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Consumer Demand System Estimation and Value Added Tax Reforms in the Czech Republic*

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Abstract

The value added tax (VAT) rates have recently changed in the Czech Republic, and in this paper I simulate the impact of these reforms. They are an example of changes in indirect taxes that change the prices of goods and services, to which households can respond by adjusting their expenditures. I first estimate the behavioral response of consumers to price changes in the Czech Republic by applying a consumer demand model of the Quadratic Almost Ideal Demand System (QUAIDS) on the basis of the Czech Statistical Office household expenditure and price data for the period from 2001 to 2011. I derive estimates of own- and cross-price and income elasticities for individual households. I then use these elasticities to estimate the impact of the changes in VAT rates that were proposed or implemented between 2011 and 2013 on households' quantity demanded and government revenues. One of the main findings is that the estimated increases in government revenues that take the consumer responses into account are more than a quarter lower than the estimates that use the static simulation.

1. Introduction

Value added tax (VAT) is one of the most important taxes in the Czech Republic, as well as in the rest of the developed world. The impact of changes in VAT depends on the microeconomic behavior of consumers and my objective here is to shed more light on the behavioral responses of Czech consumers to tax rate changes.

A rigorous analysis of the impact is particularly pertinent in the Czech Republic since the reduced and standard VAT rates have recently gone through important changes. They were, respectively, 10% and 20% in 2011, 14% and 20% in 2012, and—after a last-minute change from the previously approved unification of rates at 17.5%—a one percentage point increase in both rates to 15% and 21% in 2013.

The existing impact evaluations of these VAT reforms have, at best, made use of microeconomic data and first order approximations such as Dušek and Janský (2012a) and Dušek and Janský (2012b). However, these studies used a static micro-

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simulation with no behavioral response and did not properly account for the potential for consumers to substitute goods as relative prices change, as discussed by Banks et al. (1996). In the case of VAT rate increases, this might cause over-estimation of the effects of VAT rate increases on government revenues.

For a more rigorous analysis it is useful to have detailed knowledge of consumers' individual preferences, about which, however, information is not readily available. So as a first step, this paper derives second order approximations which do not display systematic biases as shown in Banks et al. (1996), but which, in contrast to first order approximations, require knowledge of the elasticities. Specifically, I estimate the Quadratic Almost Ideal Demand System (QUAIDS) as developed by Banks et al. (1997).

The QUAIDS model was previously estimated for the Czech Republic by Dybczak et al. (2010) to derive elasticities and analyze the impact of regulated price changes on consumer demand. The QUAIDS model has also been applied in the analysis of VAT reforms in the UK by Crawford et al. (2010) and Mexico by Abramovsky et al. (2012). Therefore, to the best of my knowledge, this is the second QUAIDS model for the Czech Republic and the first QUAIDS model built specifically for the analysis of tax policy in the Czech Republic.

The model employs household expenditure and demographic data from the Household Budget Survey (HBS) and price data from the consumer price index (CPI), both from the Czech Statistical Office (CZSO). This demand system differs from the existing models for the Czech Republic in terms of the consumer price information used. Regarding prices, I rely solely on the CPI, rather than on the HBS.

I have chosen to classify expenditure so that it reflects not only functional groupings (e.g. food, clothes) but also identifies goods and services that incur different VAT rates. I thus apply an approach similar to that of Abramovsky et al. (2012), who pioneered the use of the QUAIDS to analyze the impacts of VAT changes. The estimated price and income elasticities appear plausible in magnitude and sign. For instance, food is found to be a necessity while eating out is found to be a luxury. Strong luxuries include transport and recreation and household goods. This categorization and these estimates of elasticities, together with a simple microeconomic simulator, enable me to estimate how consumers respond to changes in VAT rates and the implications for consumers' spending patterns, quantity demanded and government tax revenues.

I then use this model to simulate the recent VAT reforms. In line with Banks et al. (1996) and similarly to previous research by Crawford et al. (2010) and Abramovsky et al. (2012), I find that for the Czech Republic too, allowing for behavioral response makes a difference to estimates of tax revenues, which are lower in comparison to the estimates produced by a first order approximation holding behavior fixed, specifically the static micro-simulation model that did not allow for any behavioral response and held the quantity of purchases fixed (nominal rise or fall of expenditures in line with the rise or fall in VAT rates).

The layout of the paper is as follows: Section 2 provides a brief literature review. In Section 3, I discuss methodology including the theoretical consumer demand model. In the *Appendix* I show the derivation of the formulae for the estimation of elasticities. In Section 3 I further describe the data and explain the simulation of the model. Section 4 presents the results especially in the form of the estimated elasticities. Section 5 discusses the application of the model's results to the evaluation of recent changes in VAT rates. It also shows the impact of these on households and government revenues. Section 6 provides a conclusion.

2. Literature Review

The literature on consumer demand and VAT is quite extensive and I will therefore focus on only three areas. First, I briefly introduce the most important contributions to demand system estimation. Second, I discuss existing articles that estimate demand systems for the Czech Republic. Third, I provide an overview of the literature on the impacts of VAT in the Czech Republic.

Stone (1954) first pioneered the estimation of a demand system based on consumer preferences theory; specifically, he estimated linear expenditure systems as developed by Klein and Rubin (1947). A number of improvements have been elaborated and proposed over the decades. One demand system that is often estimated nowadays is the Almost Ideal Demand System (AIDS) developed by Deaton and Muellbauer (1980). The Quadratic Almost Ideal Demand System (QUAIDS), developed by Banks et al. (1997), is essentially a version of AIDS that allows Engel curves to be quadratic. Furthermore, Poi (2002) and Poi (2008) are useful introductions to estimating the QUAIDS using the STATA software, as I do here. Recent applications of the QUAIDS model similar to those used in this paper are Crawford et al. (2010), who present estimates of the impact of a hypothetical unification of VAT rates in the UK and also discuss the implications of VAT for labor market participation based on UK data, and Abramovsky et al. (2012), who evaluate Mexican tax reform.

Second, demand systems have recently been estimated for the Czech Republic, most notably in two research papers. Using the AIDS in a modification by Edgerton (1996), Janda et al. (2010) estimated elasticities focusing on alcoholic beverages and found, for example, a very low own-price elasticity of demand for beer. Dybczak et al. (2010) were the first to estimate the QUAIDS for the Czech Republic and divide expenditure into eight categories—food, clothing, energy, housing, health, transport, education and other—that do not, however, align with VAT rates (as do the categories used in this paper). They estimated own- and cross-price and income elasticities and used them to analyze the impact of changes in regulated prices on consumer demand. In addition, a number of studies, such as Dubovicka et al. (1997) and Janda et al. (2000), have focused on estimating Czech food demand elasticities using flexible function forms, to which both the AIDS and QUAIDS also belong. Last, but not least, Crawford et al. (2004) developed a new method for the estimation of price reactions and applied it to the Czech data. By estimating the QUAIDS model with the most recent data and for the purposes of indirect tax policy analysis, I contribute to the existing literature on demand system estimation in the Czech Republic, most notably Dybczak et al. (2010).

Third, a short overview of VAT in the Czech Republic and the related literature: the Czech Republic introduced VAT in 1993, and it applies to most household expenditures at one of its two rates. In recent years the reduced and standard rates have been, respectively, 10% and 20% in 2011, 14% and 20% in 2012, and in 2013 —after a last-minute change from the previously approved unification of rates at

17.5%—the government increased both its reduced and standard rates by one percentage point to 15% and 21%, respectively. VAT and changes thereof in the Czech Republic have been studied by Schneider (2004), who analyzed the tax burden of households and found VAT to be relatively regressive, and more recently by Klazar et al. (2006), who use a micro simulation model to estimate incidence of taxes but without the use of elasticities, and by Klazar et al. (2007), who focused on the impact of EU-accession related harmonization of VAT rates. Klazar and Slintáková (2010) studied VAT in the Czech Republic and its impact on households, and found VAT to be regressive when annual income is analyzed, though their lifetime income analysis indicated that VAT is progressive.

