by fuel price increases but also the highest average mileage is reported for these two types. A possible explanation for this might be that people owning such cars also tend to have a higher income than all the others (9,587 CHF/month vs 6,773 CHF/month). Additionally, they might have higher expectations of car comfort as they spend more time in their cars (higher mileage).

When analyzing the influence of the different incentive schemes on the propensity to choose/not to choose car types affected by those schemes, no clear pattern could be recognized. However, only the results of the envisaged statistical models can provide definitive insights into the significance of such an influence.

8.1.4 Engine size

Table 13 summarizes the respondents' reactions in terms of adjusting motorization. While in most situations the engine size was kept constant, it is obvious that higher fuel prices lead to a higher propensity to acquire smaller engined cars. When the decision was to choose a smaller engine, the engine size was usually reduced by only one category (-500 ccm).

Table 13: Changes of engine size in SP1

	Change engine size						
Price Gaz [CHF/l]	Car sharing	No car	<-500 cmm	>-500 cmm	equal	<+500 cmm	>+500 cmm
1.5		.7%	1.3%	5.2%	89.2%	2.2%	1.3%
2		1.0%	1.7%	7.4%	87.4%	1.8%	.7%
3		2.1%	1.7%	10.4%	84.2%	1.4%	.3%
4	.1%	4.6%	3.9%	16.0%	73.9%	1.2%	.3%
5	.3%	7.4%	3.4%	17.9%	70.7%	.3%	
Total Share	.1%	3.1%	2.4%	11.4%	81.1%	1.4%	.5%

When separated according to car type, people owning compact, mid-sized, full-sized cars and mini MPVs are about twice as likely (in about 22% of the cases) to downsize their engines than SUV/luxury and sports car owners. Since hardly any engine of the currently owned micro and subcompact cars does not belong to the smallest engine category, not much potential is left here.

Adjustments are also made concerning the engine type: While the percentage of diesel-engined cars in the sample is 14.8%, in the SP experiment, the share increases depending on the fuel price level to 23.1% (1.5 CHF/l) up to 31.6%. Albeit on a lower level, the same trend also applies to hybrids (2.0-11.0%) and natural gas powered cars (1.1-3.1%). Electric cars, however, do not get beyond a share of 1.7%, which might be caused by the unfamiliarity of the respondents with the concept or concerns about the rather restricted range of such cars.

8.1.5 Influence of different demand reactions on consumption reduction

The influence of different demand reactions on consumption reduction was tested by employing a linear regression model with the change of the total consumption as the dependent variable and change of car type, fuel type, engine size, car ownership and mileage as the independent variables. The variance explained between the independent variables is broken down between the independent variables by multiplying the standardized regression coefficients by the correlation of the independent variable with the dependent variable. The sum total of these terms adds up to total explained variance. (Aigner (1971)).

Table 14 lists the standardized coefficients and variance explained of this regression showing the magnitude of the effect of different demand reactions on the different dependent variables. In addition, the column "observerd share" accounts for the share of choice situations in which the respondents reacted (on a household level) by varying the respective variable compared to today's state.

Table 14: Influence of different demand reactions on consumption reduction

Variable	Observed share	Stand. coeff.	t-test	corr.	var. explained
Less mileage	32.3%	0.70	59.59	0.71	71.5%
Gasoline to diesel	18.6%	0.24	21.16	0.27	9.3%
Smaller engine size	19.3%	0.28	22.44	0.34	13.7%
Smaller car	29.3%	0.09	7.28	0.21	2.8%
Discarding car	5.4%	0.07	6.35	0.25	2.7%
					R^2=0.69

For the most part, consumption reduction is realized by reducing mileage. In comparison, the selection of smaller engines, the switch from gasoline to diesel cars and the selection of car types affects consumption at a much lower rate. The influence of discarding a car is the least important option, as it is the least often observed.

8.1.6 Season ticket ownership

Table 15 lists the shares of the different types of public transport season tickets according to the different price levels of public transport and fuel. Whereas prices changes for public transport seem to have little influence, higher fuel prices tend to boost at least the sale of transport network passes.

Table 15: Influence of price variations on season ticket ownership in SP1

Price Level public transport	GA	Half-Fare Card	Network pass	No seasoncard
-10%	3.1%	16.4%	12.5%	68.0%
+20%	3.1%	15.9%	10.6%	70.4%
+50%	3.0%	16.1%	11.7%	69.2%
Total share	3.1%	16.1%	11.6%	69.2%
Fuel prices [CHF/l]				
1.5	2.9%	15.6%	10.8%	70.7%
2	2.5%	14.7%	11.1%	71.6%
3	3.6%	16.8%	11.9%	67.7%
4	2.9%	15.3%	11.6%	70.2%
5	3.5%	18.5%	12.6%	65.4%
Total	3.1%	16.1%	11.6%	69.2%

Overall, the impact of changing fuel costs ist much less distinctive for A public transport season ticket than for car ownership. Besides the effective inertia of season ticket ownership, this result might also have been caused by the given fact that the survey sample and screen design emphasized car ownership. However, definitive conclusions about the impact of both car and public transport costs on season ticket ownership can only be provided by the envisaged econometric models.

8.1.7 Internalization of increased fuel efficiency

One argument when promoting policies for higher car fuel efficiency is often a potential neglect, or at least inappropriate consideration, of the internalization of increased fuel efficiency by increasing mileage. Given the option of adjusting car type, engine size, fuel type and mileage, the hypothesis would be that respondents scaling down car type, engine size and fuel type used the efficiency/monetary gains to increase their mileage. It is assumed that fuel consumption increases with car size. The segmentation of relative changes in car size applied in this analysis follows the order of car size as given in Table 4. For example, if in one situation a respondent changed from a compact to a micro car, this observation would belong to the category "-2".

Table 16: Internalization of increased fuel efficiency in SP1

Fuel price [CHF/l]	Change Car type (sizes) -4	-3	-2	-1	0	1	2	Car sharing	No car	Total
1.5		-833	-588	-971	-326	417			-2000	16.6%
2	-286	-867	-313	-724	-382	500			-3214	21.8%
3		-613	-1902	-1070	-1216	1111			-4000	22.4%
4	-2130	-1605	-1566	-1451	-1918	250	833	-4000	-2194	20.8%
5	-667	-3032	-1367	-1820	-1975	111	-167	-4000	-2193	18.3%
Total	2.3%	3.7%	6.4%	10.4%	70.1%	1.5%	2.5%	0.1%	3.1%	100.0%

According to Mann-Whitney tests (and intuitively apparent from Table 16), this hypothesis is not confirmed in our data. The respondents who scale down car type also tend to drive less and, on average, do not tend to reduce their mileage to a smaller amount compared to respondents who kept their car type. However, this does not hold for higher fuel prices ($\geq$4 CHF/l), and respondents who selected a smaller car type do restrict mileage less than respondents who kept their current car type.

In addition, the effects of adjusting engine size and fuel type on the envisaged mileage were tested. The change of fuel type (diesel instead of gasoline) does not significantly affect the considered mileage restriction. However, respondents who chose smaller, more fuel-efficient engines did not reduce mileage as much as respondents who kept their old engine size.

8.1.8 Substitution effects

Scott and Axhausen (2006) found the inclusion of substitution effects critical when modeling mobility tool ownership in regions with viable public transport systems. Given the increasing fuel prices in the SP experiment, the joint modeling of car and public transport season ticket ownership might be even more important. To check the propensity of the respondents to acquire a public transport season ticket as a substitute for a car, Table 17 compares the relative number of newly acquired (or not renewed) season tickets based on the change of the number of vehicles in a given household. Since substitution effects can be motivated by changes of transport cost and residence location, this analysis includes data from both SP1 and SP2.

Table 17: Substitution effects SP1 and SP2

		Change of number of cars in the household						
		-1	0	-1	0	-1	0	
		Half-fare card		Network pass		GA		Total share
Change of number of season cards card number	-2	.3%	.2%	1.1%	.0%	.0%	.3%	0.2%
	-1	4.0%	1.3%	1.1%	.3%	.8%	.4%	0.8%
	0	86.0%	96.9%	82.5%	95.3%	91.6%	99.0%	96.3%
	1	7.5%	1.2%	11.1%	3.9%	6.5%	.2%	2.3%
	2	2.2%	.4%	4.3%	.5%	1.1%	.1%	0.5%
Total share		8%	92%	8%	92%	8%	92%	100%

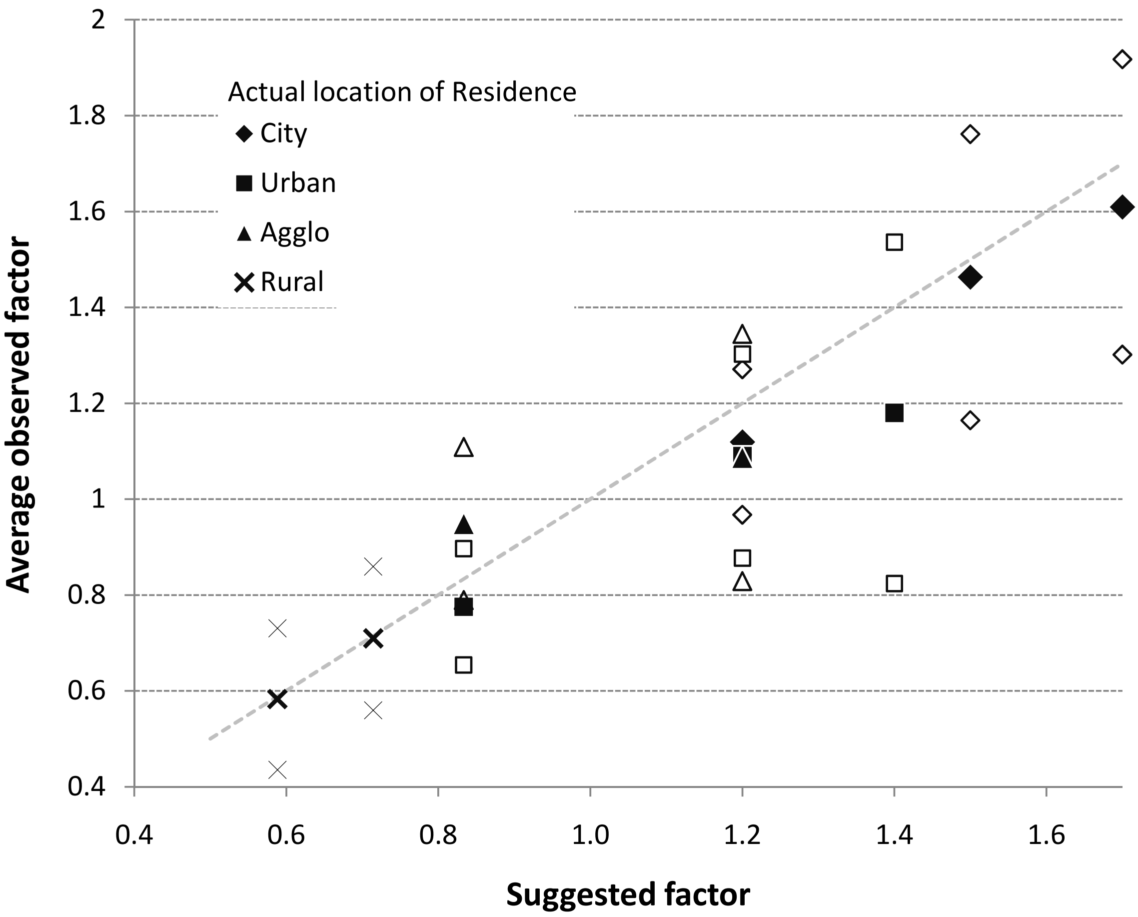
First, it has to be highlighted that in only about 8% of the cases did the respondents reduce the number of cars in the household, while in about 3.7% of the cases ,the level of season ticket ownership was adjusted. However, when a household decides to get rid of a car, season ticket ownership is clearly influenced. For example, in 11.1% and 4.3% of the cases, the abolishment of a car is compensated by the acquisition of one, respectively two transport network season passes. Summarized over all types of season ticket, in 25.1% and 7.6% of the cases, the abandoned car is substituted by one, respectively two, season tickets. This finding stresses the need to design the subsequent econometric model to represent substitution effects.

8.1.9 Data viability

As it is unclear whether the reconsideration of mileage and car characteristics overstrains respondents' abilities, the viability of the responses needs to be checked by analyzing possible differences between the adjusted mileage and car choice indicated in the SP2 with data describing the present situation.

Figure 8 plots the suggested changes against the observed relative changes in mileage when moving from one to another spatial type of residence. On one hand, it is obvious that the respondents have been influenced by the software-generated mileage indications that reflect the representative findings from the Microcensus of 2005 (Swiss Federal Statistical Office (2006)). On the other hand, the standard deviations of the mileage change factors (plotted by the outlined marks) indicate that the respondents did change the mileage beyond the software's indication.

Figure 8: Divergence of yearly mileage in SP1 and SP2: filled marks show observation average, outlined marks +/- one standard deviation



However, the comparison of the car type distribution, separated for the different spatial types of residence as reported for the present situation, with the distribution as stated in SP2 (supposing a new residential location) also shows clear differences. When the data is analyzed on the disaggregated household level, it becomes obvious that households tend to stick with their preferred type of car. However, RP panel data from earlier studies suggests that people also adjust their mobility tools when moving between different spatial types (e.g., Beige (2008)). Two reasons for this discrepancy seem to be possible: People have difficulty anticipating changing needs when moving between different spatial types, which would call the formulation of the experiment into question. However, it could also be that people decide to change the spatial type of residence for reasons that might also influence mobility tool ownership. For example, a young urban couple expecting the birth of a child is both likely to purchase a (larger) car and to move to more rural areas. Such life-stage related effects are obviously not covered by this experiment.

8.2 Modeling

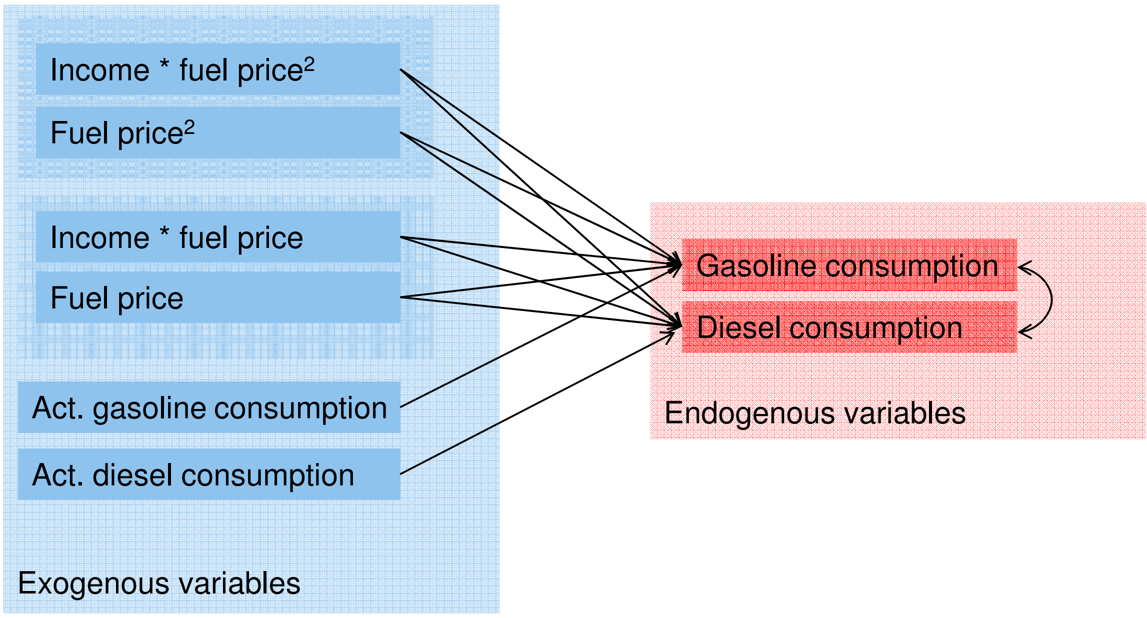
8.2.1 Considered data

In the analysis of SP3, it is shown that respondents reveal strong inertia effects concerning the residence location. Given the willingness to pay according to the figures presented in section 9.3.2, one can assume that fuel price induced shifts of the spatial type of the residence location are very unlikely. In addition, the envisaged mileage indication and considered car type of SP2 might be biased because of overstraining the respondents as shown in section 8.1.9. Therefore, it was decided to neglect the SP2 data when estimating fuel consumption and fuel price elasticity.

8.2.2 Modeling approach

The data is modeled using a structural equation model (SEM) with gasoline, diesel, natural gas, electricity fuel equivalent and public transport mileage as separate endogenous variables, while controlling for error term correlation both between endogenous and exogenous variables. The data is modeled on a household level, meaning that consumption/public transport mileage is aggregated over the household members. The total fuel consumption is given by the sum of gasoline, diesel and natural gas and therefore does not need to be modeled separately. In the beginning, basic models that included only fuel costs, income and the actual annual consumption as exogenous variables and gasoline and diesel consumption as endogenous variables were estimated in order to find an appropriate model form. Different model forms such as Cobb-Douglas, Translog and quadratic formulations were tested. The estimated parameters are highly significant for all three models. The diesel consumption (see Figure 6) clearly shows a quadratic pattern. This results mainly from the fact that up to the fuel price level of 3 CHF/l, gasoline cars are substituted by diesel cars. Above this level, however, further substitution effects become minor compared the decreasing diesel consumption caused by higher fuel prices. Therefore it was decided to use the quadratic formulation (Figure 9) as a basis for the further model development. However, the derived elasticities of all basic models are comparable. It should be noted that when using the quadratic model form, parameter estimates cannot be interpreted directly as elasticities. In fact, elasticities not only depend on fuel price, as Equation (19) in Section D.2.3 indicates, but also on interacting sociodemographic variables such as income. Moreover, due to the quadratic function the consumption estimated and elasticities are only valid within the considered fuel price range of 1.5 CHF/l to 5 CHF/l and any extrapolation should be omitted.

Figure 9: Basic form of the structural equations model(SEM)



The model includes a constant as well as the actual fuel consumption per household as inertia variables. This covers - up to a certain degree - panel data aspects by including the respondents' household actual consumption. However, it is clear that no panel data aspects are included concerning the households' different reaction to changing fuel prices. The fuel price is modeled both in linear and squared form allowing it to fit non-linear consumption curves as observed for both diesel and gasoline consumption (see Figure 6). Given the information on actual fuel consumption, it became obvious that the best model fit is reached if sociodemographic variables such as income are only included as interacting with fuel price. As a consequence, no classic income elasticity of fuel demand can be derived from the model, since income is only modeled in interaction with fuel price.

