Modelling Consumer Demand and Household Labour Supply:

Welfare Effects of Increasing Carbon Taxes[*]

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Abstract

The main objective of this paper is to analyse consumer response and welfare effects due to changes in energy or environmental policy. To achieve this objective we formulate and estimate an econometric model for non-durable consumer demand in Sweden that utilises micro- and macro-data. In the demand model male and female labour supply is included as conditioning goods. To account for possible changes in labour supply due to increasing carbon taxes we estimate separate labour supply functions for men and women. In the simulations we consider two revenue neutral scenarios that both imply a doubling of the CO_2 tax; one that returns the revenues in the form of a lower VAT and one that subsidise public transport. One conclusion from the simulations is that the CO_2 tax has regional distribution effects, in the sense that household living in sparsely populated areas carry a larger share of the tax burden.

Keywords: Consumer economics, demand analysis, energy taxation, labour supply

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1. Introduction

The main objective of this paper is to analyse consumer response due to changes in energy or environmental policy. More specifically the objective involves simulations of various non-marginal tax changes.[1] Since the focus in this paper is on energy and environmental policy, most of the attention will be devoted to the demand for various energy goods, and/or groups of goods that are relatively energy intensive. The basic motivation for the empirical issues raised in this paper can be found in the development of Swedish energy and environmental policy and the emerging interest in using environmental taxes in Sweden and other countries.

The empirical issue raised in this paper is also important considering the outcome from the climate convention held in Kyoto 1997. According to the Kyoto protocol the overall emissions of greenhouse gases from the developed countries should be at least 5% below 1990 levels in the commitment period 2008 to 2012. The commitment for the European Union is an 8% reduction for the same period. If all the countries within the EU ratify the protocol the burden share for Sweden will be a 4% increase, compared with the 1990 level.[2] Thus this paper could be viewed as one input in the evaluation of the costs and distributional impacts of Swedish compliance with the Kyoto protocol.

Energy policy in Sweden became particularly active in conjunction with the oil crisis in the early seventies. In the 1970s Swedish energy policy was focused on problems related to the fear of an oil shortage. In the 1980s the motivation for policy intervention switched from shortage concerns to environmental concerns. This switch was emphasised with the appointment of the Commission of Environmental Charges in 1988 (SOU 1990:59), whose best-known suggestion was a tax on CO_2 emissions. The CO_2 tax, introduced in 1991, was initially set at the level of 250 SEK/ton (30 USD/ton) of CO_2 released, and it was levied on all fossil fuels. As of January 1, 1997 the tax has risen to 390 SEK/ton (46 USD/ton) of emitted CO_2.[3] A further "greening" of the Swedish tax system has been on the policy agenda ever since. However, the focus has switched somewhat towards the interaction between environmental taxation and public finance, the so-called “double-dividend” issue.[4] One of the few areas of consensus reached in this public debate is that, apart from environmental considerations, the

[1] Examples of similar simulations can be found in Baker, McKay & Symons (1990), Nichèle & Robin (1995), and Hansson-Brusewitz (1997).

[2] The burden share within EU is the result of negotiations within EU. The allowance of an increase in Swedish emissions can be explained by the fact that 1990 was an unusually warm year, which led to unusually low emission levels, and the fact that Sweden already has relatively low emissions per capita.

[3] A number of other policy measures were proposed and undertaken, see for example, Brännlund & Kriström (1999) and Brännlund & Gren (1999).

[4] For a discussion of the double dividend issue, see Oates (1995), Bovenberg & Goulder (1996), and Starret (1999).

size, structure and stability of the relevant tax bases are important parameters to consider in environmental policy.

To achieve the main objective of this paper we formulate and estimate an econometric model for non-durable consumer demand in Sweden that utilises micro- and macro-data.[5] The system of demand equations is derived assuming cost-minimising households. The basic model employed here is essentially a two-stage budgeting model, which combines micro-data from the Swedish Household Expenditure Surveys with aggregate data from the Swedish National Accounts. In the first stage it is assumed that the household determines how much to spend on non-durable goods and how much to spend on durable goods (including savings). In the second stage it is assumed that the household allocates its total expenditure for non-durable goods on each non-durable commodity.