Most recently Dušek and Janský (2012a) and Dušek and Janský (2012b) used a simple static micro-simulator—without using a demand system and accounting for behavioral response to VAT changes as I do in this paper—to provide the first independent estimates of the impact of the recently proposed VAT rate changes in the Czech Republic on the living standards of households as well as on the government's tax revenues. One objective of this paper is to compare the results of analysis of these VAT reforms according to whether behavioral change is taken into account or not. By accounting for behavioral response in tax policy analysis and showing the differences in the result when compared with the static micro-simulation methodology that holds fixed the quantity of goods and services purchased, I contribute to the existing literature on simulation of VAT reforms in the Czech Republic (see Dušek and Janský, 2012a and Dušek and Janský, 2012b).

3. Methodology

I estimate the demand system according to the Quadratic Almost Ideal Demand System form developed in Banks et al. (1997) and I further use this for indirect tax policy analysis, as proposed by Banks et al. (1996) and applied in Crawford et al. (2010) and Abramovsky et al. (2012). The QUAIDS model allows me to take consumers' substitution responses into account when relative prices change due to VAT reforms, whereas this is the first such model built in the Czech Republic specifically for the analysis of tax policy.

3.1 QUAIDS

The model is based on an indirect utility function from which the shares of expenditure on various categories of goods and services are derived, and these are then updated with demographic characteristics. Similarly as in the only QUAIDS previously estimated for the Czech Republic by Dybczak et al. (2010), demand depends not only on prices and incomes, but also on other household characteristics such as the size of the household or the employment status or age of the household's head. It is estimated by seemingly unrelated regression equations with parameter restrictions so that the estimated demand system satisfies the conditions of adding-up, homogeneity, symmetry and negativity (negative semi-definiteness).[1]

The QUAIDS model is a generalization of the Almost Ideal Demand System (AIDS) model that allows for quadratic Engel curves. The QUAIDS can therefore

[1] The model does not allow for positive or negative externalities from expenditure on certain goods and this assumption of no externalities is a limitation on the usefulness of the QUAIDS when looking at the effects of excise duties on goods with negative externalities such as fuel or tobacco.

allow a good to be a luxury at one level of income and a necessity at another, a property that Banks et al. (1997) found to be of empirical relevance for the UK and they also showed that it is sufficient for the nonlinear term to be a quadratic in log income.[2] This was documented for the Czech Republic by Dybczak et al. (2010).

Here I briefly introduce the QUAIDS model, essentially as developed and presented by Banks et al. (1997), but I do so in a more complete way, including the derivation of the elasticities, in the *Appendix*. The QUAIDS model is based on the following indirect utility[3]:

$$\ln V = \left\{ \left[\frac{\ln x - \ln a(p)}{b(p)} \right]^{-1} + \lambda(p) \right\}^{-1}$$

Where x is total expenditure, p stands for prices, $a(p)$, $b(p)$ and $\lambda(p)$ are defined as:

$$\ln a(p) = \alpha_0 + \sum_i \alpha_i \ln(p_i) + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln(p_i) \ln(p_j)$$

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

$$\ln \lambda(p) = \sum_{i=1}^{n} \lambda_i \ln(p_i)$$

where $i = 1,..., n$ denotes a good, ln $a(p)$ is the translog price aggregator function, and $b(p)$ is defined as the simple Cobb-Douglas price aggregator.

Applying Roy's identity to the equation for ln $a(p)$, I have the following equations for w_i, the share of expenditure on good i in total expenditure for each household:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(p_j) + \beta_i \ln\left(\frac{x}{a(p)}\right) + \frac{\lambda_i}{b(p)}\left(\ln \frac{x}{a(p)}\right)^2$$

These equations are the subject of the estimation by seemingly unrelated regression equations.

3.2 Data

To estimate the QUAIDS model I employ the best available data for the Czech Republic in the form of two datasets from the Czech Statistical Office (CZSO). The Household Budget Survey (HBS) is a representative sample of approximately 3,000 Czech households collected on a yearly basis.[4] For each of them, the HBS contains information on how much they spend on various goods and services (around 250 expenditure items), who they are (around 60 demographic

[2] Some studies identified the importance of further terms in income for some, but not all, expenditure share equations before Banks et al. (1997); see for example Atkinson et al. (1990) or Blundell et al. (1993) and Banks et al. (1997) for further discussion and references.

[3] The same indirect utility function defines the AIDS model, but with the $\lambda(p)$ term set to zero.

variables) and how they earn their income (around 30 income items).[5] The HBS has been applied to the estimation of demand systems by both Janda et al. (2010) and Dybczak et al. (2010) and it was also used by Crawford et al. (2004).[6] In terms of the years, there is a trade-off between the amount of data and their quality and consistency; I resolve this issue by using 11 years. I employ data for the period between 2001 and 2011.[7] Therefore I have data from approximately 33,000 households in total and I assume this to be a representative sample for the Czech Republic.

I use CZSO price data, gathered for the purpose of the consumer price index (CPI), that are classified into approximately 150 categories according to the classification of individual consumption by purpose (COICOP).[8] The price information is available for the Czech Republic as a whole and separately for the country's capital city, Prague.

I rely on the CPI as the sole source of price information; this is in contrast to Janda et al. (2010), who used the HBS not only as a source of expenditure information, but also as a source of price information. Specifically, they divided the expenditures by the quantity of purchased goods and services. In this way they derived unit values and used them as prices. Their approach has some advantages of relatively easily obtaining expenditure- and household-specific prices and of having these in a very detailed form, i.e. as detailed as the HBS expenditure data, which might

[4] The CZSO gathered the HBS data in such a way that only the data for the period 2006–2011 can be considered, after applying the supplied weights, to be representative of the overall Czech population. However, as some preliminary robustness checks did not find significant differences between the two periods and since Dybczak et al. (2010) showed the same, I conclude that there is no significant risk in using the data for the longer period for the purpose of estimating a demand system. Still, some concerns remain and although treatment of the potential problems of this nature is largely beyond the scope of this paper, I will briefly review them here. The CZSO was criticized for failing to provide the full HBS dataset to European Union representatives (Eurostat 2009). Furthermore, as Crawford and Smith (2002) discuss, systematic over- or under-reporting of expenditures can occur in this type of data collection due to forgetfulness (e.g., consumption outside the home), active concealment (e.g., a receipt from a beauty salon) and guilt (e.g., cigarettes). This kind of problems is also discussed in Svátková (2006) and Klazar et al. (2006).

[5] One of the problems mentioned by Crawford and Smith (2002) that may occur in the Czech HBS is that, since some expenditures are recorded monthly, large and infrequent purchases may be underestimated. This is one of the reasons why I exclude housing from the expenditure data, both purchase and rent (the corresponding HBS codes in the 2011 data are 4010, 4080, 5440, 5550), with a further reason being that relatively high and infrequent housing expenditures would likely distort the model estimation. By excluding housing expenditures, I am also excluding their potential implications for wealth and, consequently, purchasing decisions of the households. This is a common approach in the existing literature, for example Banks et al. (1997).

[6] One of the drawbacks of the HBS is that the data are gathered by purposive quota sampling and although the designers of the survey have made efforts to make it as similar to a random sample as possible, its characteristics are not the same as those of a random sample. One implication of this suboptimal sampling is that results based on the data might be biased. However, my use of the data is in line with the efforts of the CZSO to make the sample resemble a random sample as closely as possible and with previous uses of the data, such as by Dybczak et al. (2010).

[7] This period includes the recent economic crisis, which could influence consumption decisions. I was able to do only a very preliminary analysis of the crisis's influence (also due to data limitations) and I therefore leave the related questions for further research, likely similar to that conducted by Crossley et al. (2013) for the United Kingdom.

[8] Some prices are regulated in the Czech Republic, either nationally (healthcare fees) or locally (waste disposal service charges) and would therefore arguably require special treatment, which I however do not provide here due to the complexity of such an exercise and because the share of regulated prices is relatively low.