8.2.3 Model development and characteristics of the final model

In the following, the basic model was extended by including the additional endogenous variables: natural gas consumption, electric fuel-equivalent consumption and public transport mileage. Additional exogenous variables were included step-wise and considered in the final model based on statistical significance. Following the structure of the basic model, the final model takes the following form:

$$
\begin{aligned}
Y_{i,k} =& Const_k + \beta_{\text{ActY}_k} \cdot \text{ActY}_{i,k} + \beta_{P_k^2} \cdot \text{P}_k^2 \cdot (1 + \beta_{I,P_k^2} \cdot \frac{\text{I}_i}{\bar{\text{I}}}) + \\
& \beta_{P_k} \cdot \text{P}_k \cdot (1 + \beta_{I,P_k} \cdot \frac{\text{I}_i}{\bar{\text{I}}} + \beta_{Rural,P_k} \cdot \text{D}_{Rural_i} + \beta_{Agglo,P_k} \cdot \text{D}_{Agglo_i} + \beta_{City,P_k} \cdot \text{D}_{\text{City}_i} + \\
& \beta_{Age,P_k} \cdot \frac{\text{Age}_i}{\overline{\text{Age}}} + \beta_{Male,P_k} \cdot \text{D}_{Male_i} + \beta_{Adults,P_k} \cdot \text{Adults}_i + \beta_{Emp,P_k} \cdot \frac{\text{Emp}_i}{100} + \\
& \beta_{BigCar,P_k} \cdot \text{BigCar}_i + \beta_{CarPaid,P_k} \cdot \text{CarPaid}_i + \beta_{GA,P_k} \cdot \text{GA}_i + \beta_{HF,P_k} \cdot \text{ST}_i + \\
& \beta_{ST,P_k} \cdot \text{ST}_i)
\end{aligned} \tag{1}
$$

with:

$\text{Y}_{i,j,k}$	Consumption [l/year],
i	household i,
k	fuel type k,
Const	constant (to be estimated),
β	parameter estimate,
ActY_k	actual consumption (inertia) [l/year],
P_k	fuel price [CHF/l] of fuel type k,
I_i	yearly income of household i,
$\bar{\text{I}}$	average income per household in the sample,
D_{Rural_i}	dummy variable Rural: 1, if the household i is located in a rural area, 0 else,
D_{Agglo_i}	dummy variable Agglo: 1, if the household i is located in an agglomeration, 0 else,
D_{City_i}	dummy variable City: 1, if the household i is located in a city centre, 0 else,
Age_i	age of the respondent in household i,
$\overline{\text{Age}}$	average age of the respondent in the sample,
D_{male_i}	dummy variable Male: 1, if the respondent of household i is male, 0 else,
Adults_i	number of adults in the household i,
Emp_i	cumulated employment rate in the household i,
BigCar_i	today's number of big cars (full-size car, SUV, sports car) in the household i,
CarPaid_i	percentage of car cost not paid by the household i,
GA_i	today's number of GA in the household i,
HF_i	today's number of Half-Fare cards in the household i,
ST_i	today's number of season tickets in the household i.

As substitution effects between the different fuel types and public transport mileage were observed, all possible combinations of the endogenous variables were correlated with each other using the corresponding error terms. Correlations of the independent variables were included whenever the Pearson correlation coefficient of two variables was significant on a 0.95-level. A matrix containing information on which independent variables were correlated in the SEM can be found in Appendix F.

The interaction terms describe the varying reactions to fuel costs changes depending on different sociodemographic characteristics of the respondent. The squared terms account for possible non-linearities in the perception of fuel costs. The variable describing today's consumption (ActCons) acts as an inertia term.

Starting with the basic model form as presented above in Figure 9, additional interacting variables were gradually included. Thereby, three metric types of independent variables were used:

- continuous variables (e.g. fuel cost, average age),
- continuous, normalized variables (e.g. $\frac{\text{Age}_i}{\overline{\text{Age}}}$),
- binary dummy variables (e.g. D_{male_i}).

Whereas the interpretation of continuous variables is straightforward, one has to divide parameter estimates of continuous, normalized variables by the underlying average of the variable in order to compare the effects with continuous variables. Categorical variables are modeled using dummy variables. The associated parameter estimates have to be interpreted as the influence of the corresponding category against a pre-defined baseline category of the independent variable.

8.3 Results

The final model form is the product of an iterative process whereby different combinations and transformations of independent variables were tested. In the final model, only significant independent variables were considered. This also applies to dummy variables such as the spatial type of residence. Therefore, the interpretations of the respective parameters might differ between the different endogenous variables: For example, if only one out of the four spatial types of residence has significant influence on price perception, the corresponding parameter indicates its influence compared to all other, non-significant spatial types.

Table 18 lists the parameter estimates and the model fit indicators for the models described above. Overall, the models have satisfactory explanatory power. However, the natural gas consumption fits poorly, and the model explaining the consumption of the fuel-equivalent of electric car had to be dropped completely as it turned out to be unstable. Given the small sample of natural gas and electric-car usage observations, this is not surprising.

Table 18: Estimation results of the final SEM according to equation 1

Variable	Gasoline		Diesel		Natural gas		PT mileage	
	β	t-test	β	t-test	β	t-test	β	t-test
Constant	863.90	16.21	92.86	2.33	-16.68	1.99	-200.59	0.66
Inertia gasoline cons.	0.28	34.69	—	—	—	—	—	—
Inertia diesel cons.	—	—	0.18	18.00	—	—	—	—
Inertia gas cons.	—	—	—	—	0.63	19.47	—	—
Inertia mileage pt	—	—	—	—	—	—	1.05	80.00
Fuel cost squared	58.13	38.63	13.27	11.74	-2.28	9.20	—	—
Income/average income$_{sq}$	-0.60	31.42	-2.08	33.14	—	—	—	—
Fuel cost	-384.98	38.94	-91.78	12.37	20.07	12.35	420.28	9.34
Income/average income	-0.40	6.51	-1.76	37.98	0.19	4.19	—	—
Res. Rural	0.07	3.47	0.24	2.63	-0.26	2.60	-0.29	1.70
Res. Agglo	—	—	0.19	2.16	-0.34	3.40	-0.24	1.72
Res. City	—	—	0.18	1.99	—	—	-0.44	2.59
Age/average age	—	—	0.22	2.60	0.29	3.62	-0.30	1.74
Male	—	—	-0.35	7.33	-0.25	4.36	—	—
Adults	-0.08	6.51	—	—	-0.12	2.61	—	—
Employment perc./100	0.25	8.42	-0.55	4.35	—	—	—	—
Big car	-0.28	16.14	-0.15	2.70	-0.19	4.19	—	—
Car paid	—	—	-1.54	9.94	1.29	6.97	—	—
Number of GA	0.13	4.00	0.31	2.87	—	—	—	—
Number of HF	0.05	3.31	0.12	2.30	—	—	—	—
Number of ST	0.03	19.47	0.17	2.06	-0.17	1.97	—	—
Model specifications								
R^2	0.71		0.57		0.24		0.74	
N	2436		2436		2436		2436	
Number of usages	1723		817		66		1782	

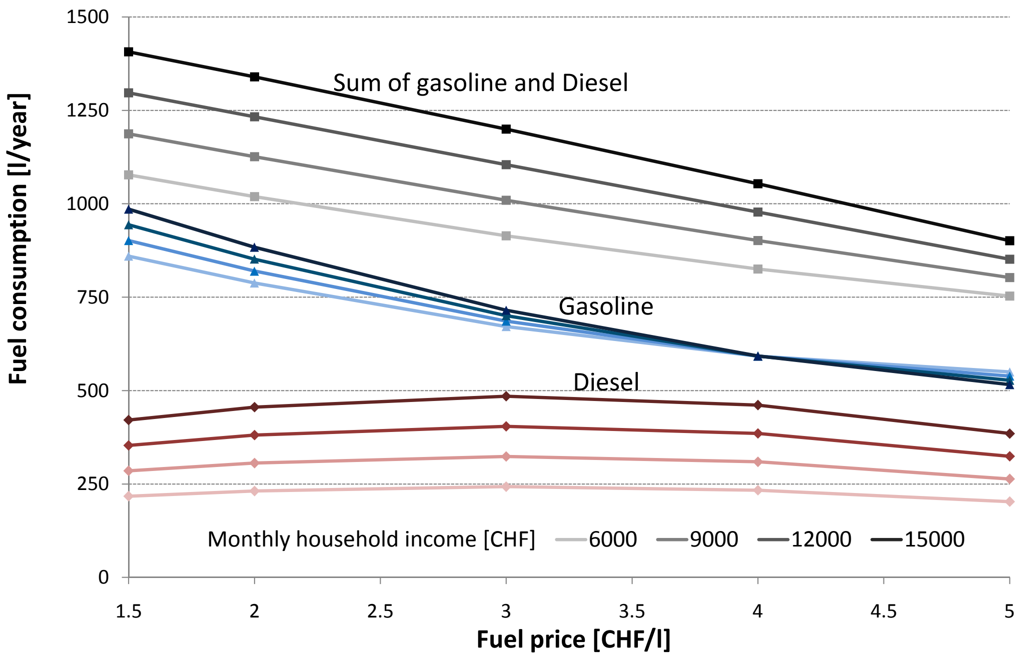
All reported parameters are significant at least on the 0.90-level, most of them exceed the 0.99 level and therefore provide a reliable basis for the further calculation of elasticities. All considered sociodemographic variables are interacted with fuel cost. As the actual fuel consumption of the household is included as an inertia variable, the parameters of the sociodemographic variables account mainly for the individual fuel cost sensitivity of the respective sociodemographic groups. When interpreting the interacted sociodemographic variables, it has to be noted that a positive parameter value means higher fuel price sensitivity and vice versa, since the β_{FC}-parameter is negative. This does not apply to natural gas consumption and public transport mileage, which serve as substitutes for gasoline and diesel cars.

Interpreting the parameter values of the sociodemographic variables, older people, heavy public transport users and people living in less accessible areas all react more to higher fuel prices. Households with more adults, driving big cars (full-size car, SUV/luxury, sports car) as well as when the respondent was male, react less to rising fuel prices. Parameters of dummy variables can be interpreted as the percentage that households of the given characteristic react more/less to price increases compared to the reference category. Concerning public transport mileage, households located in rural areas react for example 29% less to fuel price changes than households located in an urban area. Parameters of scaled variables can be interpreted as the change of the percentage that households of the given characteristic react more/less to price increases if the variable changes one unit. The presence of an additional adult in the household, for example, reduces the linear part of the cost sensitivity by 8%. However, it has to be noted that those interactions only apply to the linear effects, while the quadratic effect of cost sensitivity is only dependent on income level.

When the squared fuel costs for gasoline and diesel consumption are interacted with income, the interpretation is less intuitive. Therefore, the estimated total consumption for different income groups and fuel price levels are plotted in Figure 10. People with higher incomes tend to substitute diesel cars for gasoline cars more often. This causes higher gasoline price elasticity compared to the lower income groups. However, the total consumption remains higher for all fuel price levels under consideration.

People with lower incomes, in contrast, tend to cut gasoline consumption mostly by reducing mileage, and substitute diesel cars less often than people with higher incomes. This leads to the unexpected result that, given fuel prices above 4 CHF/l, people with lower incomes reduce gasoline consumption less than people with higher incomes.

Figure 10: Estimated fuel consumption dependent on income and fuel price according to the results reported in table 18



8.3.1 Effect of CO_2 reduction schemes

Interestingly, none of the CO_2 reduction scheme variables turned out to have significant influence on total fuel consumption, which is rather surprising as some measures (CO_2 charge per fuel unit) lead to overall price increases. Other measures, however, offer incentives for fuel-efficient cars and taxes for inefficient cars, while the cost structure for all others remained constant. In addition, the dependence of the chosen car type in terms of energy efficiency class on the CO_2 reduction schemes was tested. However, it turned out to be statistically independent for all tested CO_2 reduction schemes. This leads to the conclusion that the respondents reacted primarily to the indicated fuel prices while neglecting other factors that might influence car costs. It is argued that this is driven by overburdening the respondent when evaluating the preferred mobility fleet in a stated adaptation survey. For future applications of stated adaptation approaches in this context, it is, therefore, highly recommended to ensure that the respondents are fully aware of the cost structure, especially if it differs from the known structure.

8.3.2 Estimation results: consumption and elasticities

Using Equation (19) in Appendix D.2.3, the calculation of the elasticities is straightforward. Due to the model formulation with sociodemographic variables interacting with fuel cost, the elasticities not only depend on the value of the fuel costs, but also on the considered sociodemographic variables. As mentioned in section 7.3, the sample is not representative for all sociodemographic variables. Therefore, reweighting is recommended in order to get representative values of total consumption and elasticities. However, a representative average is not available for all significant sociodemographic variables, e.g., fuel consumption. Therefore, the sample was reweighted to a representative sample according the variables: sex, age, income and public season ticket ownership. The weighted values finally employed are summarized in Table 19 and replace the unweighted sample values needed to calculate y in Equation 1, which in turn is needed to calculate the elasticity (Equation 19).

Table 19: Reweighting relevant sociodemographic variables

Variable	Unweighted	Weighted	Source
Inertia total consumption	1171.90	1302.53	Sample
Inertia gasoline consumption	976.65	1063.26	Sample
Inertia diesel consumption	190.45	236.69	Sample
Inertia natural gas consumption	4.80	2.59	Sample
Inertia mileage pt	2910.17	2808.23	Sample
Income/average income	0.99	1.11	MZ
Res. Rural	0.32	0.33	MZ
Res. Agglo	0.30	0.33	MZ
Res. City	0.28	0.26	MZ
Age/average age	1.00	0.97	MZ
Male	0.55	0.48	MZ
Adults	1.67	1.72	Sample
Employment percentage	67.50	72.69	Sample
Big car	0.29	0.32	de Haan *et al.* (2009)
Car paid	0.03	0.04	Sample
Number of GA	0.06	0.03	MZ
Number of HP	0.26	0.35	MZ
Number of SC	0.12	0.06	MZ

Figure 11 plots the expected fuel consumption and price elasticity for the price range 1.5 to 5 CHF/l based on the SEM estimation results. In the fuel price range between 1.5 and 4 CHF/l, the fuel price elasticity gets smaller, indicating a higher sensitivity to increasing fuel prices. At first glance, the convex form of the fuel price elasticity for fuel prices beyond 4 CHF/l seems counterintuitive. However, data evidence (sample averages) suggests that the gradient of fuel consumption between 4 and 5 CHF/l is effectively lower than that in the range of fuel prices below 4 CHF, since the chosen model form, including fuel costs both linearly and squared, would also allow a concave form of the elasticity slope. While it can be argued that gasoline consumption alone might be fit even better to other model forms such as logarithmic transformation, diesel consumption data evidence clearly urges the use of a function that includes linear and squared fuel costs. As the endogenous variables are coupled by the error term, it turns out that the suggested model form with the same functional form for both gasoline and diesel consumption outperformed all other form combinations under consideration.

Figure 11: Estimation results: gasoline consumption according to the SEM results reported in table 18 and reweighted according to table 19

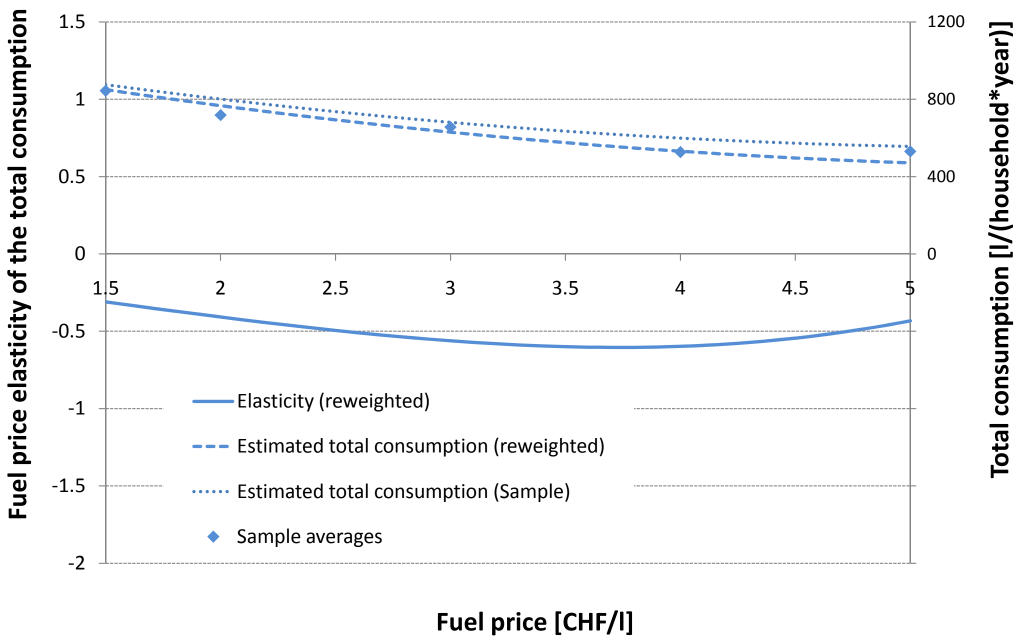
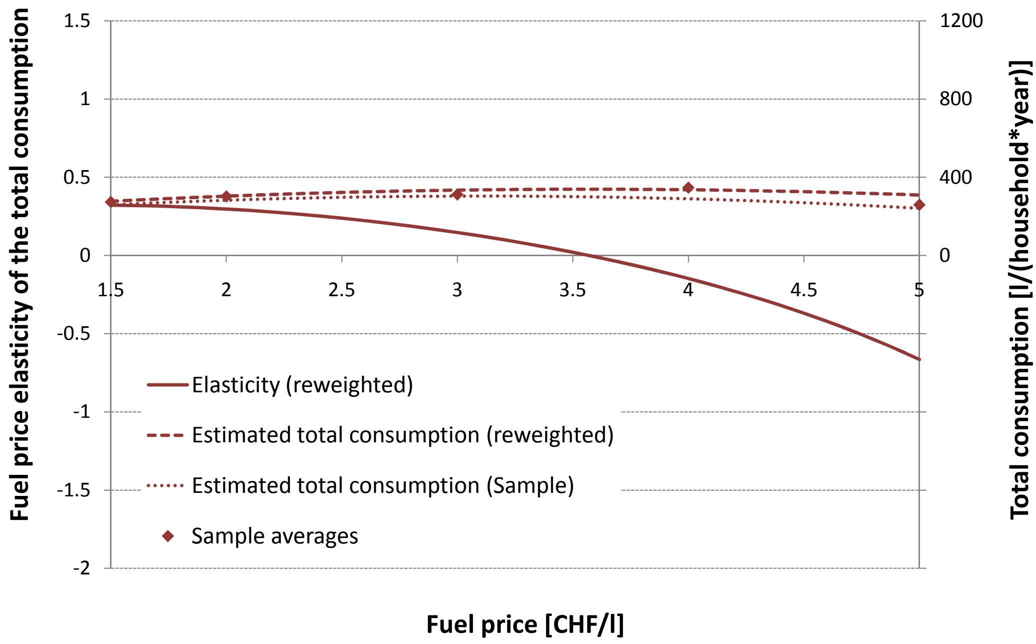


Figure 12: Estimation Results: diesel consumption according to the SEM results reported in table 18 and reweighted according to table 19



Diesel consumption rises until a fuel price of 4 CHF/l, mainly driven by substitution effects (Figure 12). With even higher fuel prices, the consumption drops, which is also reflected in the price elasticity, which falls below zero. As the number and usage of natural gas and electric cars rises only marginally in absolute values, it is suggested that further substitution effects only play a minor role, but car usage actually becomes restricted.