The present study contributes to the existing literature by simultaneously relaxing assumptions that in previous studies are only partly relaxed. The assumptions considered here are, separability between the labour-leisure choice and the goods consumption choice, linear income effects, and the assumption concerning purchasing behaviour. In this study labour supply is included in the model and we can explicitly test for separability between labour supply and demand for non-durable goods. Non-linear income effects are allowed and tested for by adding non-linear expenditure terms into the system of demand equations, and to cope with the zero expenditure problem Heckman's (1979) two-step approach is used.

The rest of the paper is structured as follows. The modelling framework is outlined in the next section, and econometric considerations are presented in Section 3. Results from the econometric model are presented in Section 4, and result from the simulations in Section 5. The paper ends with some concluding remarks in Section 6.

2. The Modelling Framework

To model the demand for petrol, public transport, other transports (including air, railway and taxi transport), residential heating (including electricity, oil-heating and district heating), and other non-durables we will use microeconomic data from three cross-section studies and aggregate time-series data from the national accounts. We begin by considering an appropriate framework for the demand model at the microeconomic level.

Most empirical studies of household demand and consumption assume that preferences over goods are separable from labour supply. However, casual observations suggest that this may be a poor assumption. Obvious examples are the costs of going to work, such as travel and child care costs. If hours of work affect preferences between individual goods then de-

[5] Examples of studies where both micro- and macro-data are utilised are Imbens & Lancaster (1994) and Jorgenson & Stoker (1997).

mand systems that take no account of this dependence may give biased estimates. To include labour supply in the demand system we will employ a conditional approach (Browning & Meghir 1991). That is, instead of estimating complete labour supply functions we include the hours of work for the husband and wife in the model as conditioning goods.

One advantage with the conditional approach is that we do not need to model the determinants of labour supply explicitly. This contrasts sharply with the unconditional approach (Blundell & Walker 1982), where joint commodity demand and labour supply systems are estimated. Another advantage with the conditional approach is that if a good is given in predetermined quantities, i.e., rationed, then it is appropriate to put the level of the rationed good on the right-hand side (Pollak 1969 and Deaton 1981). This provides a methodological advantage since we do not have to deal with issues of (involuntary) unemployment explicitly, i.e., individuals with zero hours of work.

Consumer demand patterns typically found in micro-data sets vary considerably across households with different household characteristics and with different levels of income. As indicated in Banks, Blundell & Lewbel (1997) some goods are non-linear in expenditure while some are linear. Furthermore, the welfare effects of an indirect tax reform is biased when a non-linear expenditure pattern is approximated with a demand system linear in total expenditure (Banks et al. 1997). A flexible functional form of consumer preferences, which can handle non-linear expenditure effects and still be exactly aggregated is the quadratic extension (Banks et al. 1997) to Deaton & Muellbauer's (1980) almost ideal model (AIDS).

We therefore take the quadratic AIDS (QAIDS) model as our basic specification and model the differences in consumption patterns between different household categories, by adding intercept and slope parameters in the budget share equations of the demand system. The preferences are characterised in such a way that, in each period *t*, household *k* makes decisions on how much to consume of the above specified commodities conditional on various household characteristics, **d**, and labour-market decisions, i.e., female and male hours of work h_f and h_m. To the intercept term α_{0i} we also include a set of variables **T** that are purely deterministic time-dependent variables, like seasonal dummies and a time trend. Household *k*'s budget share for good *i*, s_{it}^k, then takes the form:

$$
\begin{aligned}
s_{it}^k = & \left(\alpha_{0i}(\mathbf{d}^k, \mathbf{T}) + \alpha_{1i} h_{ft}^k + \alpha_{2i} h_{mt}^k\right) + \sum_j \gamma_{ij} \ln p_{jt} \\
& + \left(\beta_{0i}(\mathbf{d}^k) + \beta_{1i} h_{ft}^k + \beta_{2i} h_{mt}^k\right) \times \ln\left[x_t^k / a_t^k(p,h,d)\right] \qquad i = 1,\ldots,n, \qquad (1) \\
& + \left(\left(\delta_{0i}(\mathbf{d}^k) + \delta_{1i} h_{ft}^k + \delta_{2i} h_{mt}^k\right) / b_t^k(p)\right) \times \left(\ln\left[x_t^k / a_t^k(p,h,d)\right]\right)^2,
\end{aligned}
$$