Table 1 Demographic and Other Variables Used in the Demand System

Variable	Description
Child	= number of children
Members	= number of household members
Age	= age of the head of household
Sex	= 1 if the head of the household is female, 0 otherwise
Employment status	= 1 if the head of the household is employed, 0 otherwise
Education–low	= 1 if the head of the household has primary education or less, 0 otherwise
Education—middle	= 1 if the head of the household has secondary education, 0 otherwise
City size	= 1 for regional capitals, = 2 for cities, 3 = for villages
Praha	= 1 if the household resides in the capital city, Praha, 0 otherwise
Time trend	= year of the survey (implemented as 2012 minus the year of the survey)

improve the precision of elasticity estimates. However, it can be inaccurate in some cases, while another drawback is that the HBS data for the quantity of purchased goods and services is incomplete. Dybczak et al. (2010) combine the two datasets, whereas they fill in missing price information in the HBS data from the CPI.

There is an obvious trade-off between these two sources of price information and there are three main reasons why I opt to use the CPI as my source of prices. First, differences in unit values can be caused by product quality differences, rather than by the price differences that I aim to study. With these unit values it is almost impossible to distinguish between the influence of changes in price and in quality, since risk observed price variation may instead reflect variations in quality. By using the CPI data, I limit the extent of this problem. Second, the HBS only includes information on the quantity of purchased goods and services for a limited number of expenditure items. Unit values can thus only be constructed for those goods for which quantity information is available. Therefore, if I used the HBS data for prices, I would need to limit my analysis to a small subset of overall expenditures, as Janda et al. (2010) did, or alternatively fill in the HBS unit values whenever these are not available using the CPI prices, as was done by Dybczak et al. (2010). In contrast to Janda et al. (2010), I prefer to analyze as high a share of overall household consumption as possible, and this is made possible by applying the CPI data. In contrast to Dybczak et al. (2010), I prefer the consistency of using only one complete source for information on prices, namely the CPI.

In the expenditure share equations estimated in the QUAIDS, I include a time trend and a number of demographic variables to take account of preference variation that may be correlated with total expenditure or prices in a way that is consistent with the model. *Table 1* provides a list of these variables.

I classify the HBS expenditure data according to the VAT rates, reduced and standard, presented in the appendices to the VAT Act as of January 2013. When HBS classification is not detailed enough to allow accurate division according to the VAT rate or when some expenditures are exempted from VAT, I assign the HBS expenditures to a group according to the VAT rate. I merge the HBS and CPI data using the HBS codes and COICOP codes and, although these two classifications do not

Table 2 Expenditure Groups and Their Average Shares in 2011

Group	Expenditure	VAT rate	Average share in the sum of these expenditures (%)
1	Food	Reduced	24.4
2	Eating out and other luxuries	Standard	10.7
3	Household goods	Standard	7.5
4	Clothing	Standard	6.2
5	Other services	Reduced	16.0
6	Transport and recreation	Standard	11.5
7	Energy	Standard	11.9
8	Other goods	Standard	11.9

always match perfectly and both of them have undergone revisions over time, no substantial compromises had to be made during the matching process.

In order to estimate the QUAIDS, I divided the detailed expenditure items into eight groups. I followed three principles while grouping the expenditure items, and in this I differ from the previously estimated demand systems for the Czech Republic. First, the division should correspond to natural categories as people might think about them, which was essentially the case in Dybczak et al. (2010). Second, the expenditure groups should be similar in size, which is advantageous both for the estimation of the model and for the interpretation of the results. Third and most importantly for my analysis, the expenditure groups should be divided according to the VAT rate as the greatest extent possible. A number of compromises had to be made when following these three principles, and when considering these, I have given highest priority to the third principle. I calculate the price indices of aggregated commodities as weighted arithmetic averages of the price indices of the individual goods and services making up the aggregated commodity for each year, and then aggregate them for each household to arrive at overall expenditure group-, household- and year-specific price indices. *Table 2* provides the names and shares in total expenditures of the eight expenditure groups for 2011. A more detailed description can be found in *Table A1* in *the Appendix* and basic summary statistics in *Table A2* in *the Appendix*. I use this categorization of expenditures into groups in my estimation.

3.3 Estimation

The estimation of QUAIDS is made in two stages and applies the approach of Abramovsky et al. (2012).[9] At the first stage of the estimation, the values of $a(p)$ and

[9] There are a number of different ways by which to estimate QUAIDS and similar models and it would be desirable to explore these options for the Czech Republic in future research. These options include variations in the expenditures included and excluded in the demand system (such as the exclusion of housing in most demand systems, including this estimation), the number of expenditure groups and division of goods among these groups, whether and how to deal with the outliers, whether to include taste shifters and demographic characteristics and if so which ones, what time period and frequency to cover, whether to use unit value prices or other, external prices, and what methods of computing elasticities (using a weighted average, as in this estimation, or a representative or average household) to employ, and whether to use a homogeneous or representative sample of the population.

$b(p)$ are unknown to me and therefore I approximate $b(p)$ as 1 and ln$a(p)$, using the Stone price index named after Stone (1954)as $\ln p^* \approx \sum_i w_i \ln p_i$.

The QUAIDS is linear in parameters conditional upon the price indices and therefore I can and do employ a linear seemingly unrelated regression (SUR) method to estimate the model. Adding-up is imposed by excluding the equation for the n-th good from the estimated system of equations; the parameters for this equation are calculated using the parameters from the other (n–1) equations and the adding-up restrictions (the results are not sensitive to the choice of the nth good). Homogeneity (by expressing all prices relative to the price of the other remaining goods) and symmetry are imposed using linear restrictions on the parameters.

The parameters estimated at the first stage are then used to calculate values for $a(p)$ and $b(p)$. The model is then re-estimated using the same specification as in the first stage, except that p^* is replaced with $a(p)$ and λ_i with $\frac{\lambda_i}{b(p)}$. The new parameter values are used to update $a(p)$ and $b(p)$, and the model is then re-estimated for a third time. This updating of price indices and re-estimation is iterated eight times, by which time the parameter values have converged to four decimal places.

I instrument for expenditure using monetary income because it may be endogenous. I do so using a control function approach as is common in the literature and as applied in Banks et al. (1997) and Abramovsky et al. (2012).[10] I calculate standard errors using bootstrapping with 1,300 iterations, with clustering at the household level.

4. Demand System Results

This section discusses the results of the estimated demand system. *Table 3* below presents the parameter estimates for the QUAIDS and the estimated parameters correspond to equation number 1 above. The table uses asterisks to indicate the statistical significance of the estimates, which is rather low and I discuss this problem below with regard to elasticities. It is difficult to interpret the parameters of the QUAIDS directly and I therefore mainly discuss the elasticities, as is also common in the existing literature. Specifically, I present the estimates of income, own- and cross-price elasticities.

I calculate the elasticities for each household individually and I subsequently construct a weighted average, with the weights being equal to the household's share of the total expenditure and to the total sample expenditure for the relevant good, for the income and price elasticities, respectively.

Table 4 presents the income elasticities, estimated using the total expenditure variable. For comparison, the table shows also the own-price elasticities, both the Marshallian (uncompensated) and the Hicksian (compensated), which are shown again together with the cross-price elasticities shown in *Tables 5* and *6*. Sections 8.2–8.5 in the *Appendix* include the elasticities formulas used in *Tables 4* to *6*.

[10] Specifically, I regress the log of total expenditure (ln$x$) and the square of the log of total expenditure $(\ln x)^2$ on the prices and demographic variables included in the demand system and on the log of household monetary income and the square of the log of household monetary income, and I include linear, square and cubic terms of the residuals from these regressions in our demand system equations.