Natural gas acts as a substitute good almost throughout the considered price range (Figure 13). Given today's low market penetration (with few filling stations) and the hypothesized respondents' restricted awareness of the alternatives, the application of these findings to policy analysis is restricted and demands caution. This applies even more to electric cars, which is why the analysis is omitted altogether in the case of electric cars.

Public transport usage (Figure 14) can be interpreted as a substitute good: The cross-price elasticity remains positive for the whole price range and rises with higher fuel prices.

Figure 13: Estimation results: natural gas consumption according to the SEM results reported in table 18 and reweighted according to table 19

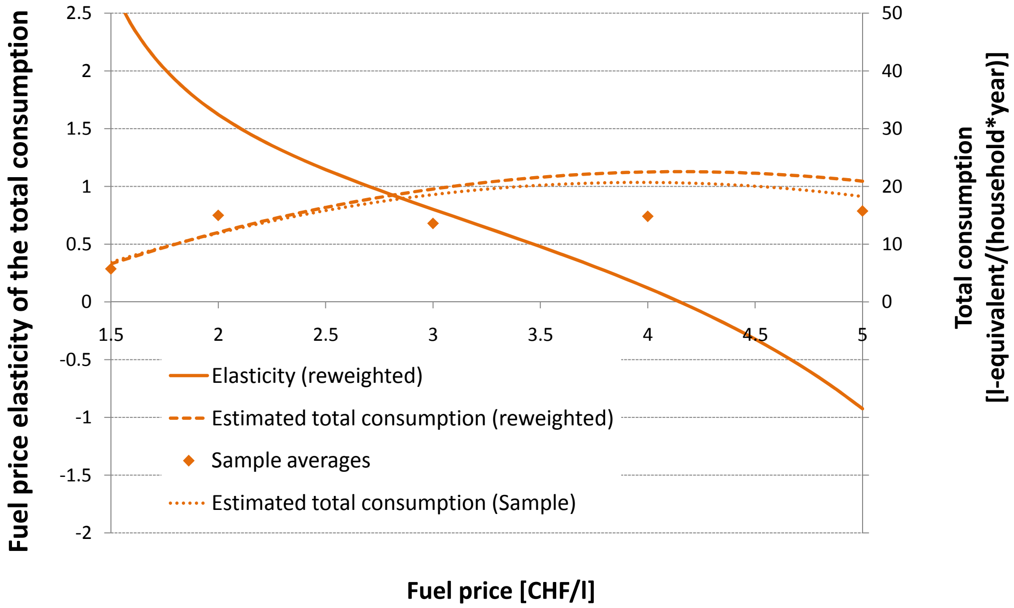
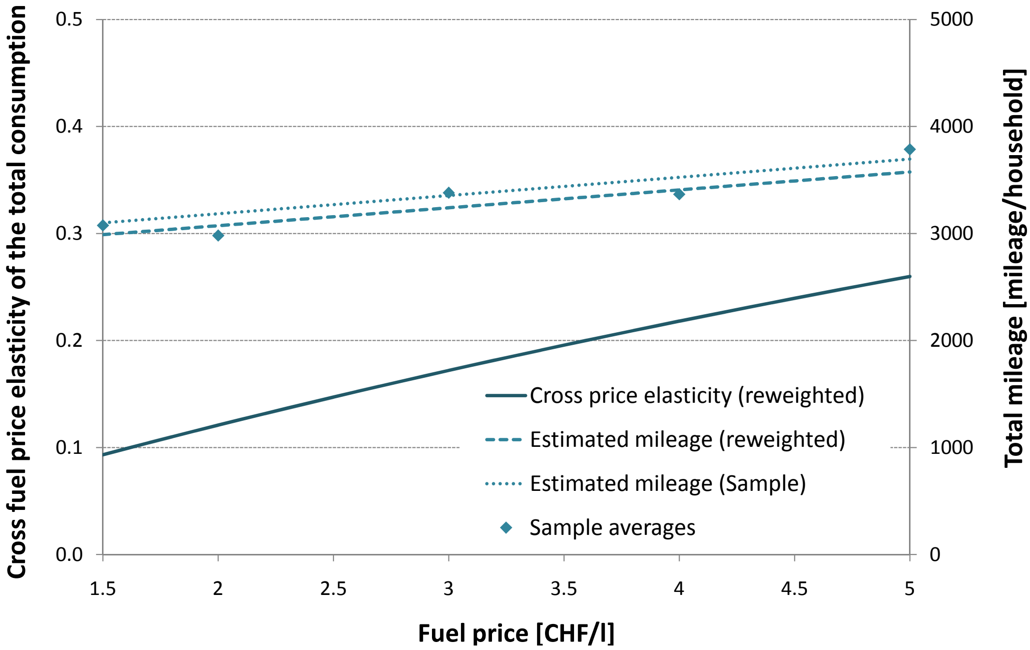
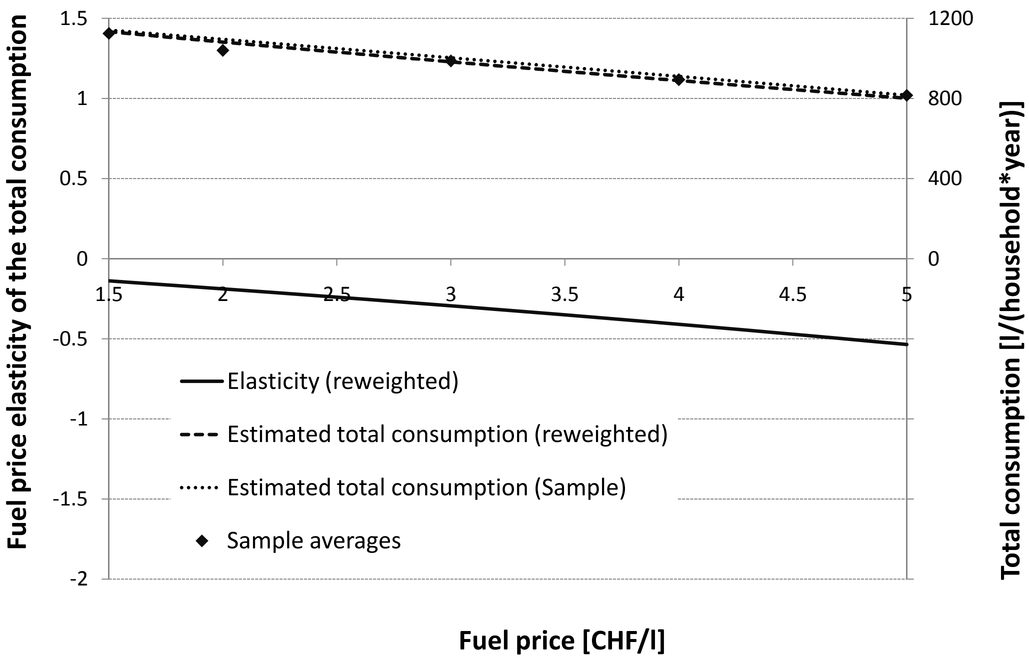


Figure 14: Estimation results: public transport mileage according to the SEM results reported in table 18 and reweighted according to table 19



Finally, Figure 15 plots both the expected total fuel consumption and price elasticity. It is derived from the total of the estimates of gasoline, diesel and natural gas consumption. The graph shows an almost linear decrease of elasticity with higher fuel prices as the convex and concave characteristic of gasoline and diesel elasticity balance each other out.

Figure 15: Estimation results: total consumption according to the SEM results reported in table 18 and reweighted according to table 19



8.3.3 Comparison of the results with other studies

Although the results presented herein are based on the for this topic novel stated adaptation approach, the results are comparable to other studies. Restricted by the methodology employed (time series analysis), Baranzini *et al.* (2009) report a long-term price elasticity of -0.27 for all fuels and -0.34 for gasoline. The model presented above suggests an elasticity at the price of 1.65 CHF/l (as of the time of the survey) of -0.15 for overall demand and -0.34 for gasoline. When comparing the results of those studies, it is important to recall the methodological differences between the two studies. While Baranzini *et al.* (2009) model the overall fuel consumption of the transport sector (except aviation), this study only considers private fuel consumption. In addition, in Baranzini *et al.* (2009) the vehicle stock is modeled as a exogenous variable whereas in this study the choice of fuel type is considered as dependent on the fuel price level. Lastly, the type of data employed is substantially different: Here, disaggregated hypothetical *stated preference* data is used while the results reported in Baranzini *et al.* (2009)

rely on aggregated time series data. The comparatively low value for total consumption in this study is driven by the increasing use of diesel cars. Such substitution effects are only partly covered in the time series analysis which covers the vehicle stock as exogenous. Additionally, it can be argued that in a hypothetical context respondents might undervalue the costs associated with a car change and hence internalize the trend towards diesel cars to be internalized too strongly.

Due to the underlying methodology, the reweighted values based on the work of Weis and Axhausen (2009) presented in Appendix G have to be do be considered as short-term price elasticities and are therefore not directly comparable to the values reported in this chapter. However, they fit very well with the short-term elasticities as given by Baranzini *et al.* (2009).

9 Residence Location Choice (SP3)

9.1 Descriptive Analysis

An important issue of any stated preference design is the inclusion of sufficient variance in the data set. Thus, approaches that maximize variance in the data set, such as orthogonal design or bayesian efficient design, have become good practice. However, due to the survey design, only the choice variables residence location, housing costs and travel times to work and shopping by car and public transport could be predefined using orthogonal design. The configuration of mobility tools and their corresponding cost, in contrast, depend directly on the respondent's choice of the stated adaptation experiments SP1 and SP2. Therefore, it is important to verify that the data set provides sufficient variance and that the individual variables are not correlated.

9.1.1 Variance

In logit models, the choice probability of each alternative is given by the utility difference between the alternatives. Table 20 lists the distribution characteristics of the difference between the two alternatives for monthly car, public transport and housing costs, namely, the variables that could not be controlled but are given by the respondent's indications in SP1/SP2.

Table 20: Descriptive characteristics of SP3 choice variables differences

Variable	Mean	Mean difference (abs)	Std. Deviation
Housing costs [per month]	1996.65	145.51	265.33
Public transport costs [per month]	98.37	27.78	80.80
Car costs [per month]	807.64	149.197	269.82

The difference between the choice alternatives shows sufficient variance for all tested variables.

9.1.2 Correlation

In the design process, the correlation of the variables describing travel time could be actively controlled, however, this only partly applies to the variables of monthly car, public transport and housing costs: One's mobility needs and housing standard can only partly be influenced by the residence location. Hence, correlations between monthly car, public transport and housing costs cannot be completely avoided. In fact, there is a trade-off between considering one's preference of mobility tools given a certain residence location choice and constructing statistically efficient survey designs. In this survey, the emphasis lies clearly on the first point, which means that correlations have to be accepted.

Table 21: Correlation of SP3 choice variables

	PT cost 1	PT cost 2	Car cost 1	Car cost 2	Hous. cost 1	Hous. cost 2
PT cost 1	1.000			.		
PT cost 2	.277**	1.000				
Car cost 1	.036	.011	1.000			
Car cost 2	.014	-.027	.898**	1.000		
Hsg. cost 1	.044*	.173**	.363**	.407**	1.000	
Hsg. cost 2	.039	.167**	.367**	.353**	.886**	1.000

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

As expected, the correlations listed in Table 21 are significant. However, as the effective values of most correlations are reasonable and, given the sample size, the estimation of significant parameters should be feasible.

9.1.3 Range of mobility tools

In SP1 and SP2, the respondents had to state the number of cars and mobility tools given a certain price regime. As mentioned above, sufficient difference between the variables of all choice alternatives is needed in order to estimate reliable results. Parameter estimates on these variables are only reliable if there is sufficient difference.

Table 22: Differences in mobility tool ownership between the two alternatives offered in SP3

		Frequency	Percent
Half-Fare	Not equal	64	2.7
	Equal	2313	97.3
GA	Not equal	36	1.5
	Equal	2341	98.5
Net pass	Not equal	95	4.0
	Equal	2282	96.0
Car	Not equal	185	7.8
	Equal	2192	92.2

The figures in Table 22 clearly show that the number of mobility tools owned by one given household does not alter much between two alternatives in the experiment. Hence, the modeling of these variables is omitted.

9.1.4 Inertia of choice behavior

The descriptive analysis of SP3 choice behavior reveals strong inertia effects concerning the residence location. In 74.3 % of the situations where one of the alternatives featured an unchanged residence location, this situation was preferred. When both situations featured different residence locations, the one more similar to the current residence is preferred. However, to what extent the variables of mobility costs and residence location jointly influence the decisions can only be revealed by the planned discrete choice modeling.

9.2 Modeling

9.2.1 Modeling approach

The modeling started by employing only the current choice variables, Namely, costs of housing, cars and public transport, travel times and the type of residence location, which are coded as dummy variables.

The model was then extended by the inclusion of sociodemographic (e.g., income) and inertia (e.g., current residence location) variables. Thereby, the key objectives were explanatory power, number of significant variables and the ability of the model to answer the key question, namely, the willingness to accept higher mobility costs before changing the residence location.

Several dozen different utility specifications were tested during the modeling process. Of all the estimated modes, the one presented in the next section best fulfilled the above stated objectives.

9.2.2 Utility function

The final model considers four key elements:

- Perception of car, public transport and housing costs
- Influence of income on cost perception
- Preference of residence area depending on today's residence location
- Influence of travel time characteristics

According to economic theory, people with higher incomes should have a lower cost sensitivity. Therefore, the model includes non-linear interaction terms that describe the income-dependency of the cost perception. The general form of such interaction terms is given by:

$$f(y, x) = \beta_x * \left(\frac{y}{\bar{y}}\right)^{\lambda_{y,x}} \cdot x, \qquad (2)$$

with:

x	observed variable, e.g., travel time, travel cost,
β_x	linear utility parameters of the observed variable x
y	observed value of the interacting variable, e.g., income, trip distance

$\overline{y}$ reference value of the variable y
$\lambda_{y,x}$ elasticity of the utility depending on the value of variable y

A negative value of the λ-parameter indicates that higher income leads to lower cost sensitivity. For example, for an individual whose income is 50% higher than the average income, the fraction $\frac{Inc}{\overline{Inc}}$ equals 1.5. Given a λ-parameter of -2.0, the sensitivity term equals 0.44 meaning that individuals with an income that is 50% above average perceive the respective costs 56% less than the average individual. Similar modeling approaches have already been used successfully in research practice, as e.g., Mackie *et al.* (2003) and Hess *et al.* (2008) show. In addition, the cost perception term is interacted with the variable describing the percentage of mobility costs that is paid by a third party, such as an employer.

As mentioned above, residence location choice is strongly influenced by the household's lifestyle. Instead of segmenting households by lifestyle description variables, such as sociodemographic (age, number of children, etc.) variables or attitudes, the suggested model includes the respondent's present residence location choice. To cover the inertia of residence location change, an interaction term describes the utility loss caused by moving from that residence location type to one of the three other types for every type of present residence location. This has the advantage of low data requirements when applying the model to scenario analysis: only the spatial distribution of household residence would be needed, without any information on attitudes or other sociodemographic variables being required..

It is assumed that the indication of travel times for public transport is of limited importance to captive car drivers and vice versa. Therefore, the terms covering the perception of travel times are interacted with variables describing modal usage within the choice alternatives.

The utility function of the suggested model takes the following form:

$$
\begin{aligned}
V_{i,j} = & C_i + \beta_{\text{HouseCost}} \left(\frac{\text{Inc}_j}{\overline{\text{Inc}}}\right)^{\lambda_{HouseInc}} \text{HouseCost}_{i,j} + \\
& \beta_{\text{PTCost}} \left(\frac{\text{Inc}_j}{\overline{\text{Inc}}}\right)^{\lambda_{PTInc}} \text{PTCost}_{i,j} * (1 - \text{PercentPTPaid}_j) + \\
& \beta_{\text{CarCost}} \left(\frac{\text{Inc}_j}{\overline{\text{Inc}}}\right)^{\lambda_{CarInc}} \text{CarCost}_{i,j} * (1 - \text{PercentCarPaid}_j) + \\
& \text{ActCityCenter}_j * (\beta_{\text{CityCenter\_Urban}} * D_{i,\text{Urban}} + \beta_{\text{CityCenter\_Agglo}} * D_{i,\text{Agglo}} + \beta_{\text{CityCenter\_Rural}} * D_{i,\text{Rural}}) + \\
& \text{ActUrban}_j * (\beta_{\text{Urban\_CityCenter}} * D_{i,\text{CityCenter}} + \beta_{\text{Urban\_Agglo}} * D_{i,\text{Agglo}} + \beta_{\text{Urban\_Rural}} * D_{i,\text{Rural}}) + \\
& \text{ActAgglo}_j * (\beta_{\text{Agglo\_CityCenter}} * D_{i,\text{CityCenter}} + \beta_{\text{Agglo\_Urban}} * D_{\text{i,Urban}} + \beta_{\text{Agglo\_Rural}} * D_{i,\text{Rural}}) + \\
& \text{ActRural}_j * (\beta_{\text{Rural\_CityCenter}} * D_{i,\text{CityCenter}} + \beta_{\text{Rural\_Urban}} * D_{i,\text{Urban}} + \beta_{\text{Rural\_Agglo}} * D_{i,\text{Agglo}}) + \\
& \text{PercCarMil}_j * (\beta_{\text{TT\_CarJob}} * \text{TT\_CarJob}_{i,j} + \beta_{\text{TT\_CarShop}} * \text{TT\_CarShop}_{i,j}) + \\
& \text{PercPTMil}_j * (\beta_{\text{TT\_PTJob}} * \text{TT\_PTJob}_{i,j} + \beta_{\text{TT\_PTShop}} * \text{TT\_PTShop}_{i,j}) + \\
& \beta_{\text{MaxCommute}} * D_{\text{i,MaxCommute}}
\end{aligned}
\tag{3}
$$

with:

$V_{i,j}$	utility of alternative i,
i	alternative i,
j	household j,
Inc_j	monthly household income,
$\overline{\text{Inc}}$	average monthly household income in the sample,
$\text{HouseCost}_{i,j}$	monthly housing cost,
$\text{PTCost}_{i,j}$	monthly cost of public transport usage,
PercentPTPaid_j	percentage of public transport paid by a third party (e.g., employer),
$\text{CarCost}_{i,j}$	monthly cost of car usage,
PercentCarPaid_j	percentage of car cost paid by a third party (e.g., employer),
ActCityCenter_j	1, if the respondent's actual residence location is city center, else 0,
ActUrban_j	1, if the respondent's actual residence location is urban area, else 0,
ActAgglo_j	1, if the respondent's actual residence location is agglomeration, else 0,
ActRural_j	1, if the respondent's actual residence location is rural area, else 0,
$D_{i,\text{CityCenter}}$	1, if the residence location in alternative i is city center, else 0,
$D_{i,\text{Urban}}$	1, if the residence location in alternative i is urban area, else 0,
$D_{i,\text{Agglo}}$	1, if the residence location in alternative i is agglomeration, else 0,
$D_{i,\text{Rural}}$	1, if the residence location in alternative i is rural area, else 0,
$\text{PercCarMil}_{i,j}$	car share of the total indicated mileage,
$\text{PercPTMil}_{i,j}$	public transport share of the total indicated mileage,
$\text{TT\_CarJob}_{i,j}$	travel time by car to the work place,
$\text{TT\_PTJob}_{i,j}$	travel time by public transport to the work place,
$\text{TT\_CarShop}_{i,j}$	travel time per car to the shopping center,
$\text{TT\_PTShop}_{i,j}$	travel time per public transport to the shopping center,
$D_{\text{MaxCommute}}$	1, if the travel time to work with the preferred mean of transport exceeds the acceptable travel time, else 0.