where p_{jt} is the price of good *j*, x_t^k is household *k*'s total expenditure on the $i = 1,\ldots,n$ goods and $\ln a_t^k(\cdot)$ and $\ln b_t^k(\cdot)$ are defined by

$$\ln a_t^k(p,h,\mathbf{d}) = \sum_j \left(\alpha_{0j}(\mathbf{d}^k) + \alpha_{1j} h_{ft}^k + \alpha_{2j} h_{mt}^k\right) \ln p_{jt} + \frac{1}{2} \sum_j \sum_l \gamma_{jl} \ln p_{jt} \ln p_{lt} \quad (2)$$

$$\ln b_t^k(p,h,\mathbf{d}) = \sum_{i=1}^{n} (\beta_{0i}(\mathbf{d}^k) + \beta_{1i} h_{ft}^k + \beta_{2i} h_{mt}^k) \ln p_{it}. \quad (3)$$

Since we only have access to three comparable cross-section surveys of household expenditures, we will combine the estimators from the micro-model with estimators from a QAIDS model estimated on aggregate data to get more precise estimates of the parameters.

3. Econometric Considerations

To estimate the microeconomic model we have used pooled cross-section data from the Swedish Family Expenditure Survey (FES) 1985, 1988 and 1992, comprising in all about 12 000 observations. From Table A1 in Appendix, we see that there are some differences in the consumption pattern of households in different regions. For households in the northern areas, the average petrol share is twice as large as for households in Stockholm. On the other hand the average budget share for public transport is about three times as large in Stockholm compared to thinly populated areas. Table A1 also indicate that households in the northern areas on average have a larger budget share for energy than households in the southern areas.

In the FES, households are asked to record their expenditures on non-durables such as food, clothing and public transport during a four-week period. For some commodities such as petrol and heating the households report their annual expenditure. This implies that we can only impose three price observations for petrol and heating. For the commodities that were purchased during the four-week accounting period, we impose price variables from quarterly observations from the national accounts corresponding to the accounting period. To overcome the problem of insufficient time variation in the micro-data we also use quarterly expenditure and price data from the national accounts, 1980:I to 1997:IV, to estimate the macroeconomic model.

The second issue we consider is the occurrence of zero expenditure in the diary recording. For public transport and other transport the occurrence of zero expenditure is as high as 49 and 76%, respectively. The model that has traditionally been used to account for censoring in commodity demand is the Tobit model (Tobin 1958 and Amemiya 1974). However, the underlying assumption in such models[6] is that the same stochastic process determines both the value of continuous observations of the dependent variable and the discrete switch at zero. That is, a zero realisation for the dependent variable represents a corner solution. This clearly restricts other possible determinants of the zero observations, such as infrequency of purchase

[6] i.e., the Tobit1 model, Amemiya (1984).

or misreporting in commodity demand. Such restrictions have been recognised in the past by, for example, Deaton & Irish (1984) and Blundell & Meghir (1987).

Infrequency of purchase is probably the most likely reason for zero expenditure on public and other transport. To allow for infrequency of purchase, Blundell & Meghir (1987) presented a bivariate alternative to the Tobit model with separate processes determining the censoring rule and the continuous observations. It is also reasonable to assume that there are separate processes determining the zero-one decision of having a car or not and the decision concerning how many kilometres to drive. One can also argue that all households have some consumption of heating, so zero expenditure on heating cannot possibly correspond to a corner solution. Therefore, to get consistent parameter estimates we follow Heckman's (1979) two-step procedure and estimate separate probit and truncated regression models for each commodity group.

As pointed out by Lewbel (1996), measurement errors in the dependent variables, i.e. the expenditure on individual goods, will complicate things further since they will contribute to errors in total expenditure. Lewbel (1996) provides a simple technique to enable consistent estimation. The technique consists of multiplying the share equation model (1) by different powers of the total expenditure and then estimating the resulting system by two stage least squares or generalised method of moments (GMM) techniques. Consistent estimators of the original demand system parameters are then obtained by transformations of the two stage least squares or GMM estimators.