Table 3 QUAIDS Parameter Estimates for the Czech Republic

	Food	Eating out	Household goods	Clothing	Other services	Transport, recreation	Energy	Other goods
α	0.034629	0.129872***	0.146827***	0.095397***	0.142082***	0.296177***	0.027498	0.127519***
α_{age}	0.001327***	-0.000792***	-0.000679***	-0.000576***	0.000644***	-0.001347***	0.001123***	0.000300***
α_{member}	0.049455***	-0.000453	-0.018151***	-0.007281***	-0.010875***	-0.017419***	0.013783***	-0.009059***
α_{child}	- 0.012259***	-0.017422***	0.005543***	0.005970***	0.023873***	0.001021	-0.008192***	0.001467*
$\alpha_{empstat}$	-0.004928***	0.014813***	-0.014546***	0.008293***	0.003614**	-0.015708***	0.008814***	-0.000350
$\alpha_{educlow}$	0.013543***	0.005296***	0.002189**	-0.004761***	-0.016510***	-0.001317	0.000541	0.001019
$\alpha_{educmid}$	0.006367***	0.005712***	0.001941*	-0.003052***	-0.008226***	-0.001056	-0.004179***	0.002493***
α_{Praha}	0.003985***	0.000245	-0.012013***	-0.004137***	-0.010341***	-0.000307	0.010270***	0.012298***
$\alpha_{city\ size}$	0.002271***	-0.005977***	0.000127	-0.002026***	-0.037137***	0.008055***	0.030973***	0.003715***
γ_1	0.128462***	0.001691	0.006585	-0.022831**	-0.005289	-0.058485***	-0.044166***	-0.005967
γ_2	0.001691	-0.021096	0.016954	-0.017499	0.049918	-0.000690	-0.021749	-0.007529
γ_3	0.006585	0.016954	-0.046039	-0.001063	0.003730	0.032677	0.002452	-0.015295
γ_4	-0.022831**	-0.017499	-0.001063	0.035773*	-0.023621	0.018662	0.032879***	-0.022300**
γ_5	-0.005289	0.049918	0.003730	-0.023621	0.000290	-0.016791	-0.020636	0.012399
γ_6	-0.058485***	-0.000690	0.032677	0.018662	-0.016791	0.060468**	-0.021107	-0.014734
γ_7	-0.044166***	-0.021749	0.002452	0.032879***	-0.020636	-0.021107	0.070200***	0.002126
γ_8	-0.005967	-0.007529	-0.015295	-0.022300**	0.012399	-0.014734	0.002126	0.051301***

	Food	Eating out	Household goods	Clothing	Other services	Transport, recreation	Energy	Other goods
β	-0.161067***	0.012994***	0.073417***	0.028031***	-0.027351***	0.147496***	-0.062735***	-0.010784
λ	-0.014765***	0.001109	0.001045	0.003093***	0.003548*	0.013542***	-0.002783*	-0.004790
Time trend	-0.001333	0.000404	0.005687***	0.000695	-0.000581	-0.001944	-0.003641***	0.000713
V 1	0.187960***	-0.034971	0.052232	0.062695**	0.069491	-0.701702***	0.312978	0.051318
V 2	-0.079719*	0.182203***	0.242166***	0.110696***	-0.038433	-0.515080***	0.006774	0.091394
V 3	-0.065040***	0.060609***	0.088550***	0.038058***	-0.009418	-0.117508***	-0.026025	0.030774
V 4	-0.006439**	0.000790	-0.002883	-0.003132***	-0.003261	0.028565***	-0.011619	-0.002021
V 5	0.000061	-0.000360***	-0.000400***	-0.000221***	0.000002	0.001088***	-0.000026	-0.000144
V 6	0.000004***	-0.000005***	-0.000007***	-0.000004***	0.000000	0.000012***	0.000002	-0.000002

Notes: The parameters V1–6 relate to the linear, square and cubic terms of the residuals from two regressions as described in footnote number 9. The cells with parameters are complemented with asterisks in line with their significance: *** implies significance at the 1% level, ** implies significance at the 5% level and * implies significance at the 10% level.

Table 4 Income and Own-Price Elasticities

Group	Expenditure	Income elasticity	Marshallian own-price elasticities	Hicksian own-price elasticities
1	Food	0.419	-0.311*	-0.194
2	Eating out and other luxuries	1.100***	-1.202	-1.081
3	Household goods	1.794***	-1.540***	-1.366***
4	Clothing	1.295	-0.533	-0.431
5	Other services	0.724*	-0.966*	-0.851
6	Transport and recreation	2.097	-0.738***	-0.414
7	Energy	0.445	-0.186	-0.139
8	Other goods	0.991***	-0.522***	-0.413***

Notes: The cells with parameters are complemented with asterisks in line with their significance: *** implies significance at the 1% level, ** implies significance at the 5% level and * implies significance at the 10% level.

Table 5 Marshallian (Uncompensated) Price Elasticities

Group	Food	Eating out and other luxuries	Household goods	Clothing	Other services	Transport and recreation	Energy	Other goods
Food	-0.311*	-0.010	-0.134	-0.385	0.036	-0.597*	-0.306	-0.062
Eating out and other luxuries	0.053	-1.202	0.116	-0.260	0.382	-0.069	-0.179	-0.070
Household goods	0.079	0.147	-1.540***	-0.039	0.046	0.148	0.080	-0.139
Clothing	-0.059	-0.168	-0.059	-0.533	-0.156	0.071	0.390	-0.206**
Other services	0.045	0.447	-0.053	-0.354	-0.966*	-0.209	-0.144	0.115
Transport and recreation	-0.156*	-0.023	0.221	0.190	-0.086	-0.738***	-0.134	-0.128
Energy	-0.127*	-0.211	-0.063	0.413	-0.117	-0.231	-0.186	0.017
Other goods	0.025	-0.078	-0.228	-0.329	0.114	-0.171	0.079	-0.522***

Notes: The cells with parameters are complemented with asterisks in line with their significance: *** implies significance at the 1% level, ** implies significance at the 5% level and * implies significance at the 10% level.

Only half of the income elasticities are statistically significant at least at the 10% level. More optimistically, the estimated income elasticities seem reasonable. Other services, which include public services, are necessities and the same holds for other goods, although these have an income elasticity of just below 1. Food and energy are both necessities, albeit not statistically significant. So both expenditure groups with the reduced VAT rate—food and other services—are necessities. Eating out, clothing, household goods and transport and recreation all have income elasticity greater than 1 and are therefore considered luxuries.

The patterns of income elasticities are relatively comparable to those estimated by Dybczak et al. (2010). Food and energy are in both cases expenditure groups with the lowest income elasticity, while transport has the highest income elasticity.

Table 6 Hicksian (Compensated) Price Elasticities

Group	Food	Eating out and other luxuries	Household goods	Clothing	Other services	Transport and recreation	Energy	Other goods
Food	-0.194	0.243	0.257	-0.092	0.214	-0.214	-0.206	0.170*
Eating out and other luxuries	0.100	-1.081	0.304	-0.121	0.464	0.120	-0.139	0.038
Household goods	0.117*	0.253	-1.366***	0.088	0.115	0.331**	0.113	-0.045
Clothing	-0.026	-0.082	0.078	-0.431	-0.098	0.211*	0.416	-0.131
Other services	0.111	0.603	0.187	-0.175	-0.851	0.029	-0.090	0.256
Transport and recreation	-0.101	0.135	0.492**	0.397	0.013	-0.414	-0.079	0.013
Energy	-0.080	-0.112	0.091	0.526	-0.050	-0.081	-0.139	0.112
Other goods	0.073	0.040	-0.042	-0.192	0.195	0.018	0.123	-0.413***

Notes: The cells with parameters are complemented with asterisks in line with their significance: *** implies significance at the 1% level, ** implies significance at the 5% level and * implies significance at the 10% level.

Tables 5 and *6* show the Marshallian (uncompensated) and the Hicksian (compensated) price elasticities, respectively. Own-price elasticities are on the diagonal and cross-price elasticities off the diagonal.[11]

Statistical significance is depicted by asterisks and the elasticities are largely statistically insignificant at the standard levels.[12] Somewhat more optimistically, most Marshallian own-price elasticities are statistically significant at least at the 10% level and this is one of the supporting reasons why I use these for simulations in the next chapter. Fortunately, the confidence intervals of the simulated impacts of tax changes on demand and revenues are relatively narrow despite the low statistical power of the elasticities. The reason for this is that the restrictions the QUAIDS model imposes on the elasticities causes them to be negatively correlated, which results in lower variance when I combine them in the simulation estimates.