9.3 Results

9.3.1 Parameter estimates

The estimated parameters that fit the data best according to the specified utility function are summarized in Table 23.

All cost parameters are negative and statistically significant, which indicates that costs have a negative influence on utility and hence on choice probability of one alternative. Most negatively perceived are housing costs. Against them, public transport costs are around 30% and car costs 50% less valued. In addition, all income sensitivity parameters are also negative and statistically significant. Hence, people with higher incomes perceive costs less. This relationship is most prominent for the perception of public transport expenses, followed by car and housing costs. For example, a household with an income of 9,000 CHF/month perceives public transport costs 60%, car costs 47% and housing costs 28% less than a household with an income of 6,000 CHF/month.

Concerning residence location, preferences are also clear: Nearly all inertia parameters are negative and highly significant, showing a strong objection to changing the spatial type of residence location. Only two parameters associated with a change of residence from the city center to the surrounding urban area or to the agglomeration are not significant. The main reason for this, however, is arguably the small number of city-center-based households in the sample (only 36 persons representing 203 or 8.5% of all evaluated choice situations). The strongest inertia is found for households currently living in a rural area, whereas the urban center is the least favored followed by urban area and agglomeration. Agglomeration households also dislike other types of residence locations. However, the overall inertia is lower and the urban area is less undesirable than the city center or the rural area. People actually living in an urban area are about as unlikely to move to the city center or to the agglomeration, while the rural area is the most disliked.

It has been remarked that the $Adj.\rho^2$ statistic of logit models cannot be directly compared to R^2 statistic of regression models as they are defined differently and based on a different estimation methodology. The $Adj.\rho^2$ gives the relationship between the LogLikelihood of the estimated model and the LogLikelihood of a model with all parameters, while the R^2 statistic stands for the proportion of variability in a data set that is accounted for by the statistical model. According to Louviere *et al.* (2000), values of $adj.\rho^2$ between 0.2 and 0.4 are considered to be indicative of extremely good model fits. Simulations reported by Domencich (1975) equivalenced this range to 0.7 and 0.9 for a linear function.

Table 23: MNL estimation results of SP3 according to the model formulation as given by equation 3

Parameter	Value	Robust Std Err	Robust t-Test	
C_1	0.038	0.088	0.44	
C_2	0.00	fixed		
β_{CarCost}	-0.0015	0.00033	-4.45	**
$\beta_{\text{HouseCost}}$	-0.0035	0.00089	-3.97	**
β_{PTCost}	-0.0024	0.00093	-2.56	*
$\beta_{\text{TT\_CarJob}}$	-0.009	0.006	-1.33	
$\beta_{\text{TT\_PTJob}}$	0.024	0.008	2.83	**
$\beta_{\text{TT\_CarShop}}$	0.006	0.011	0.57	
$\beta_{\text{TT\_PTShop}}$	-0.003	0.013	-0.26	
$\beta_{\text{Agglo\_City}}$	-1.36	0.20	-3.76	**
$\beta_{\text{Agglo\_Urban}}$	-0.74	0.24	-5.75	**
$\beta_{\text{Agglo\_Rural}}$	-1.41	0.28	-5.08	**
$\beta_{\text{CityCenter\_Agglo}}$	-0.42	0.27	-1.54	
$\beta_{\text{CityCenter\_Urban}}$	0.28	0.31	0.90	
$\beta_{\text{CityCenter\_Rural}}$	-1.09	0.41	-2.65	**
$\beta_{\text{Urban\_Agglo}}$	-1.13	0.24	-4.64	**
$\beta_{\text{Urban\_CityCenter}}$	-0.97	0.19	-5.22	**
$\beta_{\text{Urban\_Rural}}$	-4.12	0.66	-6.24	**
$\beta_{\text{Rural\_Agglo}}$	-1.29	0.28	-4.61	**
$\beta_{\text{Rural\_Urban}}$	-3.28	0.28	-11.77	**
$\beta_{\text{Rural\_City}}$	-2.47	0.29	-8.65	**
$\beta_{\text{MaxCommute}}$	-0.38	0.16	-2.38	*
λ_{CarInc}	-1.53	0.18	-8.52	**
$\lambda_{HouseInc}$	-0.81	0.24	-3.34	**
λ_{PTInc}	-2.20	0.31	-7.00	**
			** significant at the 0.01 level	
			* significant at the 0.05 level	
			$Adj.\rho^2$=0.30	

In similar experiments, travel time parameters regularly turned out to influence choice behavior (e.g., Vrtic *et al.* (2007), Beckmann *et al.* (2002)). The respective parameters in the present model, however, are not significant or have a counterintuitive sign, such as in the case of travel time for shopping by car,. It is argued that this is partly due to correlation issues. Although the experiment design included several travel time levels for each residence location type, there is still substantial correlation between the variables describing travel time and residence location. In models estimated for test purposes that excluded residence location variables, the travel time parameters were all significant with the expected negative sign. This finding leads to the assumption that the respondent paid more attention to the indicated residence location than to travel time. This research highlights the trade-off between residence location and mobility costs. Therefore, models including the inertia of residence location are favored. For future studies, however, it is recommended that the experiment design be improved by considering a more extensive decoupling of travel times and residence location and/or more choice situations with both alternatives of the same residence location type.

Although suggested by earlier research (e.g., Walker and Li (2007)) no evidence of the influence of the presence and number of children in the household nor the average age on the propensity to changing the residence location was found. All respective parameters proved to be non-significant, regardless of whether discrete (with dummy variables) or continuous formulations were employed.

9.3.2 Value of staying at present residence location

The indication of the willingness to pay (derivation presented in Appendix D.1.2, Equation 17) for staying at the present residence location is straightforward and given by the ratio of the parameter value of the aversion to changing residence location and the parameter value of cost perception. Given the model formulation, this value is dependent on the current and expected residence location and income.

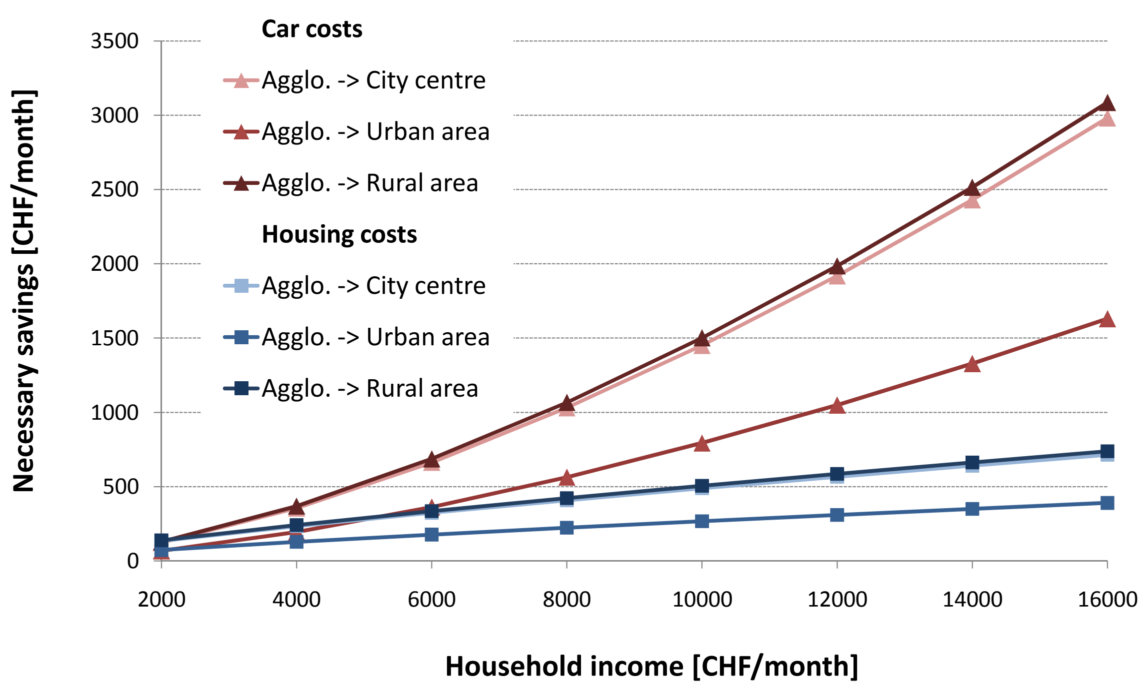
$$WTP_{R_1,R_2,C_{Type,Inc}} = \frac{\beta_{R_1,R_2}}{\beta_{C_{Type,Inc}} \left(\frac{\text{Inc}_j}{\overline{\text{Inc}}}\right)^{\lambda_{Type,Inc}}}, \tag{4}$$

with:

$WTP_{R_1,R_2,C_{Type,Inc}}$	the willingness to pay to stay at residence location type 1 against moving to residence location type 2,
β_{R_1,R_2}	parameter of the aversion to changing residence location type 2 when living currently at type 1,
$\beta_{C_{Type,Inc}}$	parameter of cost perception depending on the type of costs and income.
$\left(\frac{\text{Inc}_j}{\overline{\text{Inc}}}\right)^{\lambda_{Type,Inc}}$	influence of income on cost perception

Figure 16 plots the willingness to pay (WTP) to remain in the agglomeration against increases of rent and car costs depending on income. According to the model formulation, higher income and β_{R_1,R_2} parameters cause also higher WTP figures. Lower β_{cost} parameters, in contrast, lead to lower WTP figures. Similar plots are also feasible for other present residence locations and also for public transport costs.

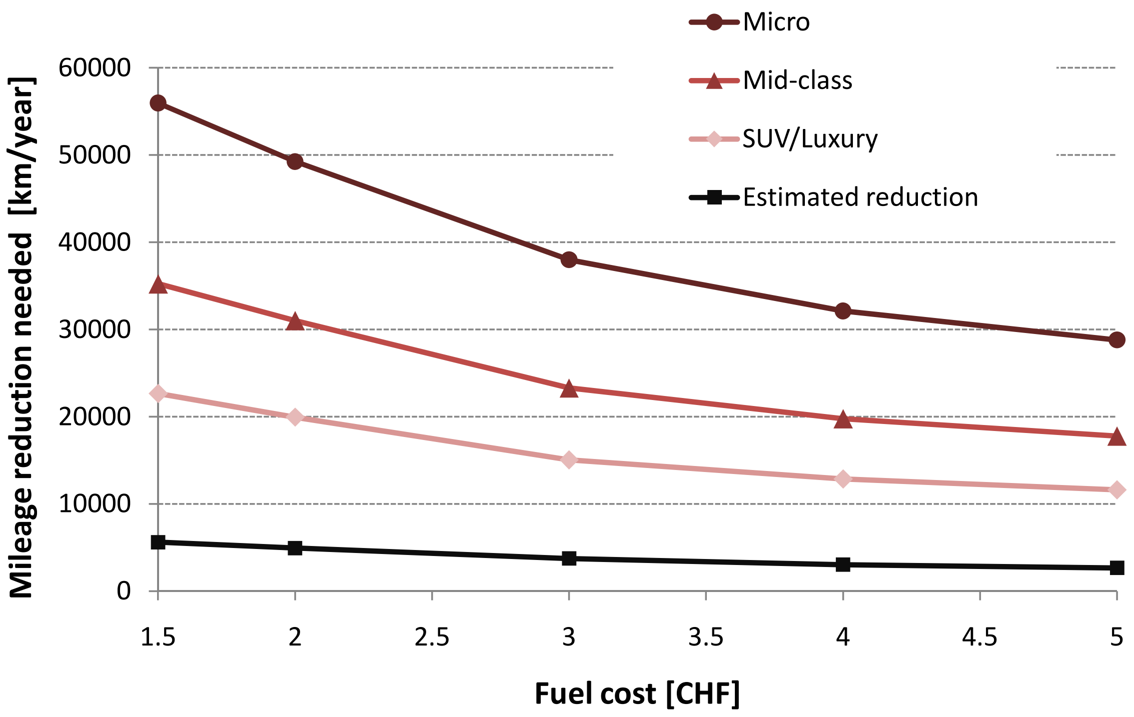
Figure 16: WTP to stay at current residence location "agglomeration" according to equation 4 and the results reported in Table 3



Given for example a household residing currently in the agglomeration with an monthly income of 10,000 CHF, an alternative apartment (in terms of space and comfort comparable) in the urban area must cost about 267 CHF/month less that it would be equally attractive. Alternatively, if the households expects to save 793 CHF/month of car costs when living in the urban area, both places would be equally attractive.

Figure 17 plots the required mileage reduction to equal 793 CH/month for a household with a yearly mileage of 30,000 km. The estimated mileage reduction is deducted from the difference of the average yearly mileage between households situated in the agglomeration and the urban area given in the *Mikrozensus 2005* Swiss Federal Statistical Office (2006). The figure also reflects the expected decline in the annual mileage given by the elasticity estimates of SP1.

Figure 17: Mileage reduction required to equal the disutility of moving from the current residence location for the example "agglomeration" to "urban area", depending on car type and fuel price, assuming an annual mileage of 30,000km)



It is obvious that the reduction in mobility costs for this household (with a rather high annual mileage) is far from the point where the WTP for staying in the agglomeration would be equaled.

9.3.3 Elasticity

Based on the model results, costs and residence location elasticities are calculated and presented in Table 24. The indicated elasticities are calculated based on sample enumeration (see Appendix D.1.2. As it is based on a scalar variable, the cost elasticity is calculated as a point elasticity according to Equation (13). The elasticity of the residence location inertia is calculated as an arc elasticity, see Equation (15) due to the nominal nature of the dummy coding. This arc elasticity figure has to be interpreted as the average increase of one alternative's choice probability if the residence location of that alternative is consistent with the present residence location. For example, the value of 0.39 indicates that the likelihood of choosing the alternative "urban area" as a residential location is 39% higher for respondents actually living in an urban area, compared to all other residential location characteristics.

Table 24: Residence location choice elasticity, derived from the results of the MNL-model (Equation 3) reported in Table 23

Variable	Elasticity
Costs: Point elasticity	
Car costs	-0.46
PT costs	-0.13
Housing costs	-2.22
Inertia: Arc elasticity (stay at present residence location)	
City center	0.12*
Urban area	0.39
Agglomeration	0.25
Rural area	0.46

*only the inertia of moving to the rural area is considered)

Interestingly, the elasticity of the car costs is higher than the elasticity of the public transport costs despite the values of the respective parameters. On average, car costs (e.g., 500 CHF/month) are much higher than public transport costs (e.g., 50 CHF/month). Therefore, the impact of a relative change (e.g., 10% -> 50 CHF car costs, 5 CHF public transport costs) is higher for car costs.

The highest residence location inertia is found for individuals living in a rural area, followed by an urban area and an agglomeration. The elasticity of the inertia to stay in the city center only considers aversion to moving to a rural area, since only this parameter is significant.

10 Conclusion

10.1 Price effects on mobility tool ownership

This report presents some possible long-term effects of substantial increases in transport costs, especially those involving fuel price increases up to the level of 5 CHF/l.

It shows that people react not only by adjusting mileage, but also by changing car types and choosing smaller engines or more fuel-efficient engine concepts, such as hybrids or diesel. In addition, substitution effects between car and season ticket ownership within households were discovered, strengthening the argument raised in recent research to jointly model mobility tool ownership and usage.

To cover such substitution effects, gasoline, diesel, natural gas consumption and public transport usage need to be estimated simultaneously. The structural equation model employed here revealed price-dependent elasticities. In the price range of 1.5 CHF/l - 5 CHF/l, the resulting fuel price elasticities ranged between -0.14 and -0.54 for gasoline and +0.32 and -0.70 for diesel. Elasticity of diesel demand is positive up to a price level of 3.5 CHF/l. The increasing demand caused by respondents that indicated to substitute gasoline cars by a diesel cars outbalance the decreasing demand of respondents that presently already use diesel cars.

Due to the small number of respondents, which might be related to the restrictions determined by the survey approach, the results of the natural gas model can only serve as a trend because the effective values are of limited precision.

Derived from the sum of the estimates of gasoline, diesel and natural gas consumption, the elasticities of total fuel consumption range between -0.14 for a fuel price of 1.5 CHF/l and -0.54 for 5 CHF/l.

Although the results presented here are based on the, for this topic, novel use of the stated adaptation approach, the results are very comparable to other studies, namely, to the recent time-series-based fuel price elasticity study of Baranzini *et al.* (2009). They report a long-term price elasticity of -0.27 for all fuels and -0.34 for gasoline. The model presented above suggests an elasticity of -0.15 for overall demand and -0.34 for gasoline at the price of 1.65 CHF/l (at the time of the survey).

The comparatively low value for total consumption in this study is driven by the increasing use of diesel cars. Such substitution effects are only partly covered by the time series analysis which covers the vehicle stock as exogenous. Additionally, it can be argued that in a hypothetical context respondents might undervalue the costs associated with a car change and hence internalize the trend towards diesel cars to be internalized too strongly.

The impact of different incentive types might not have been satisfactorily described by the descriptive analysis. It can be argued, that the respondents, given the vast number of possible combinations of car types, engine types and sizes, might have had problems finding out which cars were eligible for the incentives. Both problems might be addressed using strategies to presample relevant choice alternatives. For example, the types of cars that a respondent effectively envisages or his propensity to move could be surveyed in a preliminary question. The alternatives for SP experiment would then be generated based on the responses to these questions. However, this would come at the expense of the a priori exclusion of new alternatives that were not considered that might by valuable anyway.

10.2 Price effects on residence location choice

In addition to mobility tool ownership, this paper also presents how mobility and housing costs influence residence location choice behavior. People react most to housing costs while car and public transport costs are less negatively perceived. However, the aversion to leave the present residence location is substantial. Depending on the current and the potential residence location type, the willingness to pay out more before moving to a more central place that would lower car costs, assuming an average income household, lies in a range between 463 CHF/month for a residence location change from an agglomeration to an urban area, and 2040 CHF/month for a move from a rural area to the city center.

Overall, the approach of generating choice situations based on results of an adaptation mobility tool choice experiment turned out to be successful. Based on the presented model formulation, all key objectives, namely, to state the aversion to changing residence location type and the valuation of housing and mobility costs, could be fulfilled. The only drawback was that the estimation of significant travel time parameters failed due to correlation issues. In addition, it has to be recognized that a meaningful inclusion of variables describing the composition of the mobility tools was not possible since people tended to stick to their fleet of mobility tools even when considering moving to areas of a different spatial type.

In future research, both issues could be addressed by simple measures. The consideration of a broader range of travel times might permit the estimation of statistically significant parameters. The collection of a larger sample might generate enough variance of mobility tools ownership, however this would also involve higher survey costs.

10.3 Limitations

The results of the statistical model explaining the fuel consumption are restricted to the price range of 1.5 CHF/l and 5 CHF/l. Given the quadratic model form, any sort of extrapolation should be avoided.

The descriptive analysis and the model results of the SP1 data suggest there is no statistical significance of the respondents' reactions in terms of fuel consumption to different CO_2 incentive/schemes. This suggests that the respondents mainly considered fuel price alone when stating their envisaged mobility fleet. It is argued that this is driven by straining the abilities of the respondent when evaluating the preferred mobility fleet in a stated adaptation survey. However, for further research, focusing on the effect of different CO_2 schemes, a less demanding survey approach, such as stated choice, might deliver more reliable results.

The same applies to the respondent's consideration of the present less prominent fuel types, such as natural gas or electricity. Considering today's market penetration and familiarity with such car types, as well as the present density of filling stations, the respondents' inertia is explainable. In further research that might focus more on possible market penetrations of such new car concepts, information on these variables should be provided or better included as decision variables in the experimental design.

When estimating the model of fuel consumption, the heterogeneity of consumers is not considered. Hence, the result of the model cover an average (typical) behavior. The distribution of the adaptation frequency per household was evaluated but no clusters were revealed.

The comparison of car type distribution, separated for the different spatial types of residences as reported for the present situation, with the distribution as stated in SP2 (the stated adaptation experiment with changed place of residence) shows clear differences. Households tend to stick with their preferred type. This stands in contrast to earlier studies suggesting that people also adjust their mobility tools when moving between different spatial types (e.g., Beige (2008)). Because of this bias, the data of SP2 was omitted from fuel price elasticity analysis.

In this study, the effect of higher fuel prices on the residence location choice was analyzed by a stated choice approach. Since such decisions are in reality rather complex, the specification of the alternatives had to be simplified and not all factors that might play a role could be included.

10.4 Further research

The SP1/SP2 data is suitable for modeling using the multiple discrete continuous model approach (MDCEV) Bhat (2005). The MDCEV approach allows a simultaneous estimation of car choice (discrete part) and car usage (continuous part). Due to the complexity of the model, the data requirements are substantial and it remains to be proven whether the collected sample is sufficiently large to deliver stable and meaningful results. A further opportunity of model advancement would be the use of a negative binominal formulation. Such a model would enable to capture the zero demand observations more consistently than by using a quadratic or translog formulation. Additionally, the use of panel data might lead to further model improvements since several observations for each household are included in the data.

The analysis revealed substantial inertia effects, which is highlighted by the fact that some respondents informally declared that they can't imagine living somewhere else. However, Beige (2008) showed that the Swiss population moves on average every seven years. Therefore, it would be meaningful to focus future research on households that are planning to move or have moved recently.

In this survey, only residence location choice was considered. Given the continuous growth of commuting distances (Fröhlich (2008)), it would be both interesting and highly relevant for policy-making to analyze how higher fuel prices might influence this trend. The suggested methodology for such a study would be a stated choice experiment with decision variables describing both the workplace (e.g., salary, company size, workplace) and transport (e.g., travel time, travel costs).

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A Survey software

A.1 SP1

Figure 18: Screenshot SP1: part 1

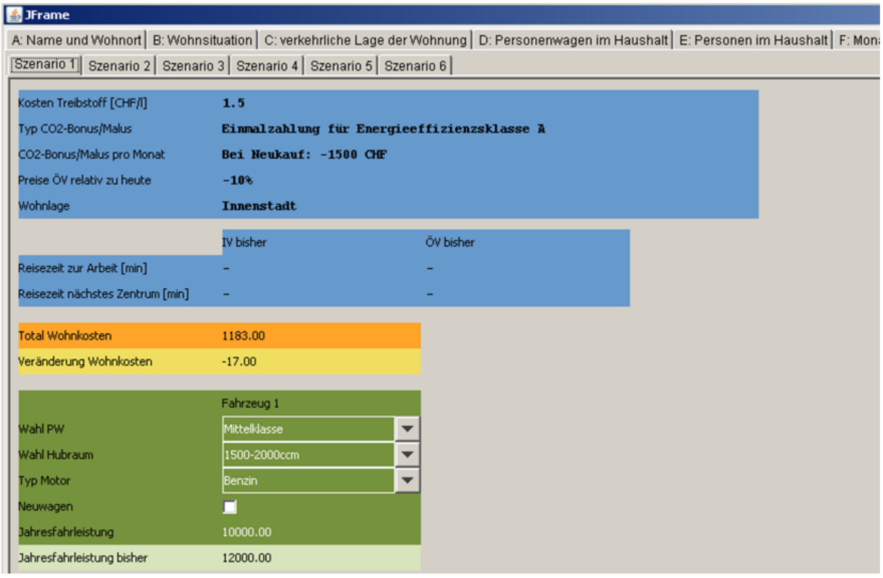
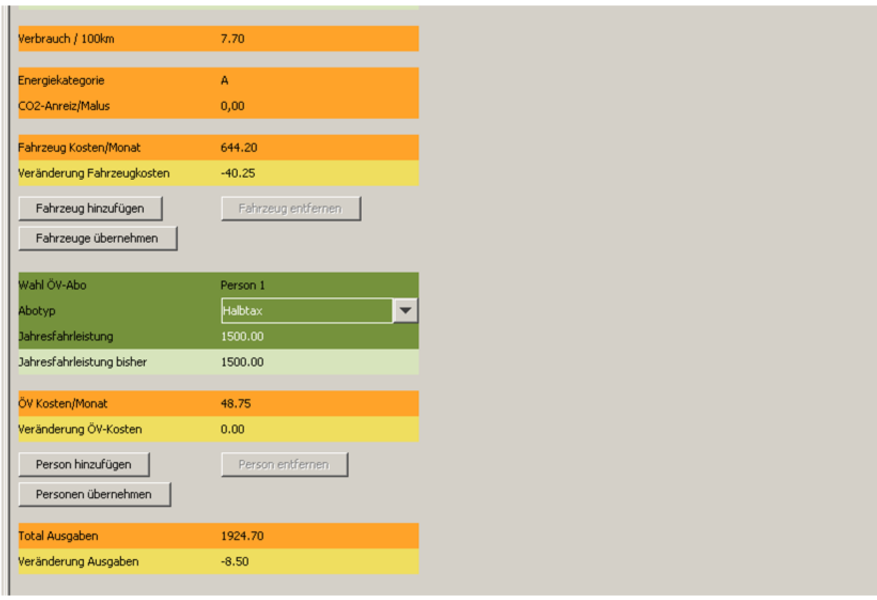
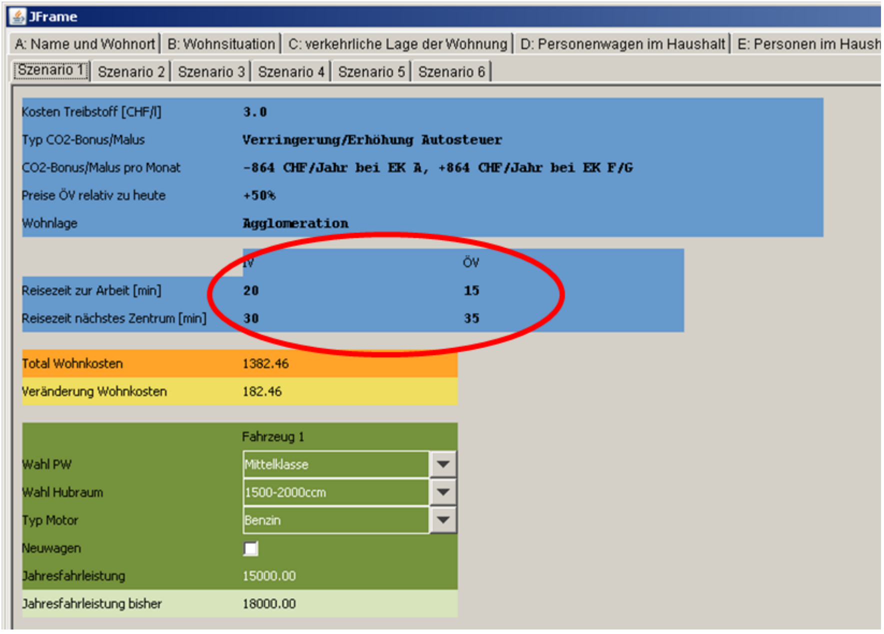


Figure 19: Screenshot SP1: part 2



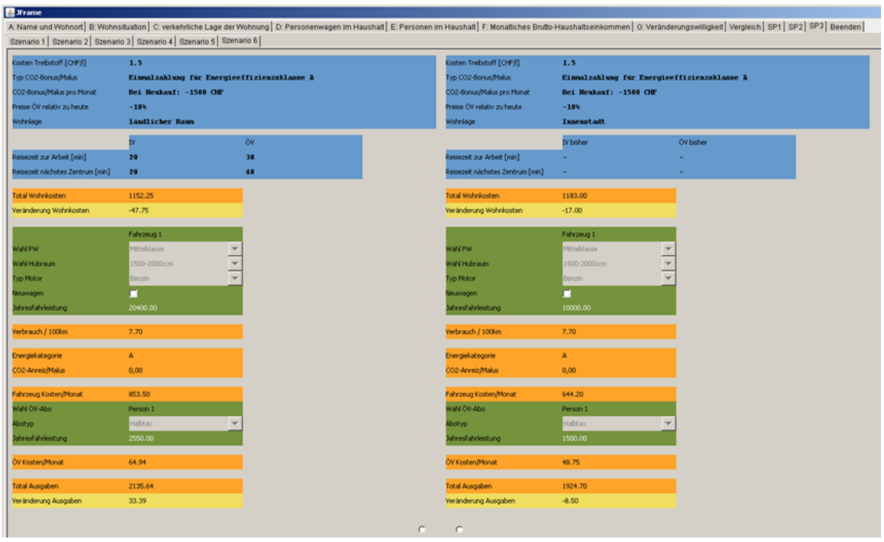
A.2 SP2

Figure 20: Screenshot SP2



A.3 SP3

Figure 21: Screenshot SP3



B Experimental design

B.1 SP1

Table 25: SP1: Experiment Plan, Stage I

ID	Residence	Cost Gas	PT Cost	CO-$_2$_Scheme	CO-$_2$_Incentive
1	Old town/ Inner city	2	1.5	Car tax surcharge/reduction	-864CHF/yr
2	Old town/ Inner city	3	0.9	CO_2 tax on fuel	+0.2 CHF/l
3	Old town/ Inner city	2	0.9	Buyer’s premium	1500 CHF
4	Old town/ Inner city	5	0.9	CO_2 tax on fuel	+0.2 CHF/l
5	Old town/ Inner city	1.5	1.2	Car tax surcharge/reduction	-432 CHF/yr
6	Old town/ Inner city	4	1.2	Buyer’s premium	1500 CHF
7	Urban area	3	1.5	Car tax surcharge/reduction	-432 CHF/yr
8	Urban area	2	1.2	CO_2 tax on fuel	+0.2 CHF/l
9	Urban area	1.5	1.5	Buyer’s premium	3000 CHF
10	Urban area	5	1.5	CO_2 tax on fuel	+0.5 CHF/l
11	Urban area	4	0.9	Car tax surcharge/reduction	-864CHF/yr
12	Urban area	3	0.9	Buyer’s premium	1500 CHF
13	Agglomeration	3	0.9	Buyer’s premium	1500 CHF
14	Agglomeration	2	1.2	Car tax surcharge/reduction	-432 CHF/yr
15	Agglomeration	1.5	0.9	CO_2 tax on fuel	+0.5 CHF/l
16	Agglomeration	5	1.2	Car tax surcharge/reduction	-864CHF/yr
17	Agglomeration	5	1.2	CO_2 tax on fuel	+0.2 CHF/l
18	Agglomeration	4	1.5	Buyer’s premium	3000 CHF
19	Rural area	5	0.9	CO_2 tax on fuel	+0.2 CHF/l
20	Rural area	3	1.2	CO_2 tax on fuel	+0.5 CHF/l
21	Rural area	2	0.9	Buyer’s premium	3000 CHF
22	Rural area	1.5	1.2	Car tax surcharge/reduction	-432 CHF/yr
23	Rural area	3	1.2	Buyer’s premium	1500 CHF
24	Rural area	4	1.5	Car tax surcharge/reduction	-864 CHF/yr

Table 26: SP1: Experiment Plan, Stage II

ID	Residence	Cost Gas	PT Cost	$CO\text{-}_2$_Scheme	$CO\text{-}_2$_Incentive
1	Old town/ Inner city	1.5	0.9	Buyer's premium	1500 CHF
2	Old town/ Inner city	5	1.2	CO_2 tax on fuel	+0.5 CHF/l
3	Old town/ Inner city	2	0.9	CO_2 tax on fuel	+0.2 CHF/l
4	Old town/ Inner city	4	1.5	Buyer's premium	3000 CHF
5	Old town/ Inner city	3	1.5	Car tax surcharge/reduction	-864 CHF/yr
6	Old town/ Inner city	5	0.9	Car tax surcharge/reduction	-432 CHF/yr
7	Urban area	2	1.2	Buyer's premium	3000 CHF
8	Urban area	1.5	0.9	Buyer's premium	1500 CHF
9	Urban area	2	1.5	Car tax surcharge/reduction	-864 CHF/yr
10	Urban area	3	0.9	Car tax surcharge/reduction	-432 CHF/yr
11	Urban area	5	1.5	CO_2 tax on fuel	+0.2 CHF/l
12	Urban area	4	1.2	CO_2 tax on fuel	+0.5 CHF/l
13	Agglomeration	1.5	1.2	Car tax surcharge/reduction	-864 CHF/yr
14	Agglomeration	2	1.2	Car tax surcharge/reduction	-432 CHF/yr
15	Agglomeration	3	0.9	CO_2 tax on fuel	+0.2 CHF/l
16	Agglomeration	3	1.5	Buyer's premium	1500 CHF
17	Agglomeration	4	0.9	CO_2 tax on fuel	+0.5 CHF/l
18	Agglomeration	5	1.5	Buyer's premium	3000 CHF
19	Rural area	1.5	1.2	Buyer's premium	3000 CHF
20	Rural area	4	1.5	CO_2 tax on fuel	+0.5 CHF/l
21	Rural area	2	1.2	CO_2 tax on fuel	+0.2 CHF/l
22	Rural area	3	1.5	Buyer's premium	1500 CHF
23	Rural area	4	0.9	Car tax surcharge/reduction	-864 CHF/yr
24	Rural area	5	0.9	Car tax surcharge/reduction	-432 CHF/yr

B.2 SP2

Table 27: SP2: Experiment Plan, Stage I

ID	Actual residence	New residence	Fuel Cost [CHF/l]	PT Cost Level	Travel time [min] to work PT	to work Car	to center PT	to center Car	CO-$_2$_Scheme	CO-$_2$_Incentive
1	Agglomeration	City center	4	1.5	15	20	4	8	Buyer's premium	3000 CHF
2	Agglomeration	Urban area	3	0.9	15	10	15	15	Buyer's premium	1500 CHF
3	Agglomeration	Urban area	2	1.2	20	25	15	10	Car tax sur./red.	-432 CHF/yr
4	Agglomeration	Urban area	4	1.5	20	15	15	5	CO_2 tax on fuel	+0.5 CHF/l
5	Agglomeration	Rural area	2	1.2	40	30	60	20	CO_2 tax on fuel	+0.2 CHF/l
6	Agglomeration	Rural area	3	0.9	60	20	60	40	Car tax sur./red.	-864 CHF/yr
7	City center	Agglomeration	1.5	1.2	25	10	20	10	Car tax sur./red.	-432 CHF/yr
8	City center	Agglomeration	3	0.9	25	10	30	20	CO_2 tax on fuel	+0.2 CHF/l
9	City center	Agglomeration	2	1.5	40	30	20	10	Car tax sur./red.	-864 CHF/yr
10	City center	Urban area	3	0.9	15	10	15	15	CO_2 tax on fuel	+0.5 CHF/l
11	City center	Urban area	2	1.5	10	15	10	10	Buyer's premium	1500 CHF
12	City center	Rural area	1.5	1.2	30	30	30	40	Buyer's premium	3000 CHF
13	Urban area	Agglomeration	1.5	1.5	25	20	10	20	Buyer's premium	3000 CHF
14	Urban area	Agglomeration	3	0.9	25	10	30	20	Buyer's premium	1500 CHF
15	Urban area	Agglomeration	2	1.2	15	20	30	10	CO_2 tax on fuel	+0.2 CHF/l
16	Urban area	City center	1.5	1.5	5	8	12	8	Car tax sur./red.	-864 CHF/yr
17	Urban area	City center	3	0.9	10	8	8	4	CO_2 tax on fuel	+0.5 CHF/l
18	Urban area	Rural area	2	1.2	40	30	60	20	Car tax sur./red.	-432 CHF/yr
19	Rural area	Agglomeration	5	0.9	40	10	20	30	CO_2 tax on fuel	+0.2 CHF/l
20	Rural area	Agglomeration	4	1.5	15	30	30	30	Car tax sur./red.	-864 CHF/yr
21	Rural area	Agglomeration	3	1.2	40	20	30	20	CO_2 tax on fuel	+0.5 CHF/l
22	Rural area	City center	5	0.9	5	15	8	12	Car tax sur./red.	-432 CHF/yr
23	Rural area	Urban area	4	1.5	20	15	15	5	Buyer's premium	3000 CHF
24	Rural area	Urban area	3	1.2	20	20	5	10	Buyer's premium	1500 CHF