Both *Tables 5* and *6* show that all own-price elasticities are negative and this observation is in line with basic economic intuition. As far as the own-price elasticity of demands is concerned, food and energy are among the least elastic, whereas other services and goods and transport and recreation are among the most elastic. The patterns of cross-price elasticities and therefore substitution and complemen-

[11] The tables show the elasticities of a good in the column with respect to price changes of the good in the row. For example for Hicksian (compensated) cross-price elasticities, the number of the column corresponds to the *i* and the number of the row to the *k* in the following equation: $\epsilon_{ik}^{c} = \epsilon_{ik}^{u} + \epsilon_{i} w_{j}$. An elasticity provides information on the percentage change in quantity demanded for a good in the row.

[12] Regretfully, there are no easy remedies. One straightforward, but not currently applicable, solution to low statistical power seems to be to get hold of better data, specifically waiting until more years of data, which should ideally be more detailed, become available. There is more potential for greater detail in the data. For example, regional price indices and quarterly expenditure data would ease the estimation by allowing it to be carried out for 14 regions on a quarterly basis in contrast to two regions on an annual basis.

tarity seem reasonable. For example, food and eating out are substitutes. Not surprisingly, cross-price elasticities are mostly relatively small and smaller than own-price elasticities.

Despite different definitions of expenditure groups and some differences between the estimated Marshallian and Hicksian elasticities, there is some scope for comparison between these elasticities and those earlier estimated for the Czech Republic by Dybczak et al. (2010) also using the QUAIDS model. Food and other goods are in both cases among the expenditure groups with the lowest own-price elasticity. There is a difference in price elasticities for energy with my very low estimates in contrast with the relatively high values determined by Dybczak et al. (2010) and this might signal the need for further, more focused research in energy-related products and related prices.

5. Simulation of Value Added Tax Reforms

This section applies the demand system results for tax policy simulation. In the case of the Czech Republic, there are a number of recent changes in VAT rates suitable for simulation. The reduced and standard VAT rates were, respectively, 10% and 20% in 2011, the last year for which data are available. Then in 2012, the rates were 14% and 20% and these were increased by one percentage point to 15% and 21% in 2013. Furthermore, there was another proposal, initially legislated and then postponed in late 2012 until 2016, that in 2013 the two rates would be unified at 17.5%.[13] The objective of this simulation is to evaluate the latest reform, namely the increase in both rates by one percentage point in 2013, and compare this with the unification proposal.

The last available year of data is from 2011, when the VAT rates were 10% and 20%, and therefore I first simulate the expenditures under the VAT rates of 14% and 20% that were in place in 2012 and establish that as the status quo. Based on this, I then simulate the outcome in 2013 in order to estimate the changes between 2012 and 2013 and compare these with the unification proposal.

I use the estimated elasticities to simulate the impacts of VAT reforms on consumer spending patterns and tax revenues. For this I use the Marshallian elasticities. Specifically, I estimate the impact of the implied change in prices for each household and expenditure group individually. Estimates incorporating such behavioral response are then compared to those based on the no-behavioral-response static micro-simulation results. When using the demand system results for these purposes, I model changes in VAT rates as changes in the prices of the eight aggregate expenditure groups used in the QUAIDS demand system. Also on the basis of

[13] A more detailed description of recent changes in VAT rates follows. Until 2011, the reduced VAT rate was 10% and the standard VAT rate was 20%. The 2011 law introduced two changes to the VAT rates to be implemented in 2012 and 2013. First, there was an increase in the reduced rate to 14% in 2012, while the standard rate remained at 20%. Second, the unification of both VAT rates at 17.5% was due to be implemented in 2013. However, in November and December 2012 another new law was approved which changed the VAT rates for 2013 so that both VAT rates increased from the 2012 levels by one percentage point, to 15% and 21% for the reduced and standard VAT rates, respectively. According to the law and the Ministry of Finance of the Czech Republic (2011), the unification of VAT rates at 17.5% should eventually happen, but only from 2016. Furthermore, VAT rates have become an important political issue since 2010 and it seems relatively likely that further changes will be made after the last general election held in October 2013.

Table 7 Simulated Average Expenditure Shares after Changes in VAT rates (%)

Group	Expenditure	2012 (14% and 20%)	2013 realised reform (15% and 21%)	2013 proposed reform (17.5% and 17.5%)
1	Food^R	24.9	25.1	25.5
2	Eating out and other luxuries^S	10.9	10.8	11.1
3	Household goods^S	7.4	7.4	7.5
4	Clothing^S	6.2	6.0	5.8
5	Other services^R	16.1	16.1	16.0
6	Transport and recreation^S	10.9	11.0	10.8
7	Energy^S	11.7	11.7	11.4
8	Other goods^S	11.9	11.9	11.9
	Total	100	100	100

Notes: The superscript R and S denote the reduced and standard VAT rates, respectively.

the discussion in Dušek and Janský (2012a), I assume that changes in VAT rates are fully reflected in prices. This assumption is more likely to be fulfilled in the long term rather than the short term, and this should be taken into account when interpreting the results.

Table 7 shows simulated estimates of average expenditure shares after the 2012 as well as 2013—including the earlier proposal—VAT rate changes. Overall, neither the 2012 nor 2013 approved VAT changes have a very substantial impact on spending patterns; the expenditure shares change only in terms of tenths of a percent. The simulation of the introduction of a uniform 17.5% VAT rate suggests a larger and more varied impact, which is not surprising due to the fact that this implies a greater change in both rates in terms of percentage points and the fact that the two rates move in opposite directions. In particular, the share of food, on which the reduced VAT rate is currently levied, increases substantially by more than half a percentage point, reflecting its low own-price elasticity of demand, while the share of other goods generally falls.[14]

Table 8 shows estimates of simulated changes in the quantity demanded in terms of the percentage of total expenditure for the two VAT rate proposals in 2013. *Table 8* includes confidence intervals, which I estimated on the basis of bootstrapped estimates of elasticities. These confidence intervals are relatively narrow, especially for the implemented 2013 reform, and generally narrower than the statistical significance of the elasticities would suggest.

I find that increasing both VAT rates by one percentage point to 15% and 21%, respectively, results in relatively small decreases in the quantity demanded, with the extent of the impact mostly corresponding with the income as well as own-price elasticities. For example, the groups that decreased the most—both household

[14] However, the approximately 2.4% (0.6 percentage point) increase in the share of food from the 2012 level is less than the 3.1% increase in the price of food following the imposition of VAT, implying the quantity of food purchased would be lower if VAT was imposed at the unified rate.

Table 8 Simulated Average Percentage Changes in the Quantity Demanded in 2013 after changes in VAT rates from the 2012 baseline (%)

Group	Expenditure	2013 realised reform (15% and 21%)	QUAIDS 95% confidence interval		2013 proposed reform (17.5% and 17.5%)	QUAIDS 95% confidence interval	
1	Food^R	-0.40	-0.41	-0.38	-0.49	-1.57	0.59
2	Eating out and other luxuries^S	-0.89	-0.95	-0.84	4.58	-1.21	10.37
3	Household goods^S	-1.74	-1.82	-1.67	3.07	-3.69	9.84
4	Clothing^S	-1.17	-1.22	-1.12	-2.14	-6.71	2.44
5	Other services^R	-0.67	-0.71	-0.63	-3.24	-6.79	0.32
6	Transport and recreation^S	-2.18	-2.25	-2.10	-3.12	-7.61	1.37
7	Energy^S	-0.42	-0.45	-0.38	-1.10	-3.61	1.41
8	Other goods^S	-0.85	-0.88	-0.82	2.30	0.49	4.11
	Total	-0.87	-0.87	-0.87	-0.10	-0.15	-0.05

Notes: The superscript R and S denote the reduced and standard VAT rates, respectively.

goods and transport and recreation, each by around 2%—also have the highest income elasticities and some of the highest own-price elasticities. The opposite pattern also holds: the groups that decreased the least—both food and energy, by 0.4%—also have the lowest income elasticities and lowest own-price elasticities. The estimated impacts for the unification proposal are once again more varied. The overall impact on quantity demanded is only slightly negative, with the largest decline, of 3.2%, for other services and the largest increase, of 4.6%, for eating out.