Table 28: SP2: Experiment Plan, Stage II

ID	Actual residence	New residence	Fuel Cost [CHF/l]	PT Cost Level	Travel time [min] to work PT	Travel time [min] to work Car	Travel time [min] to center PT	Travel time [min] to center Car	CO2 Scheme	CO2 Incentive
1	Agglomeration	City center	5	1.5	5	8	5	10	Buyer's premium	3000 CHF
2	Agglomeration	Urban area	3	0.9	10	10	20	20	CO_2 tax on fuel	+0.2 CHF/l
3	Agglomeration	Rural area	2	1.2	40	30	60	20	Car tax sur./red.	-432 CHF/yr
4	Agglomeration	Urban area	5	1.5	25	10	10	15	Buyer's premium	3000 CHF
5	Agglomeration	Rural area	3	0.9	60	40	40	30	CO_2 tax on fuel	+0.2 CHF/l
6	Agglomeration	Urban area	2	1.2	10	20	25	20	Car tax sur./red.	-432 CHF/yr
7	City center	Agglomeration	3	1.5	15	20	35	30	Car tax sur./red.	-864 CHF/yr
8	City center	Urban area	5	1.2	15	10	15	15	CO_2 tax on fuel	+0.5 CHF/l
9	City center	Rural area	1.5	0.9	30	20	40	20	Buyer's premium	1500 CHF
10	City center	Urban area	1.5	0.9	15	15	15	10	Buyer's premium	1500 CHF
11	City center	Agglomeration	5	1.2	35	30	15	20	CO_2 tax on fuel	+0.5 CHF/l
12	City center	Rural area	3	1.5	40	40	30	40	Car tax sur./red.	-864 CHF/yr
13	Urban area	City center	2	1.5	5	8	10	5	Car tax sur./red.	-864 CHF/yr
14	Urban area	Agglomeration	4	1.2	25	10	15	30	CO_2 tax on fuel	+0.5 CHF/l
15	Urban area	Rural area	1.5	0.9	40	30	60	40	Buyer's premium	1500 CHF
16	Urban area	Agglomeration	2	1.5	15	10	35	30	Car tax sur./red.	-864 CHF/yr
17	Urban area	Agglomeration	1.5	0.9	25	20	15	10	Buyer's premium	1500 CHF
18	Urban area	Rural area	4	1.2	60	40	40	30	CO_2 tax on fuel	+0.5 CHF/l
19	Rural area	Urban area	1.5	1.2	25	15	15	10	Buyer's premium	3000 CHF
20	Rural area	Urban area	5	0.9	15	20	20	10	Car tax sur./red.	-432 CHF/yr
21	Rural area	City center	4	1.5	10	8	5	15	CO_2 tax on fuel	+0.5 CHF/l
22	Rural area	Agglomeration	4	1.5	15	30	15	10	CO_2 tax on fuel	+0.5 CHF/l
23	Rural area	Agglomeration	5	0.9	35	10	25	30	Car tax sur./red.	-432 CHF/yr
24	Rural area	City center	1.5	1.2	15	12	15	10	Buyer's premium	3000 CHF

B.3 SP3

Table 29: SP3: Experiment Plan, Stage I

	Situation 1			Situation 2					
SP3 ID	Residence	SP Type	ID	Residence	SP Type	ID	Old residence	Fuel Price [CHF/l]	PT price level
1	City center	2	1	Urban area	2	4	Agglomeration	4	1.5
2	Urban area	2	2	Rural area	2	6	Agglomeration	3	0.9
3	Urban area	2	3	Rural area	2	5	Agglomeration	2	1.2
4	Agglomeration	2	7	Rural area	2	12	City center	1.5	1.2
5	Agglomeration	2	8	Urban area	2	10	City center	3	0.9
6	Agglomeration	2	9	Urban area	2	11	City center	2	1.5
7	Agglomeration	2	13	City center	2	16	Urban area	1.5	1.5
8	Agglomeration	2	14	City center	2	17	Urban area	3	0.9
9	Agglomeration	2	15	Rural area	2	18	Urban area	2	1.2
10	Agglomeration	2	19	City center	2	22	Rural Area	5	0.9
11	Agglomeration	2	20	Urban area	2	23	Rural Area	4	1.5
12	Agglomeration	2	21	Urban area	2	24	Rural Area	3	1.2
13	City center	2	1	Rural area	1	18	Agglomeration	4	1.5
14	Urban area	2	2	Agglomeration	1	13	Agglomeration	3	0.9
15	Urban area	2	3	Agglomeration	1	14	Agglomeration	2	1.2
16	Agglomeration	2	7	Rural area	1	5	City center	1.5	1.2
17	Agglomeration	2	8	Urban area	1	2	City center	3	0.9
18	Agglomeration	2	9	City center	1	1	City center	2	1.5
19	Agglomeration	2	13	Agglomeration	1	9	Urban area	1.5	1.5
20	Agglomeration	2	14	Rural area	1	12	Urban area	3	0.9
21	Agglomeration	2	15	Agglomeration	1	8	Urban area	2	1.2
22	Agglomeration	2	19	Agglomeration	1	19	Rural Area	5	0.9
23	Agglomeration	2	20	Urban area	1	24	Rural Area	4	1.5
24	Agglomeration	2	21	Agglomeration	1	20	Rural Area	3	1.2

Table 30: SP3: Experiment Plan, Stage II

	Situation 1			Situation 2					
SP3 ID	Residence	SP Type	ID	Residence	SP Type	ID	Old residence	Fuel Price [CHF/l]	PT price level
1	City center	2	1	Urban area	2	4	Agglomeration	5	1.5
2	Urban area	2	2	Rural Area	2	5	Agglomeration	3	0.9
3	Rural Area	2	3	Urban area	2	6	Agglomeration	2	1.2
4	Agglomeration	2	7	Rural Area	2	12	City center	3	1.5
5	Urban area	2	8	Agglomeration	2	11	City center	5	1.2
6	Rural Area	2	9	Urban area	2	10	City center	1.5	0.9
7	City center	2	13	Agglomeration	2	16	Urban area	2	1.5
8	Agglomeration	2	14	Rural Area	2	18	Urban area	4	1.2
9	Rural Area	2	15	Agglomeration	2	17	Urban area	1.5	0.9
10	Urban area	2	19	City center	2	24	Rural Area	1.5	1.2
11	Urban area	2	20	Agglomeration	2	23	Rural Area	5	0.9
12	City center	2	21	Agglomeration	2	22	Rural Area	4	1.5
13	City center	2	1	Agglomeration	1	18	Agglomeration	5	1.5
14	Urban area	2	2	Agglomeration	1	15	Agglomeration	3	0.9
15	Rural Area	2	3	Agglomeration	1	14	Agglomeration	2	1.2
16	Agglomeration	2	7	City Center	1	5	City center	3	1.5
17	Urban area	2	8	City Center	1	2	City center	5	1.2
18	Rural Area	2	9	City Center	1	1	City center	1.5	0.9
19	City center	2	13	Urban area	1	9	Urban area	2	1.5
20	Agglomeration	2	14	Urban area	1	12	Urban area	4	1.2
21	Rural Area	2	15	Urban area	1	8	Urban area	1.5	0.9
22	Urban area	2	19	Rural Area	1	19	Rural Area	1.5	1.2
23	Urban area	2	20	Rural Area	1	24	Rural Area	5	0.9
24	City center	2	21	Rural Area	1	20	Rural Area	4	1.5

C Transport cost calculation

Table 31: Car consumption depending on type and capacity

	Micro	Subcompact	Lower Mid-class	Minivan
1000-1500 ccm	4.5	5	6	6.5
1500-2000 ccm	5.5	6	6.5	7.25
2000-2500 ccm	6.5	7	7.5	8.25
2500-3000 ccm	n.a.	8.5	9	9.75
>3000 ccm	n.a.	10	10.5	11.25

	Mid-class	Upper mid-class	SUV/Luxury	Sports car
1000-1500 ccm	6.5	n.a.	n.a.	7
1500-2000 ccm	7	7.5	n.a.	8.5
2000-2500 ccm	8	8.5	9	10
2500-3000 ccm	9.5	10	10.5	11.5
>3000 ccm	11	11.5	13	14

Table 32: Fixed and variable cost of public transport

Yearly mileage	<500	<2000	<4000	<7000	<12,000	<20,000	<30,000	<40,000
Only variable costs								
No season ticket	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Half-Fare card	0.4	0.3	0.23	0.2	0.2	0.2	0.2	0.2
Fixed and variable costs								
Local season ticket (monthly)								
Additional unit costs [CHF/km]	1.416	0.35	0.22	0.17	0.19	0.22	0.26	0.32
Fixed costs	708	708.00	860.00	1163.57	2230.24	4363.57	7830.24	12630.24
Local season ticket (yearly)								
Additional unit costs [CHF/km]	1.18	0.30	0.18	0.14	0.15	0.18	0.22	0.26
Fixed costs	590	590.00	716.67	969.64	1858.53	3636.31	6525.20	10525.20
Regional season ticket (monthly)								
Additional unit costs [CHF/km]	2.4	0.60	0.31	0.18	0.15	0.16	0.19	0.23
Fixed costs	1200	1200.00	1250.00	1250.00	1783.33	3170.00	5623.33	9143.33
Regional season ticket (yearly)								
Additional unit costs [CHF/km]	2	0.50	0.26	0.15	0.12	0.13	0.16	0.19
Fixed costs	1000	1000	1041.667	1041.667	1486.111	2641.667	4686.111	7619.444
Only fixed costs								
GA	3100	3100	3100	3100	3100	3100	3100	3100
GA Student	2250	2250	2250	2250	2250	2250	2250	2250
GA Partner	2100	2100	2100	2100	2100	2100	2100	2100
GA Senior	2350	2350	2350	2350	2350	2350	2350	2350
GA Disabled	2200	2200	2200	2200	2200	2200	2200	2200
GA 1st Class	4850	4850	4850	4850	4850	4850	4850	4850
GA Student 1st Class	3600	3600	3600	3600	3600	3600	3600	3600
GA Partner 1st Class	3200	3200	3200	3200	3200	3200	3200	3200
GA Senior 1st Class	3700	3700	3700	3700	3700	3700	3700	3700
GA Behinderte 1st Class	3500	3500	3500	3500	3500	3500	3500	3500

D Methodologies

D.1 Logit model

In the logit model, the utility of the discrete choice alternatives is described by a systematic, a deterministic and a random (error term) component. The utility U of alternative j for a person q can then be expressed as:

$$U_{jq} = V_{jq} + \varepsilon_{jq} \tag{5}$$

with:

V_{jq}	systematic, measurable component
ε_{jq}	non-systematic, non-measurable component to capture unobservered, individual idiosyncrasies and errors in measurement

The utiltity functions of V_{iq} are user-defined combinations of alternative- and person-specific attributes. The chosen alternative j is then the one that exhibits the highest utility for person q:

$$\begin{aligned} &U_{jq} \geq U_{iq}, \forall i \neq j \\ &V_{jq} - V_{iq} \geq \varepsilon_{iq} - \varepsilon_{jq}, \forall i \neq j \end{aligned} \tag{6}$$

Since the value of $\varepsilon_{iq} - \varepsilon_{jq}$ is unknown, only an estimation of the choice probability of one alternative can be described. Hence, the choice probability of alternative j is given by

$$\begin{aligned} &P_{jq} = P(\varepsilon_{iq} \leq \varepsilon_{jq} + V_{jq} - V_{iq}), \forall i \neq j \\ &P_{jq} = \int f(\varepsilon) d\varepsilon, \end{aligned} \tag{7}$$

whereas $f(\varepsilon)$ stands for the density function of the mutual error term. For the multinominal logit model, the error terms are expected to be independent and Gumbel-distributed with an average value of 0 and equal standard deviation. Then, the choice probability of alternative j is given by:

$$P_j = \frac{e^{V_j}}{\sum_i e^{V_i}} \tag{8}$$

D.1.1 Logit model estimation methodology

Logit models are estimated by the maximum likelihood method. The likelihood function is given by:

$$\prod_{i=1}^{N} P_{in} g_{in}, \tag{9}$$

with:

N	number of observations
g_{in}	1, if for observation n alternative i is chosen, 0 else
P_{in}	choice probability of alternative i in observation n, given the estimated parameters

For the estimation, transformation to a natural logarithm is employed:

$$\ln L = \sum_{n=1}^{N} g_{in} * \ln P_{in} \tag{10}$$

Equation 10 is maximized by optimizing the parameters so that the modeled behavior fits as much as possible the observed behavior. The goodness of fit is defined by the value of the log-likelihood function. As this indicator is not standarized and depends on the number of observations, the alternative indicator $adjusted\ \rho^2$ measures the share of the explained variance considering the number of observations and degree of freedom:

$$Adj.\rho^2 = 1 - \frac{L - k}{L_0} \tag{11}$$

with:

L	LogLikelihood of the estimated model
L_0	LogLikelihood of the estimated model with all parameters set to 0
k	Degree of freedom (= number of estimated parameters)

In this project, all logit model estimations were computed with the software BIOGEME Bierlaire (2008) using the CFSQP algorithm.

D.1.2 Result interpretation, elasticity and further derivatives

Based on the parameter estimates, direct and cross elasticities of all choice specific variables (e.g., price, travel time) with statistically significant parameters can be calculated. In the context of discrete choice models, direct elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in an attribute of the same alternative. Cross elasticity measures the percentage change in the probability of choosing a particular alternative in the choice set with respect to a given percentage change in an attribute of the competing alternative.

Hence, direct point elasticities in the MNL model are defined as follows:

$$E^{P_{iq}}_{X_{ikq}} = \frac{\partial P_{iq}}{\partial X_{ikq}} \cdot \frac{X_{ikq}}{P_{iq}}, \tag{12}$$

with

$E^{P_{iq}}_{X_{ikq}}$	the elasticity of choosing alternative i with respect to changes in variable k for person q
P_{iq}	the probability of choosing alternative i for person q
X_{ikq}	the value of variable k of alternative i for person q

In the case of linear formulations of the utility term, the partial derivatives equal the β parameters and the equation collapses to:

$$E^{P_{iq}}_{X_{ikq}} = \beta_{ik} X_{ikq}(1 - P_{iq}), \tag{13}$$

for the direct point elasticity and

$$E^{P_{iq}}_{X_{jkq}} = -\beta_{jk} X_{jkq}(P_{jq}), \tag{14}$$

for the cross point elasticity.

For non-scalar variables (e.g., dummy variables such as those used for the preference of residence location choice), only arc elasticities can be calculated:

$$E^{P_{iq}}_{X_{ikq}} = \frac{(P^1_{iq} - P_{iq})/(X^1_{ikq} - X_{ikq})}{(P^1_{iq} + P_{iq})/(X^1_{ikq} + X_{ikq})} \tag{15}$$

Elasticities are relative to the absolute value of the variables and the choice probability of one given alternative. Therefore, the correct indication of an average elasticity requires sample enumeration. For all situations in the sample, an individual elasticity is calculated and later aggregated to an average elasticity (Equation 16).

$$E^{\overline{P}_i}_{X_{ikq}} = \frac{\sum_{q=1}^{Q} \hat{P}_{iq} E^{P_{iq}}_{X_{ikq}}}{\sum_{q=1}^{Q} \hat{P}_{iq}} \tag{16}$$

Based on the resulting parameters, an MNL model, Willingness to Pay (WTP) figures can be obtain by dividing the parameter (β_x) of any variable x of interest by the cost parameter (β_x) (Equation 17).

$$WTP_x = \frac{\beta_x}{\beta_{cost}} \tag{17}$$

In case of an interaction of either the cost parameter or the variable of interest, the WTP figure becomes dependent on the interacting variable, therefore, the interaction needs to be included in Equation 17.

D.2 Structural equations model (SEM)

D.2.1 Formulation

With linear regression models, only one dependent variable can be estimated at a time. Therefore, substitution effects, such as the change from gasoline to diesel cars, cannot be adequately covered, while the non-consideration of such effects leads to biased parameter estimates. Structural equation models (SEM) allow the effects of the independent (exogenous) variables on several indicators (endogenous variables) to be estimated simultaneously. Furthermore, the model structure allows accounting for correlations between both exogenous and endogenous variables. This is especially important if substitution effects between exogenous variables are expected, as in the case of gasoline and fuel consumption.

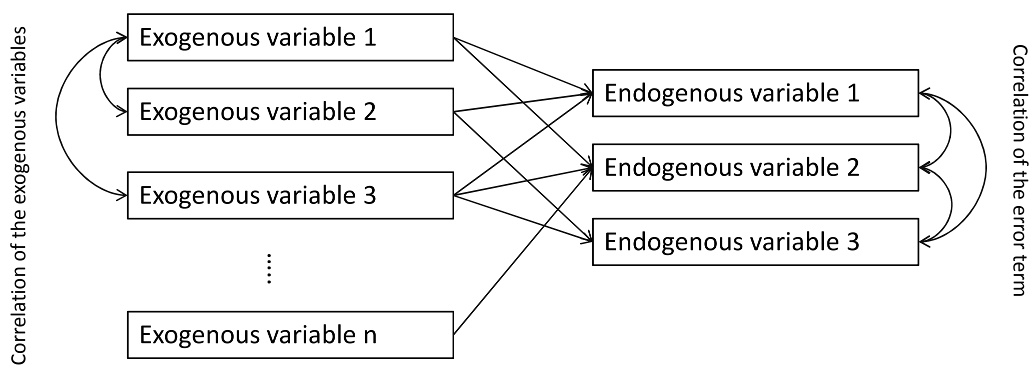
The structural equations approach (Bollen (1989)) is a confirmation method for testing and quantifying assumed causal relationships between various factors. The general formulation is as follows:

$$y = By + \Gamma x + \zeta \quad (18)$$

where y is an m x 1 vector of endogenous variables, B an m x m matrix of coefficients associated with the right-side endogenous variables, x and n x 1 vector of exogenous variables, Γ and m x n matrix of coefficients associated with the exogenous variables, and ζ and m x 1 vector of error terms associated with the endogenous variables.

The chart in Figure 22 represents the causal effects implied by the basic models. The model assumes direct causal relationships between a number of dependent variables and the independent endogenous variables, while considering the error correlation structure both between exogenous and endogenous variables.

Figure 22: SEM approach



D.2.2 Estimation

The SEM was fitted using the AMOS 7.0 software package (Byrne (2001)). SEM fitting is performed using a covariance-based structural analysis, also referred to as the method of moments (MoM), consisting of minimizing the difference between actual sample covariances and those implied by the model parameters (Bollen (1989)). Various optimization techniques are available for estimating structural equation models. In the AMOS software package, computing intercepts for the endogenous variables is only feasible when using the maximum likelihood approach. As the literature (seeKuppam and Pendyala (2001); Golob (2003)) finds only marginally changing values for the estimated coefficients between this method and the asymptotically distribution-free method (ADF), which one would ideally apply to such a problem, the maximum likelihood method (MLE) is used for estimation. As AMOS does not allow accounting for panel data, such information could not be included in the analysis.

D.2.3 Result interpretation, elasticity and further derivatives

Given the model formulation in Figure 9 the point elasticity of the independent variable y_k (consumption of fuel type k) is given by:

$$\epsilon = \frac{\partial y_k}{\partial x} \cdot \frac{x}{y_k} \tag{19}$$

Therefore, the elasticity value is dependent on both the value of the dependent and independent variables.

E SP1: Tested basic models

Table 33: SP2: Experiment Plan, Stage I

Model type	Model form		AIC
Quadratic	$Y_i =$	$C_i + \beta_{ActY_i} * ActY_i + \beta_{P_i} * P + \beta_{P_i^2} * P^2 +$ $\beta_{PI_i} * PI + \beta_{I_i} * I + \beta_{I_i^2} * I^2, i = G, D$	45776.9
Translog	$ln(Y_i) =$	$C_i + \beta_{ActY_i} * ln(ActY_i) + \beta_{P_i} * ln(P) +$ $\beta_{P_i^2} * ln(P)ln(P) + \beta_{I_i^2} * ln(I)ln(I) +$ $\beta_{PI_i} * ln(P)ln(I), i = G, D$	25728.3
Cobb-Douglas	$ln(Y_i) =$	$C_i + \beta_{ActY_i} * ln(ActY_i) + \beta_{P_i} * ln(P) +$ $\beta_{I_i} * ln(I) +$	25815.7

F SEM: Considered error term correlation

Table 34: Considered error term correlation in the SEM

	Gasoline consumption	Diesel consumption	Nat. gas consumption	Electr. consumption	PT mileage	Fuel costs	Income/average income	Res. Rural	Res. Agglo	Res. City	Age/average age	Male	Adults	Employement percentage	Big car	Car paid	Number of GA	Number of Half Fare cards	Number of SC	Milege PT * 1000
Gasoline consumption		X	X*	X	X*															
Diesel consumption	X		X*	X*	X*															
Nat. gas consumption	X*			X*	X						X		X							X
Electr. consumption	X	X*	X*		X*															
PT mileage	X*	X*	X	X*						X	X	X	X	X			X	X	X	
Fuel costs																				
Income/average income													X		X	X				
Res. Rural									X	X		X	X	X		X				
Res. Agglo								X		X	X		X	X	X					
Res. City					X			X	X		X	X	X	X			X	X		X
Age/average age			X		X				X	X			X	X	X		X	X	X	X
Male					X			X		X			X	X						X
Adults			X		X		X	X	X	X	X	X		X	X		X	X	X	X
Employement percentage					X			X	X	X	X	X	X		X			X		X
Big car							X		X		X		X	X		X		X		
Car paid							X	X							X					
Number of GA					X					X	X		X					X		X
Number of Half Fare cards					X					X	X		X	X	X		X			X
Number of SC					X						X		X							X
Milege PT * 1000			X							X	X	X	X	X			X	X	X	

X*=not significant and therefore rejected

G SBB study

G.1 Motivation and objectives for consideration in this report

Given the increase of fuel prices in 2008 and 2009, the Swiss Federal Railways (SBB) commissioned the IVT to do a study to analyze Short- and long-term demand reactions to substantial transport price changes (Fuel prices up to a level of 5 CHF/l, public transport costs up to 50%). The emphasis of the study was on public transport.

The data to estimate demand reactions was collected with two types of stated choice experiments:

- Short-term reactions: In the mode choice experiment, the respondent had to choose between a car and a public transport alternative. Both alternatives were based on a reported trip but travel times and costs were altered.
- Long-term reaction: In the mobility tool ownership experiment, the respondent had to choose between two sets of mobility tools to satisfy his mobility needs.

As the survey was conducted paper-based, the mobility tool ownership experiment could only be designed as a stated choice survey. Thus, appraisals of desired mobility tool ownership (type of car and/or season ticket) and usage (mileage) needed to be predetermined. Though it is argued that this survey methodology can produce reliable results concerning public transport season ticket ownership, its relevance when estimating long-term fuel price elasticity is restricted.

In addition, the survey sample is not representative in terms of considered trip distribution and sociodemographic characteristics for the Swiss population and therefore needed to be reweighted for this report.

G.2 Mode choice experiment

G.2.1 Survey design

The basis of the mode choice experiment was reported car or public transport trips (in case of no reported car trip) from the KEP (continuous travel survey of SBB). For each trip, the most likely route was generated by employing the Swiss national road transport model Vrtic *et al.* (2005) (car trips) and by an automated query of the public transport timetable.

Based on these routes, the choice alternatives were specified by multiplying the alternative specific attributes with the different factors given in Table 35. How to combine these factors most efficiently in order to obtain reliable statistical models for an experiment plan was elaborated using the specialized software NGENE.

In the paper-based survey, each respondent was asked to state his choice for six situations.

Table 35: Attribute characteristics of the mode choice experiment

Alternative	Variable	Characteristics
Car	Travel time	Sum of travel time under free flow and congestion
	Travel time free flow	-10%, 0%, +10% compared to today's value
	Travel time congested	0%, 10%, 20% of the free flow travel time
	Fuel costs	-10%, +50%, +100%, +150% of today's value
Public transport	Travel time	sum of in-vehicle and transfer time
	In-vehicle time	-10%, 0%, +10% of today's value
	Transfer time	0, 10, 15 minutes
	Transfer frequency	0, 1 times
	Costs	-10%, +20%, +50% of today's value

G.2.2 Modeling

From a basis model with only linear utility terms, the model was extended by adding non-linear interaction terms to capture the influence of non-alternative specific variables, such as income or the interaction between alternative specific variables. Additionally, cost and travel time sensitivity were considered by travel purpose specifically (commuting, business, leisure, shopping). Similar modeling approaches had already been successfully used in practice as the examples of Mackie *et al.* (2003) and Hess *et al.* (2008) show. The general form of such interaction terms is given by:

$$f(y,x) = \beta_x * \left(\frac{y}{\bar{y}}\right)^{\lambda_{y,x}} \cdot x, \tag{20}$$

with:

x	observed variable, e.g., travel time, travel cost
β_x	linear utility parameters of the observed variable x

y	observed value of the interacting variable, e.g., income, trip distance
$\overline{y}$	reference value of the variable y
$\lambda_{y,x}$	elasticity of the utility depending on the value of variable y

The choice of the reference value of $\overline{y}$ is arbitrary and has no influence on the value of the estimated parameter λ nor the model fit. However, for the ease of interpretation of the model results, it is common to use the median or average value of y in the sample. Thus, the parameter β_x can be directly interpreted without considering the $\lambda_{y,x}$-parameter since for any $\lambda_{y,x}$, the term $\left(\frac{y}{\overline{y}}\right)^{\lambda_{y,x}}$ equals 1.

The utility functions of the recommended statistical model take the following form:

$$\begin{aligned}
V_{\text{car}} = {} & \beta_{\text{car}} * \text{car} + \beta_{\text{male}} * \text{male} + \sum_j \beta_{\text{age}_j} * \text{age}_j + \beta_{\text{occ}} * \text{occupation} \\
& + \beta_{n_{\text{car}}} * n_{\text{car}} + \sum_k \beta_{\text{muntype}_k} * \text{municipality-type}_k \\
& + \beta_{\text{car-availability}} * \text{car-availability} + \beta_{\text{cong}} * \text{congestion} \\
& + \sum_i \text{purpose}_i * \beta_{\text{cost,i}} * \left(\frac{inc}{\overline{\overline{inc}}}\right)^{\lambda_{inc,cost,i,car}} * \left(\frac{dist}{\overline{\overline{dist}}}\right)^{\lambda_{dist,cost,i,car}} * \text{cost}_{\text{car}} \\
& + \sum_i \text{purpose}_i * \beta_{\text{travel time}_{\text{car}},\text{i}} * \left(\frac{inc}{\overline{\overline{inc}}}\right)^{\lambda_{inc,tt,i,car}} * \text{travel time}_{\text{car}}
\end{aligned} \tag{21}$$

and

$$\begin{aligned}
V_{\text{pt}} = {} & \beta_{\text{Half Fare}} * \text{Half Fare} + \beta_{\text{GA}} * \text{GA} + \beta_{\text{Transfer}} * \text{Transfer} + \beta_{\text{Wait}} * \text{Wait} \\
& + \sum_i \text{purpose}_i * \beta_{\text{cost,i}} * \left(\frac{inc}{\overline{\overline{inc}}}\right)^{\lambda_{inc,cost,i,pt}} * \left(\frac{dist}{\overline{\overline{dist}}}\right)^{\lambda_{dist,cost,i,pt}} * \text{cost}_{\text{pt}} \\
& + \sum_i \text{purpose}_i * \beta_{\text{travel time}_{\text{pt}},i} * \left(\frac{inc}{\overline{\overline{inc}}}\right)^{\lambda_{inc,tt,i,pt}} * \text{travel time}_{\text{pt}}
\end{aligned} \tag{22}$$

with:

car	= 1, if car is chosen for the reported trip
male	= 1, if the respondent is male, else 0
age_j	= 1, if the respondent belongs to age category j, else 0
occupation	= 1, if the respondent works at least part-time, else 0

municipality type$_k$	= 1, if the respondent lives in a municipality of type k, else 0
car availability	= 1, if the respondent's car is always available, else 0
Half Fare	= 1, if the respondent owns a Half Fare ticket, else 0
GA	= 1, if the respondent owns a season ticket, else 0
congestion	= percentage of the trip in congested traffic
transfer	= number of transfers
Wait	= waiting time during the transfer
purpose$_i$	= 1, if the indicated travel purpose matches the trip purpose category i
cost$_{\text{car}}$	= cost of the car alternative
travel$_{\text{car}}$	= travel time of the car alternative
cost$_{\text{pt}}$	= cost of the public transport alternative
travel$_{\text{pt}}$	= travel time of the public transport alternative
$\left(\frac{inc}{\overline{inc}}\right)^{\lambda_{inc,cost,i,j}}$	= interaction term income-cost for traffic purpose i
$\left(\frac{inc}{\overline{inc}}\right)^{\lambda_{inc,tt,i,j}}$	= interaction term income-travel time for traffic purpose i and mode j
$\left(\frac{dist}{\overline{dist}}\right)^{\lambda_{dist,cost,i,j}}$	= interaction term traveled distance-cost for traffic purpose i

G.2.3 Results

The estimated parameters which fit the data best according to the given utility function are summarized in Table 36. Non-significant variables are not listed. For clarity purposes, only the results of the non-purpose-specific models are presented in this section.

Table 36: Resulting parameters that fit the data best, according to the mode choice experiment (Equation 21 and 22

)

Alternative	Variable	Parameter	Value	t-stat
Common	Costs	β_{costs}	-0.041	-7.15
		$\lambda_{\text{income,costs}}$	-0.417	-3.71
Car	Inertia	β_{car}	1.51	12.34
	Travel time	$\beta_{\text{travel time,car}}$	-0.036	-11.96
		$\lambda_{\text{dist,travel time\_car}}$	-0.305	-6.6
	Share of congestion	$\beta_{\text{congestion}}$	-1.29	-2.54
	Car availability	$\beta_{\text{car availability}}$	0.228	2.88
ÖV	Travel time	$\beta_{\text{travel time,public transport}}$	-0.019	-9.52
		$\lambda_{\text{dist,travel time\_pt}}$	-0.263	-4.68
	Transfer	β_{transfer}	-0.355	-2.67
	Waiting time	$\beta_{\text{waiting time}}$	-0.014	-1.24
	Half Fare card	$\beta_{\text{Half Fare card}}$	1.25	12.67
	GA	β_{GA}	1.81	12.08
				$Adj.\rho^2$=0.282

All parameters show the expected sign and also the relative proportions of the parameters are of the same magnitude as similar Swiss studies suggested. According to the model fit indicator, the model shows sufficient explanation power. It is remarked, that the $Adj.\rho^2$-statistic of Logit models cannot be directly compared to R^2-statistic of regression models as they are defined differently, based on a different estimation methodology. The $Adj.\rho^2$ gives the relation between LogLikelihood of the estimated model and the LogLikelihood of a model with all parameters set to zero while the R^2-statistic stands for the proportion of variability in a data set that is explained by the statistical model. The negative λ_{inc} parameter indicates that negative perception of costs decreases with increasing income. The same applies to the relation between distance and cost: the higher the trip distance, the lower the perception of the associated cost.

For purposes of clarity, in this report only the results for non-purpose-specific results are presented. However, Weis and Axhausen (2009) estimated purpose-specific models allowing purpose-specific elasticities to be indicated. It turned out that price elasticity for the trip purposes commuting and shopping are significantly lower than for leisure.

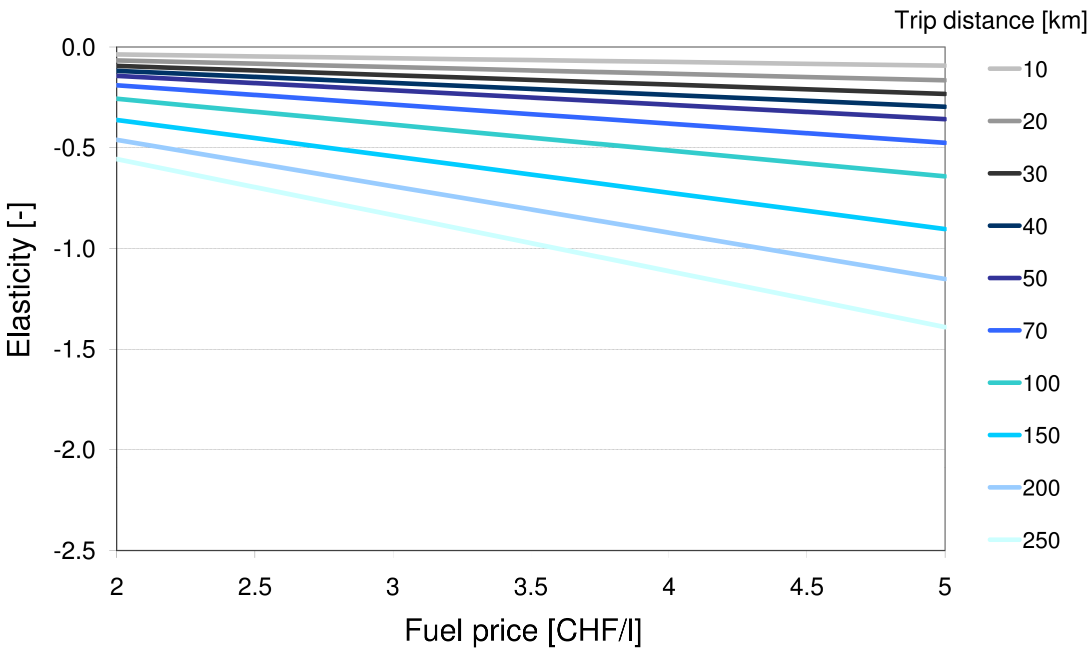
G.2.4 Elasticities

According to the formulation of the utility term (Equation 21), choice probability elasticities can be calculated for several variables. However, in this study, but also in the report of Weis and Axhausen (2009), the analysis is restricted to price elasticities. The additional terms to capture the influence of trip distance and income on the cost perception act simply as an additional multiplicand of the β parameter. Hence, the elasticity formula stated in Equation 13 extends to:

$$E_{X_{ikq}}^{P_{iq}} = \beta_{ik} \cdot \left(\frac{y}{\overline{y}}\right)^{\lambda_{y,x}} \cdot X_{ikq} \cdot (1 - P_{iq}), \tag{23}$$

Accordingly, the elasticity depends on income and trip distance and its distribution has to be considered when indicating an average elasticity. As a result, one can indicate the price elasticity depending on income and trip distance. Figure 23 shows fuel-price elasticity in dependence on trip distance for car trips for the average income of the sample. Price elasticity increases with higher costs, but decreases with lower trip distances. For the highest considered fuel price of 5 CHF/l, the elasticity ranges from -0.2 up to -1.5, depending on trip distance. Based on a wider range of fuel price increases, these values indicate a higher sensitivity than earlier studies (e.g., Vrtic *et al.* (2007), where the fuel price was kept in a more modest range.)

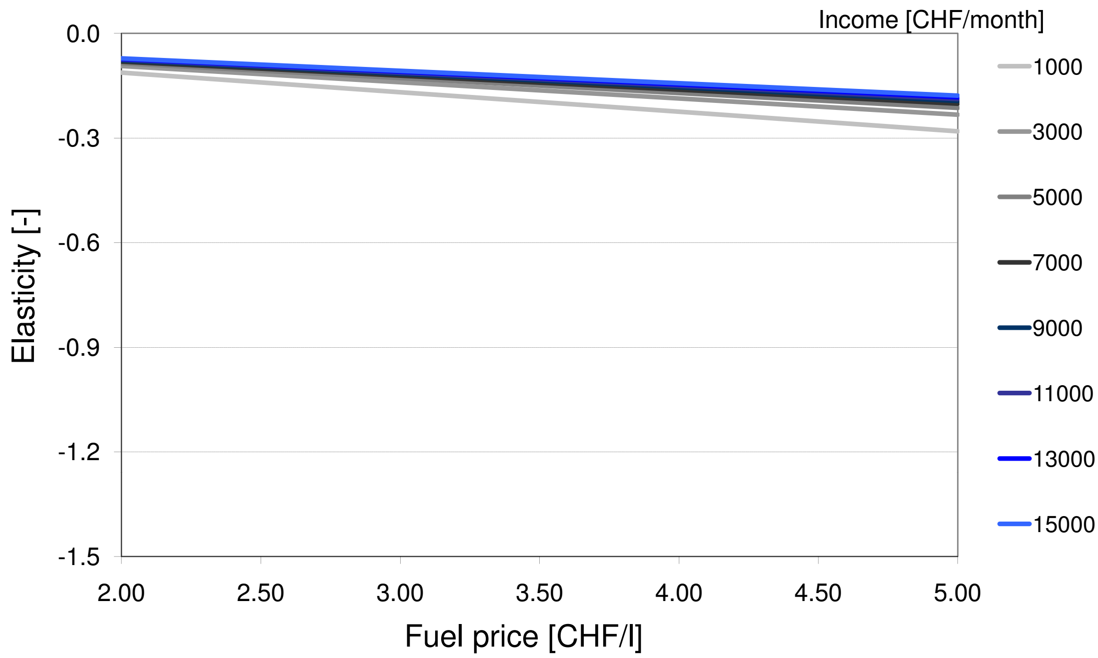
Figure 23: Fuel price elasticity depending on trip distance for an average income according to the MNL-model results reported in Table 36 and Equation 23



Given a relevant fuel price during the study of 2 CHF/l, the resulting price elasticity ranges between -0.1 and -0.6, depending on the trip distance.

Figure 24 shows the fuel price elasticity depending on income for car trips for the average trip distance in the sample (28.8 km). The elasticity increases with lower income and higher fuel prices. However, the income sensitivity is rather low, especially when compared to the sensitivity to fuel price levels and trip distances as shown in Figure 23.

Figure 24: Fuel price elasticity depending on income for an average trip distance of 28.8 km according to the MNL-model results reported in Table 36 and Equation 23



G.2.5 Reweighting

As the sample is not representative for both trip distances and income, the results need to be reweighted. Therefore, twenty distance and eight income classes were defined and representatively weighted according to the Swiss Federal Statistical Office (2006). The average value of the elasticity is then given by:

$$x = \sum_{i}^{20} \sum_{j}^{8} w_{i,j} \cdot x_{i,j}, \tag{24}$$

with:

i	distance class i
j	income class j
y	observed value of the interacting variable, e.g., income, trip distance
$w_{i,j}$	weight of distance class i and income class j
$x_{i,j}$	variable value (here elasticity) for distance class i and

income class j

The average car trip distance in the *Mikrozenus Verkehr 2005* is 9.75 km. As Figure 23 shows, fuel price elasticity for short trips is rather small. Accordingly, the representative average elasticities reported in table 37 also range between -0.04 and -0.17, depending on the trip purpose. These values correspond very well with the short-term fuel price elasticity reported by Baranzini *et al.* (2009), which confirms the validity of the stated preference approach.

Table 37: Weighted (trip distance and income) fuel price elasticity

Trip purpose	Elasticity
All	-0.1
Commuting	-0.1
Shopping	-0.04
Business	-0.17
Leisure	-0.1

G.3 SBB study: mobility tool choice experiment

G.3.1 Survey design

The second experiment was designed to analyze people's responses to increasing fuel prices in terms of their mobility tool ownership. Figure 25 shows such a choice situation from the questionnaire. Given a certain pricing scheme, the respondents had to choose between two given bundles of mobility tools with given usage. One alternative always consisted of the reported mobility tools bundle with the costs reflecting the new price regime. The second alternative was a new car with lower consumption but higher fixed costs. Additionally, a certain part of the car mileage was reallocated to public transport and the public transport season ticket, which minimized the total public transport costs for the given mileage. As a result, the respondent was prohibited from changing the total (car and public transport) mileage.