Table 9 shows simulation results for government revenues corresponding to the VAT rate changes, which are estimated on the basis of a sample of Czech households extrapolated for the whole population of the Czech Republic. These estimates necessarily reflect only the VAT levied on household consumption and, since the impact in other sectors is not taken into account, do not reflect the overall impact on government revenues. Furthermore, I do not model any administrative savings or lower levels of tax evasion that the unification of rates might bring about.

The first part of *Table 9* shows the results for the implemented proposal (15% and 21%), the second part for the repealed 2013 proposal (unified VAT rate of 17.5%).

In each of the two parts of *Table 9*, the first column shows the estimated revenues from the reforms using a static micro-simulation not allowing for any behavioral response and holding the quantity of purchases fixed. This is a similar approach to that used in Dušek and Janský (2012a), i.e. no results from the QUAIDS model were employed to simulate these impacts. The second column uses the QUAIDS results to allow for spending patterns changing in response to the price changes, similarly to *Tables 7* and *8*. The third and fourth columns report their confidence intervals, which I estimated on the basis of bootstrapped estimates of elasticities. The confidence intervals are relatively narrow for most estimates, especially for the implemented 2013 reform. This is somewhat more encouraging from the point of

Table 9 Effect of Consumer Demand Response on Revenues from Changes in VAT Rates (CZK billion)

Group	Expenditure	2013 realised reform (15% and 21%)	2013 realised reform (15% and 21%)	2013 realised reform (15% and 21%)	2013 realised reform (15% and 21%)
		No behavioural response	*QUAIDS*	*QUAIDS 95% confidence interval*	
1	Food[R]	2.31	1.86	1.84	1.88
2	Eating out and other luxuries[S]	1.04	0.73	0.70	0.76
3	Household goods[S]	0.84	0.48	0.46	0.51
4	Clothing[S]	0.65	0.53	0.40	0.65
5	Other services[R]	1.53	1.13	1.09	1.17
6	Transport and recreation[S]	1.49	0.88	0.86	0.90
7	Energy[S]	0.97	0.74	0.71	0.77
8	Other goods[S]	1.11	0.78	0.76	0.80
	Total	9.95	7.13	6.99	7.27

Group	Expenditure	2013 proposed reform (17.5% and 17.5%)	2013 proposed reform (17.5% and 17.5%)	2013 proposed reform (17.5% and 17.5%)	2013 proposed reform (17.5% and 17.5%)
		No behavioural response	*QUAIDS*	*QUAIDS 95% confidence interval*	
1	Food[R]	8.25	6.78	6.33	7.23
2	Eating out and other luxuries[S]	-2.54	-1.53	-2.48	-5.88
3	Household goods[S]	-2.06	-1.45	-2.03	-0.87
4	Clothing[S]	-1.59	-0.59	-2.41	1.22
5	Other services[R]	5.45	3.70	2.80	4.59
6	Transport and recreation[S]	-3.64	-3.02	-3.20	-2.85
7	Energy[S]	-2.37	-2.14	-2.36	-1.92
8	Other goods[S]	-2.70	-1.97	-2.26	-1.69
	Total	-1.20	-0.23	-2.51	2.05

Notes: The superscript R and S denote the reduced and standard VAT rates, respectively.

view of relevance of this simulation than the low statistical significance of elasticities would suggest.[15]

The magnitude of difference between the two estimation methods is in line with expectations: allowing for consumer spending patterns to change in response to VAT changes has a relatively large impact on the resulting change in VAT revenues. With the static micro-simulation model the estimated impact on VAT revenues is, rounding these figures, CZK 10 billion for the implemented proposal (15% and 21%) and CZK -1 billion for the repealed 2013 proposal (unified VAT rate of 17.5%). The corresponding estimates using the QUAIDS are CZK 7 billion and around zero,

[15] The reason is that the restrictions the QUAIDS model imposes on the elasticities causes them to be negatively correlated, which results in lower variance when I combine them in the simulation estimates.

i.e. lower in total by almost CZK 3 billion and approximately CZK 1 billion, respectively. Nevertheless, as the confidence intervals show, the differences are more important in the case of the implemented 2013 reform (15% and 21%) than the repealed 2013 reform (17.5% and 17.5%),where the difference does not seem statistically significant.

The estimated tax revenue after allowing for consumers' behavior to adjust (in accordance with QUAIDS preferences) is, as expected, lower in magnitude than the estimate using the static micro-simulation methodology that holds fixed the quantity of goods and services purchased. For the implemented 2013 proposal—one percentage point increase in both VAT rates—the estimated increases in government revenues that take the consumer responses into account are 28% lower than the estimates with no behavioral response. These differences are important and have policy implications.[16] The 28% difference is higher than the estimates for similar VAT simulation in Mexico presented in Abramovsky et al. (2012), whose findings imply a difference of only about 7% and 16% for proposed and approved VAT reforms, specifically. The relatively high variation in these estimates suggests a need for further research as to the extent of this difference, which should be, at least before the estimates converge more closely, both country- and reform-specific. These differences show that behavioral responses can be quantitatively important and that they should be considered in order for revenue projections to be more precise.

6. Conclusion

In this paper I have employed detailed data from the Czech Statistical Office to estimate a consumer demand model of the quadratic almost ideal system (QUAIDS), derived the own- and cross-price and income elasticities and simulated the impacts of recent VAT reforms in the Czech Republic on households and on government revenues. Accounting for behavioral response yielded substantially different estimates of the impacts of the most recently implemented reform on government revenues. The estimated tax revenue after allowing for behavior adjustment in line with QUAIDS preferences is substantially lower (by as much as 28%) than the estimate using the static micro-simulation methodology that holds fixed the quantity of goods and services purchased. This contributes to the existing simulation of VAT reforms as well as more generally to the quality of evidence-based policymaking in the Czech Republic. Specifically, these findings highlight the need for the Ministry of Finance of the Czech Republic to take these behavioral responses rigorously into account by, for example, incorporating the best practice in the form of the QUAIDS model into its own models.

[16] For example, these differences might partly explain the past cases of over-estimation of VAT revenues by the Ministry of Finance of the Czech Republic and might lead to further future cases. On p. 12 and 13 of the government's budget report for 2013 (Ministry of Finance of the Czech Republic, 2012), the overall increase (mostly due to a one percentage point increase in both VAT rates and an expected increase in consumption) in VAT revenues is estimated at 1.2% and at CZK 9.8 billion for the central government, and since approximately one-third of VAT revenues goes to the regional governments, this corresponds to around CZK 14 billion in total. Although my estimates of approximately CZK 10 billion and CZK 8.5 billion are limited in the sense that they cover only the VAT revenues raised from household consumption and are therefore not directly comparable with the ministry's numbers, my expert estimate is that the ministry's numbers are around the upper bounds of (my) realistic estimates and that—depending on the presumed growth of household consumption in 2013—their numbers might be overestimated, possibly partly as a result of failing to properly account for behavioral response.

In the course of this research I have identified at least two interesting areas for further research. First, there are a number of ways in which these simulation methods could be improved, such as by including the simulation of the effect of VAT on cross-border trade or by taking into account any administrative savings and lower levels of tax evasion that the unification of rates might result in. More generally, there are a number of different ways in which to estimate the QUAIDS and similar models and it would be desirable to explore these options, such as a comparison between the use of prices and unit values in estimation, for the Czech Republic and ideally across countries. Second, when data for 2012 and 2013 are available, it would be enriching to look at the actual behavior of consumers and to compare that with the estimates of the models presented here.

APPENDIX

A1 QUAIDS model

This section provides an overview of the QUAIDS model, essentially as presented in Banks et al. (1997). The QUAIDS model is based on the following indirect utility[17]:

$$\ln V = \left\{ \left[\frac{\ln x - \ln a(p)}{b(p)} \right]^{-1} + \lambda(p) \right\}^{-1}$$

where x is total expenditure, p stands for prices, and $a(p)$, $b(p)$ and $\lambda(p)$ are defined as:

$$\ln a(p) = \alpha_0 + \sum_i \alpha_i \ln(p_i) + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln(p_i) \ln(p_j)$$

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

$$\ln \lambda(p) = \sum_{i=1}^{n} \lambda_i \ln(p_i)$$

where $i = 1,..., n$ denotes a good, $\ln a(p)$ is the translog price aggregator function, and $b(p)$ is defined as the simple Cobb-Douglas price aggregator.