Figure 25: SBB study: Mobility tool choice experiment example

Verhalten	**wie bisher**	**alternativ**
ÖV-Abonnement	Halbtax	GA
ÖV-Abokosten	250.- CHF / Jahr	4500.- CHF / Jahr
ÖV-Fahrleistung	9000 km / Jahr	22000 km / Jahr
	(= ca. 30 %)	(= ca. 70 %)
ÖV-Kosten total	2200.- CHF / Jahr	4500.- CHF / Jahr
PW	wie bisher	neu
Benzinverbrauch	6.0 Liter / 100 km	5.4 Liter / 100 km
Fixe Kosten	600.- CHF / Jahr	700.- CHF / Jahr
PW-Fahrleistung	22000 km / Jahr	9000 km / Jahr
	(= ca. 70 %)	(= ca. 30 %)
Benzinkosten *	4200.- CHF / Jahr	1600.- CHF / Jahr
PW-Kosten total	4800.- CHF / Jahr	2300.- CHF / Jahr
Mobilitätskosten total	7100.- CHF / Jahr	6800.- CHF / Jahr

← Ihre Wahl →

* Ergibt sich aus einem angenommenen Benzinpreis von 3.20 CHF / Liter.

The characteristics of the experiment plan are similar to the mode choice experiment and reported in Table 38. Again, the respondents had to state their choice for six given situations.

Table 38: Attribute characteristics of the mobility tools choice experiment

Mode	Variable	Characteristics
Public transport	Costs	-10%, +20%, +50%
	Share of the total mileage	10%, 30%, 70%
Car	Fixed costs	+20%, +60%
	Fuel price	-10%, +60%, +140%
	Consumption	-25%, -10%

G.3.2 Modeling

The data from the mobility tool ownership questionnaire is again analyzed using multinominal logit models. The utility function consists of a linear combination of all variables listed on the questionnaire, inertia variables to comprise the influence of the present mobility tools fleet and sociodemographic variables:

$$\begin{aligned}
V_{\text{Old}} = Const &+ c_{\text{SameSeasonTicket}} + \beta_{\text{HalfFare}} * \text{HalfFare}_{\text{Old}} + \beta_{\text{GA}} * \text{GA}_{\text{Old}} \\
&+ \beta_{\text{SeasonTicketCost}} * \text{SeasonTicketCost}_{\text{Old}} + \beta_{\text{CarFixedCost}} * \text{CarFixedCost}_{\text{Old}} \\
&+ \beta_{\text{PTVariableCost}} * \text{PTVariableCost}_{\text{Old}} + \beta_{\text{PTVariableCost}} * \text{PTVariableCost}_{\text{Old}} \\
&+ \beta_{\text{PTMileage}} * \text{PTMileage}_{\text{Old}} + \beta_{\text{CarConsumption}} * \text{CarConsumption}_{\text{Old}} \\
V_{\text{New}} = c_{\text{SameSeasonTicket}} &* \text{SameSeasonTicket}_{\text{New}} + \beta_{\text{HalfFare}} * \text{HalfFare}_{\text{New}} + \beta_{\text{GA}} * \text{GA}_{\text{New}} \\
&+ \beta_{\text{SeasonTicketCost}} * \text{SeasonTicketCost}_{\text{New}} + \beta_{\text{CarFixedCost}} * \text{CarFixedCost}_{\text{New}} \\
&+ \beta_{\text{PTMileage}} * \text{PTMileage}_{\text{New}} + \beta_{\text{CarConsumption}} * \text{CarConsumption}_{\text{New}} \\
&+ \beta_{\text{PTVariableCost}} * \text{PTVariableCost}_{\text{New}} + \beta_{\text{PTVariableCost}} * \text{PTVariableCost}_{\text{New}} \\
&+ \beta_{\text{FuelPrice}} * \text{FuelPrice} + \beta_{\text{AgeCar}_{\text{Old}}} * \text{AgeCar}_{\text{Old}}
\end{aligned} \tag{25}$$

$\text{SameSeasonTicket}_{\text{New}}$	= 1, if the season ticket of the new alternative is the same as the one currently owned
Half-Fare	= 1, if the a Half-Fare card is part of the accoutrement, else 0
GA	= 1, if a GA is part of the accoutrement, else 0
$\text{SeasonTicketCost}_i$	= cost of the season ticket of alternative i (in 1,000 CHF)
PTVarCost_i	= public transport variable costs of alternative i (in 1,000 CHF)
CarFixedCost_i	= fixed car costs of alternative i (in 1,000 CHF)

CarVarCost_i	= variable car costs (only fuel) of alternative i (in 1,000 CHF)
PTMileage	= mileage by public transport of alternative i (in 1,000 km)
Consumption	= fuel consumption of the car in alternative i ($l/100km$)
FuelPrice	= price of fuel for the given choice situation (CHF$/l$)
Age_{Car}	= age of the car currently owned by the respondent

G.3.3 Results

Table 39: Model results of the mobility tool ownership experiment

Variable	Parameter	Parameter value	t-stat
Constant (old set of mobility tools)	$Const$	2.293	6.17
Standard dev. of error term	σ	1.997	16.18
Constant same season ticket	$c_{\text{SameSeasonTicket}}$	0.643	4.98
Half-Fare	$\beta_{\text{Half-Fare}}$	0.11	0.7
GA	β_{GA}	1.192	2.02
Season ticket costs	$\beta_{\text{SeasonTicketCost}}$	-0.313	-2.03
Public transport variable costs	$\beta_{\text{PTVariableCost}}$	-0.038	-0.51
Car fixed costs	$\beta_{\text{CarFixedCost}}$	-0.912	-9.7
Car variable costs (fuel costs)	$\beta_{\text{CarVariableCost}}$	-0.242	-6.4
Public transport mileage	$\beta_{\text{PTMileage}}$	-0.049	-2.95
Fuel price	$\beta_{\text{FuelPrice}}$	0.351	-3
Consumption	$\beta_{\text{Consumption}}$	-0.292	6.76
Age of the currently owned car	β_{AgeCar}	0.033	1.51
			$Adj.\rho^2$=0.266

All inertia parameters are positive, indicating that the respondents tend to keep their current choice of mobility tools. However, the respondents also reacted to price regime changes as the significant cost parameters show. Interestingly, fixed car costs are perceived around three times more negatively than the equivalent for public transport (season ticket costs).

In addition, a mileage shift from car to public transport is negatively evaluated. The same applies to fuel consumption. The positive value of the parameter for fuel price indicates that with higher fuel prices, the respondents were more likely to choose the new alternative (featuring a more energy-efficient car). Additionally, the likelihood of choosing the alternative of a new car is higher for people with older cars.

G.3.4 Elasticities

The computation of elasticities derived from the mobility tool ownership experiment is not as straightforward as in the case of the mode choice experiment. First, the decision for mobility tool ownership is highly dependent on the overall travel demand of an individual and the travel mode which satisfies this demand (modal split). When constructing the choice experiment, certain assumptions were made about reasonable mileage shares, depending on the mobility tools offered. However, to indicate representative elasticities, one has to consider the real distribution of mileage and mobility tool ownership, which leads to the second reason for the complexity of this computation: No information about yearly mileage for either public transport or private motorized traffic on an individual level could be found in any representative Swiss travel survey.

Hence, a pseudo-distribution of the yearly daily driven mileage based on the trips reported in the *Mikrozensus Verkehr 2005* Swiss Federal Statistical Office (2006) was generated by aggregating the reported trip length during a given day subject to the following variables:

- 9 income classes
- Gender
- 3 types of employment
- 5 age classes
- 5 spatial types of residence
- Ownership of Half-Fare card
- Ownership of a GA

To calculate the distribution of the yearly mileage, the average daily mileage of each combination was then multiplied by 365. In a next step, the yearly mileage was separated into 16 distance classes and for every class, both the modal split of the average public transport and car mileage was evaluated for individuals with Half-Fare, GA and non-season tickets. Then, the season ticket ownership probabilities can be calculated using the parameters indicated in Table 39. To reproduce the current General Abonnement and Half-Fare card-holding rates, the model was calibrated by adjusting the GA and Half-Fare constants.

The elasticities are again given by Formula 13 and have to be indicated in every class for Half-Fare and GA subscribers separately. Since the mobility tool ownership is not evenly distributed over the different mileage classes, and whereas elasticity depends directly on the mileage class, the sample needs to be reweighted according to the following equation:

$$E_j = \frac{\sum_i^{16} e_{ij} * w_{ij}}{\sum_i^{16} w_{ij}}, \tag{26}$$

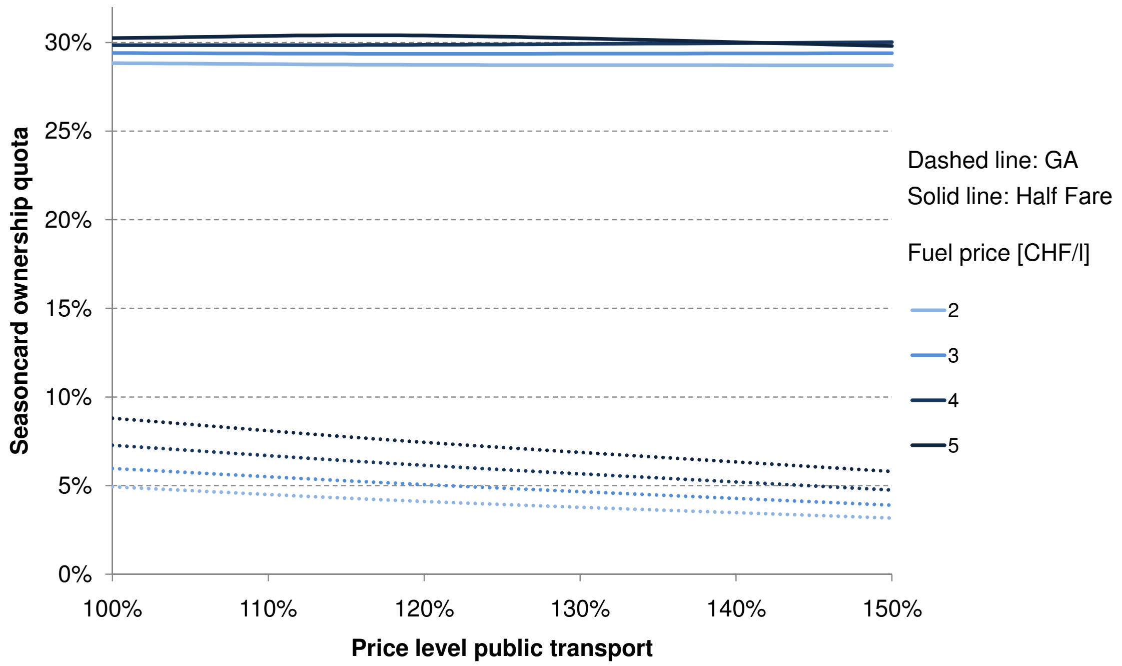
with:

i	distance class i
j	mobility tool type j
$e_{i,j}$	elasticity for distance class i and mobility tool ownership j
$w_{i,j}$	weight of all individuals for distance class i owning mobility tool j

Since the choice probabilities, and hence elasticities, depend on price level, this procedure was run for the different fuel and public transport price levels as given in Table 38.

Figure 26 shows the expected market shares of Half-Fare cards and the General Abonnement (GA), an all-Switzerland travel pass, for different fuel and public transport price levels. Obviously, GA ownership reacts to price changes more than Half-Fare card ownership. There are two reasons for this: First, the Half-Fare card is the economically most efficient season ticket for individuals intending to travel between 1,000 km and 21,000 km per year by public transport, albeit the public transport price level (given that the price of season tickets increases at the same rate as ticket costs). As a result, people will only reevaluate their ownership status when they decide to travel either less than 1,000 km or more than 21,000 km. Second, Half-Fare card owners spend less money on public transport tickets compared to their overall transport costs. According to the pseudo-distribution of mileage generated based on the *Mikrozensus Verkehr 2005* data, for Half-Fare card owners, the average yearly mileage traveled by public transport is 2,908 km, which corresponds to an average mode share of 16.5%. This makes it clear that the Half-Fare card acts as a complement to other mobility tools (car/regional season ticket). Compared to overall transport costs, the money spent to purchase a Half-Fare card and travel the average mileage of 2,908 km (557 CHF/year) is rather low, wherefore some individuals might neglect it.

Figure 26: Expected season ticket market shares for different fuel price levels according to the results of the mobility tool experiment (Equation 25)



The elasticities of season ticket ownership with respect to its prices and cross-elasticities with respect to fuel prices are shown in Figures 27, 28, 29 and 30. As expected, price elasticity for the Half-Fare card is much lower than that for the GA. In contrast, the cross-price elasticities are higher for the Half-Fare card. This is because the GA is only efficient if one travels more than 21,000 km a year by public transport, which is also reflected by the comparatively low market share of nearly 5%. Higher prices have an increasing effect on both elasticity and cross-elasticity. This is given by the non-linearity of the logit function, which shows the highest elasticity for alternatives with equal utilities.

Since appraisals of desired mobility tool ownership (type of cars and/or season ticket) and usage (mileage) needed to be predetermined, its relevance is restricted when estimating long-term fuel price elasticity. Therefore, the survey of this project includes *stated adaptation* experiments, where the respondents indicate their preferred type of car and its usage according to the stated fuel price.

Figure 27: GA: Price elasticity according to the results of the mobility tool experiment (Equation 25)

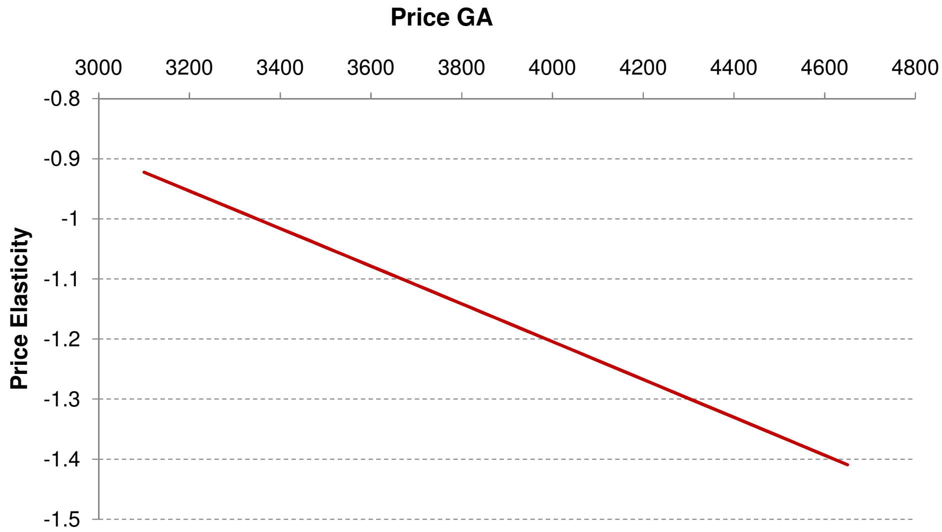


Figure 28: Half-Fare card: Price elasticity according to the results of the mobility tool experiment (Equation 25)

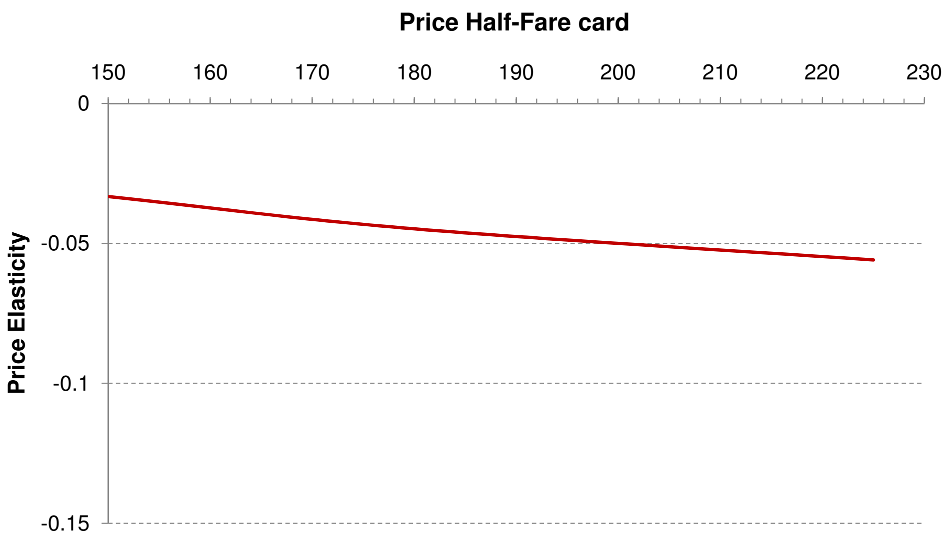


Figure 29: GA: Cross-price elasticity of fuel costs according to the results of the mobility tool experiment (Equation 25)

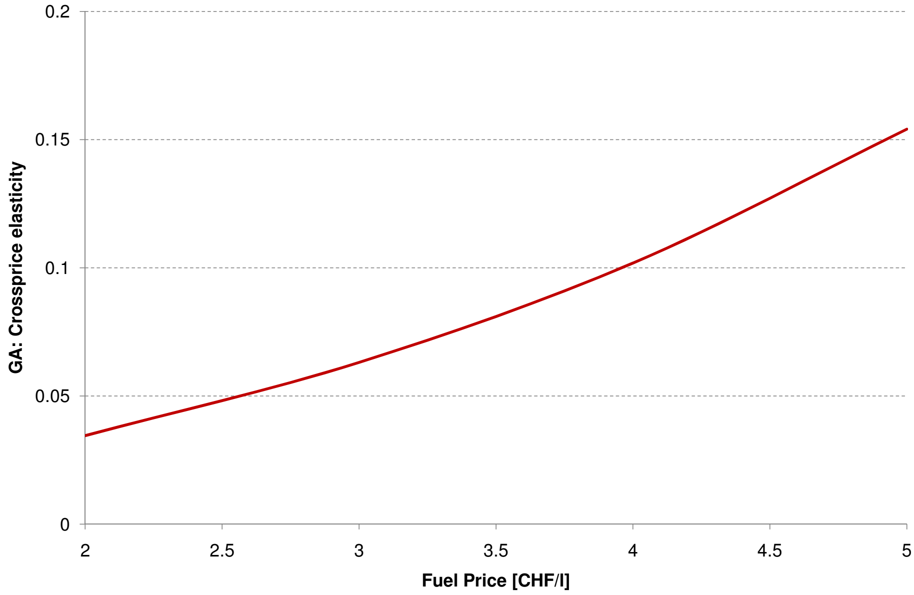


Figure 30: Half-Fare card: Cross-price elasticity of fuel costs according to the results of the mobility tool experiment (Equation 25)