Applying Roy's identity to the equation for $\ln a(p)$, I have the following equations for w_i, the share of expenditure on good i in the total expenditure for each household:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(p_j) + \beta_i \ln\left(\frac{x}{a(p)}\right) + \frac{\lambda_i}{b(p)} \left(\ln \frac{x}{a(p)}\right)^2$$

[17] The same indirect utility function defines the AIDS model, but with the $\lambda(p)$ term set to zero.

These budget shares are quadratic in $\ln\left(\frac{x}{a(p)}\right)$ and, as Banks et al. (1997) demonstrate, quadratic in $\ln(x)$ itself. For the resulting demands to be consistent with utility maximization, the demand system must satisfy four key properties: adding-up, homogeneity, symmetry and negativity (negative semi-definiteness). Only negativity cannot be imposed, but the estimated Slutsky matrix can be tested to see if it satisfies this criterion. The first three properties can be imposed using linear restrictions on the parameters of the model:

$$\sum_{i=1}^{n}\alpha_i = 1; \sum_{i=1}^{n}\beta_i = 0; \sum_{i=1}^{n}\gamma_{ij} = 0\,\forall j; \sum_{i=1}^{n}\lambda_i = 0$$

(adding up)

$$\sum_{i=1}^{n}\gamma_{ij} = 0\,\forall j$$

(homogeneity)

$$\gamma_{ij} = \gamma_{ji}$$

(symmetry)

I make use of the QUAIDS characteristic to allow for household demographics and other variables such as a time trend to affect demands in a fully theoretically consistent manner. Demographics, a time trend and other variables enter as taste-shifters in the share equations, z_k, and, to maintain integrability, are therefore part of α_i terms in $\ln a(p)$:

$$\ln a(p) = \alpha_0 + \sum_i \left\{\alpha_i + \sum_{k=1}^{K}\alpha_{ik} z_k\right\}\ln(p_i) + \frac{1}{2}\sum_i\sum_j \gamma_{ij}\ln(p_i)\ln(p_j)$$

which gives me the following new adding-up conditions that replace $\sum_{i=1}^{n}\alpha_i = 1$:

$$\sum_{i=1}^{n}\alpha_i = 1; \sum_{i=1}^{n}\alpha_{ik} = 0$$

Price and total expenditure elasticities are derived and presented in Banks et al. (1997) and I do the same in the following subsections.

A2 Income Elasticities

First, I derive the total expenditure, or income, elasticity. I differentiate the share equation with respect to $\ln x$ to obtain

$$\mu_i = \frac{\partial w_i}{\partial \ln x} = \beta_i + 2\frac{\lambda_i}{b(p)}\ln\left(\frac{x}{a(p)}\right)$$

I know that

$$\frac{\partial w_i}{\partial \ln x} = \frac{\partial w_i}{\partial x}\frac{\partial x}{\partial \ln x} = \frac{\partial w_i}{\partial x}x$$

And I also know that

$$\frac{\partial w_i}{\partial x} = \frac{\partial\left\{\frac{p_i q_i}{x}\right\}}{\partial x} = -\frac{p_i q_i}{x^2} + \frac{p_i}{x}\frac{\partial q_i}{\partial x} = -\frac{w_i}{x} + \frac{w_i}{q_i}\frac{\partial q_i}{\partial x}$$

And putting these together I arrive at

$$\frac{\partial w_i}{\partial \ln x} = \frac{\partial w_i}{\partial x}x = -\frac{p_i q_i}{x} + p_i\frac{\partial q_i}{\partial x} = -w_i + \frac{w_i x}{q_i}\frac{\partial q_i}{\partial x}$$

And after rearranging at

$$\frac{x}{q_i}\frac{\partial q_i}{\partial x} = \frac{\partial w_i}{\partial \ln x}\frac{1}{w_i} + 1$$

Which yields income elasticity as

$$\epsilon_i = \frac{x}{q_i}\frac{\partial q_i}{\partial x} = \left\{\beta_i + 2\frac{\lambda_i}{b(p)}\ln\left(\frac{x}{a(p)}\right)\right\}\frac{1}{w_i} + 1 = \frac{\mu_i}{w_i} + 1$$

A3 Own-Price Elasticities

Second, I derive the uncompensated (Marshallian) own-price elastitcities. I differentiate the share equation with respect to $\ln p_1$ to obtain

$$\mu_{ii} = \frac{\partial w_i}{\partial \ln p_i} = \gamma_{ij} - \left\{\beta_i + 2\frac{\lambda_i}{b(p)}\ln\left(\frac{x}{a(p)}\right)\right\}\left\{\alpha_i + \sum_j \gamma_{ij}\ln\left(p_j\right)\right\} - \frac{\lambda_i\beta_i}{b(p)}\left\{\ln\left(\frac{x}{a(p)}\right)\right\}^2$$

where I use

$$\frac{\partial\left(\frac{1}{b(p)}\right)}{\partial p_i} = -\frac{1}{b(p)^2}\frac{\partial \ln b(p)}{\partial p_i}\frac{\partial b(p)}{\partial \ln b(p)} = -\frac{1}{b(p)^2}\beta_i b(p) == -\frac{\beta_i}{b(p)}$$

and

$$\frac{\partial\left(\frac{\lambda_i}{b(p)}\left\{\ln\left(\frac{x}{a(p)}\right)\right\}^2\right)}{\partial p_i} = \frac{\partial\left(\left\{\ln\left(\frac{x}{a(p)}\right)\right\}^2\right)}{\partial p_i}\frac{\lambda_i}{b(p)} + \frac{\partial\left(\frac{\lambda_i}{b(p)}\right)}{\partial p_i}\left\{\ln\left(\frac{x}{a(p)}\right)\right\}^2$$

Therefore I derive the own-price elasticities in the following way

$$\frac{\partial w_i}{\partial \ln p_i} = \frac{\partial w_i}{\partial p_i} p_i$$

and

$$\frac{\partial w_i}{\partial p_i} = \frac{\partial \left\{ \frac{p_i q_i}{x} \right\}}{\partial p_i} = \left(q_i + \frac{\partial q_i}{\partial p_i} p_i \right) \frac{1}{x} = \left(1 + \frac{\partial q_i}{\partial p_i} \frac{p_i}{q_i} \right) \frac{q_i}{x} = \left(1 + \epsilon_{ii}^u \right) \frac{q_i}{x}$$

and

$$\frac{\partial w_i}{\partial \ln p_i} = \frac{\partial w_i}{\partial p_i} p_i = \left(1 + \epsilon_{ii}^u \right) \frac{q_i}{x} p_i = \left(1 + \epsilon_{ii}^u \right) w_i$$

and therefore

$$\epsilon_{ii}^u = \left\{ \frac{\partial w_i}{\partial \ln p_i} \right\} \frac{1}{w_i} - 1$$

I arrive at

$$\epsilon_{ii} = \left\{ \begin{array}{l} \gamma_{ij} - \left\{ \beta_i + 2 \frac{\lambda_i}{b(p)} \ln \left(\frac{x}{a(p)} \right) \right\} \left\{ \alpha_i + \sum_j \gamma_{ij} \ln \left(p_j \right) \right\} - \\ - \frac{\lambda_i \beta_i}{b(p)} \left\{ \ln \left(\frac{x}{a(p)} \right) \right\}^2 \end{array} \right\} \frac{1}{w_i} - 1 = \frac{\mu_{ii}}{w_i} - 1$$

which is the uncompensated own price elasticity.

I use the Slutsky equation, $\epsilon_{ii}^c = \epsilon_{ii}^u + \epsilon_i w_j$, to calculate the set of compensated (Hicksian) elasticities, ϵ_{ii}^c.

A4 Cross-Price Elasticities

Third, I derive the uncompensated (Marshallian) cross price elastitcities. I differentiate the share equation with respect to ln p_j to obtain

$$\mu_{ik} = \frac{\partial w_i}{\partial \ln p_k} = \gamma_{ik} - \left\{ \beta_i + 2 \frac{\lambda_i}{b(p)} \ln \left(\frac{x}{a(p)} \right) \right\} \left\{ \alpha_k + \sum_j \gamma_{ij} \ln \left(p_j \right) \right\} - \frac{\lambda_i \beta_i}{b(p)} \left\{ \ln \left(\frac{x}{a(p)} \right) \right\}^2$$

where I use

$$\frac{\partial w_i}{\partial \ln p_k} = \frac{\partial w_i}{\partial p_k} p_k$$

and

$$\frac{\partial w_i}{\partial p_k} = \frac{\partial \left\{ \frac{p_i q_i}{x} \right\}}{\partial p_k} = \left(\frac{\partial q_i}{\partial p_k} p_i \right) \frac{1}{x} = \left(\frac{\partial q_i}{\partial p_k} \frac{p_i}{q_i} \right) \frac{q_i}{x} = \epsilon_{ik}^{u} \frac{q_i}{x} = \epsilon_{ik}^{u} \frac{w_i}{p_i}$$

and

$$\frac{\partial w_i}{\partial \ln p_k} = \frac{\partial w_i}{\partial p_k} p_k = \epsilon_{ik} \frac{w_i}{p_i} p_i = \epsilon_{ik}^{u} w_i$$

and therefore

$$\epsilon_{ik}^{u} = \frac{\partial w_i}{\partial \ln p_k} \frac{1}{w_i}$$

I arrive at

$$\epsilon_{ik}^{u} = \left\{ \gamma_{ik} - \left\{ \beta_i + 2 \frac{\lambda_i}{b(p)} \ln\left(\frac{x}{a(p)} \right) \right\} \left\{ \alpha_k + \sum_j \gamma_{ij} \ln\left(p_j \right) \right\} - \frac{\lambda_i \beta_i}{b(p)} \left\{ \ln\left(\frac{x}{a(p)} \right) \right\}^2 \right\} \frac{1}{w_i} = \frac{\mu_{ik}}{w_i}$$

which is the uncompensated cross-price elasticity.

The uncompensated price elasticity, both cross and own, could be written as

$$\epsilon_{ik}^{u} = \frac{\mu_{ik}}{w_i} - \delta_{ik}$$

where δ_{ik} is the Kronecker delta (value of 1 if the variables are equal, and 0 otherwise).

I use the Slutsky equation, $\epsilon_{ik}^{c} = \epsilon_{ik}^{u} + \epsilon_i w_j$, to calculate the set of compensated (Hicksian) elasticities, ϵ_{ik}^{c}.

A5 Detailed Definition of Expenditure Groups

Table A1 Detailed Definition of Expenditure Groups

Group	Expenditure	2011 HBS codes	Expenditure items
1	***Food (mostly reduced VAT)***		
	Food	2010–2820, 2860, 2870, 2890, 2910	Meat, oils and fats, milk, cheese, eggs, bread and cereals, vegetables, fruit, sugar, chocolate, confectionery, coffee, tea and cocoa, mineral waters, soft drinks, school and kindergarten cafeteria
2	***Eating out and other luxuries (mostly standard VAT)***		
	Eating out	2880, 2900, 2920–2970	Cafeterias and eating out, drinks out
	Alcoholic beverages	2830–2850	Alcoholic beverages
	Tobacco	3900	Tobacco
	Cosmetics	3320, 3340, 4430	Cosmetics, hairdressing
3	***Household goods (mostly standard VAT)***		
	Household goods	3400–3490	Furniture and furnishings
	Household goods	3510–3570	Household appliances
	Household goods	3660	Children's prams
	Household goods	3700	Mobile phones
	Household goods	3710–3760	Audio-visual, photographic, information technology equipment
	Household goods	3770–3790	Communication appliances, toys and other goods
	Household goods	3850	Stationery
	Household goods	4360, 4370	Maintenance or repair of household appliances
	Household goods	4380	Repair of audio-visual, photographic, information technology equipment
4	***Clothing (mostly standard VAT)***		
	Clothing	3010–3100	Clothing
	Clothing	3210–3270	Footwear
	Clothing	3310	Washing goods for clothes
	Clothing	4310	Repair or hire of clothing
	Clothing	4320	Repair or hire of footwear
5	***Public and other services (mostly reduced VAT)***		
	Healthcare	3300, 3370, 3380	Medicines
	Healthcare	3360, 3390	Medical products and appliances
	Leisure	3860-3890	Newspapers and books
	Other services	4040	Heat energy and hot water supply
	Other services	4050	Cold water
	Other services	4070	Refuse collection service
	Public transport	4110–4130, 4150, 4170	Public passenger transport by railway, road
	Public transport	4160	Public passenger transport by air
	Other services	4440	Financial services
	Leisure	4450	Flowers and plants
	Education	4500–4560	Pre-primary, primary and secondary education
	Leisure	4630	Accommodation
	Leisure	4650	Recreational or cultural services
			continued

Group	Expenditure	2011 HBS codes	Expenditure items
	Healthcare	4710-4750	Outpatient services
	Healthcare	4760-4790	Outpatient services—regulatory fees
6	***Transport and recreation (mostly standard VAT)***		
	Transport	3600–3630	Purchase of vehicles
	Transport	3640	Fuels and lubricants for personal transport equipment
	Transport	3650	Spare parts and accessories for personal vehicles
	Recreation	3810–3840	Other recreational items and equipment
	Transport	4140, 4180	Road transport - taxi, other paid transport services
	Transport	4330–4350	Maintenance/repair of personal transport equipment
	Recreation	4610	Recreation at home
	Recreation	4620	Recreation abroad
	Recreation	4640	Recreational and sport services
7	***Energy (mostly standard VAT)***		
	Energy	3910–3930	Solid fuels
	Energy	4020, 4030	Electricity, gas
8	**Other goods (mostly standard VAT)**		
	Other goods	3330, 3350	Goods for the maintenance of the dwelling
	Other services	4060, 4410, 4420	Other housing related services
	Other services	4210–4250	Postal, telephone or telefax services
	Other services	4460	Other administrative and consultancy services
	Other goods	5310–5340	Pets, animals and gardening

A6 Summary Statistics

Table A2 Summary Statistics for 2001–2011

Variable	Mean	Standard deviation	Minimum	Maximum
Share of group 1	0.251	0.083	0.027	0.773
Share of group 2	0.109	0.059	0	0.635
Share of group 3	0.087	0.073	0	0.767
Share of group 4	0.075	0.041	0	0.396
Share of group 5	0.151	0.081	0	0.818
Share of group 6	0.117	0.111	0	0.926
Share of group 7	0.101	0.075	0	0.645
Share of group 8	0.110	0.059	0	0.673
Price of group 1	105.664	8.782	95.761	118.803
Price of group 2	104.703	10.390	91.954	122.635
Price of group 3	101.428	12.967	86.100	127.882
Price of group 4	99.467	10.891	85.294	117.875
Price of group 5	107.489	16.356	86.277	131.491
Price of group 6	99.301	2.416	96.051	103.726
Price of group 7	114.670	22.512	88.722	148.253
Price of group 8	99.295	7.618	87.052	107.474
Log of price 1	4.657	0.082	4.562	4.777
Log of price 2	4.646	0.098	4.521	4.809
Log of price 3	4.612	0.123	4.456	4.851
Log of price 4	4.594	0.108	4.446	4.770
Log of price 5	4.666	0.151	4.458	4.879
Log of price 6	4.598	0.024	4.565	4.642
Log of price 7	4.723	0.193	4.486	4.999
Log of price 8	4.595	0.079	4.467	4.677
Expenditure	212086.9	117216.2	6033	1179924
Log of expenditure	12.111	0.581	8.705	13.981
Monetary income	24389.6	13760.08	1496.33	349326.3
Age	49.272	14.571	19	90
Members	2.484	1.183	1	8.08
Children	0.727	0.927	0	6.08
Employment status	0.767	0.423	0	1
Education—low	0.313	0.464	0	1
Education—middle	0.380	0.485	0	1
Prague	0.137	0.344	0	1
City size	2.004	0.772	1	3
Year	6.128	3.183	1	11

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