Therefore, we estimate the quadratic almost ideal demand system in expenditure form. To simplify the simulations, we follow Blundell, Pashardes and Weber (1993) and use household specific Stone price index, $\ln P_t^k = \sum_i s_{it}^k \ln p_{it}$, instead of the translog form price index, $\ln a_t^k(p,h,d)$, and set the price aggregator, $\ln b_t^k(p,d,h)$, equal to one.[7] The estimated demand system in expenditure form for household k is

$$\begin{aligned} y_{it}^k = & \left(\alpha_{0i}(\mathbf{d}^k,\mathbf{T}) + \alpha_{1i}h_{ft}^k + \alpha_{2i}h_{mt}^k\right)x_t^k + \left(\sum_j \gamma_{ij}\ln p_{jt}\right)x_t^k \\ & + \left(\beta_{0i}(\mathbf{d}^k) + \beta_{1i}h_{ft}^k + \beta_{2i}h_{mt}^k\right)\times \ln\left[x_t^k / P_t^k\right]x_t^k \\ & + \left(\delta_{0i}(\mathbf{d}^k) + \delta_{1i}h_{ft}^k + \delta_{2i}h_{mt}^k\right)\times\left(\ln\left[x_t^k / P_t^k\right]\right)^2 x_t^k + \varphi_i\hat{\lambda}_{it}^k + \varepsilon_{it}^k, \end{aligned} \qquad \begin{aligned} i &= 1,\ldots,n \\ k &= 1,\ldots,r \end{aligned} \qquad (4)$$

where ε_{it}^k is an error term reflecting unobserved taste variation and r denoting the subsample for which $y_{it}^k > 0$. $\hat{\lambda}_{it} = \phi(\hat{\psi}_i\mathbf{z})/\Phi(\hat{\psi}_i\mathbf{z})$ is the estimated inverse Mills ratio, where $\phi(\cdot)$ and

[7] For the demand equation (1), suppressing the household specific parameters, this simplification implies that $s_{it} = \alpha_i + \Sigma_j \ln p_{jt} + \beta_i(\ln x_t + \omega(\ln x_t)^2)$, where ω is some constant, requiring that $\delta_i = \beta_i\omega$, that is, the ratio of the coefficients on expenditures and squared terms in expenditures must be the same for all commodities (see Banks et al. 1997 and Blundell et al. 1993). This restriction has not been imposed on the estimated demand system.

$\Phi(\cdot)$ are the probability density and cumulative distribution functions of the standard normal distribution, with $\hat{\psi}_i$ estimated in a first step from a univariate probit model for good *i* (see i.e., Leung and Yu 1996). The explanatory variables included in $\mathbf{z}_t$ are the number of children 0-2, 3-6, and 7-17 years old, number of children over 18 years with and without employment, number of adults, locational variables, male and female working hours, the prices of the commodities in the demand system, the log of total expenditures, seasonal dummy variables and a time trend, all multiplied with total expenditures x_t^k as in (4).

The expenditure system has a set of within-equation and cross-equation restrictions that we wish to impose. These are homogeneity, which gives rise only to within-equation restrictions, and symmetry, which gives rise to cross-equation restrictions. Homogeneity can thus be imposed in a first stage by estimating single equations, whereas cross-equation restrictions can be imposed in a second stage, using a minimum distance estimator (see Ferguson 1958). Let μ be a $q \times 1$ vector of unrestricted parameters, and let θ be a vector of symmetry-restricted parameters of dimension $p \times 1$. Then under the null $\theta = g(\mu)$, where g is a known function and $p \leq q$, the symmetry restricted parameter estimates can be obtained by minimising

$$\Psi(\theta) = [\hat{\mu} - \theta]' \hat{\Sigma}_\mu^{-1} [\hat{\mu} - \theta] \tag{5}$$

where $\hat{\mu}$ is the vector of unrestricted estimates and $\hat{\Sigma}_\mu$ is an estimate of the covariance matrix of $\hat{\mu}$. The minimised value of $\Psi(\theta)$ follows a chi-square distribution with degrees of freedom equal to the number of restrictions. The consistency of the minimum distance estimator simply requires that the restrictions are correct and that $\hat{\mu}$ is a consistent estimator. For the linear case the restrictions simplify to $\theta = K\mu$, where K is a $q \times p$ matrix. To deal with the possibility of endogeneity of total expenditures and hours of work we estimate each equation with GMM in TSP 4.3, and instead of specifying a particular form of the heteroscedasticity we employ White's (1980) approach to calculate the standard errors.

Blundell et al. (1993) show that exact aggregation over households of the quadratic almost ideal demand system yields a macro-model with similar structure, provided that distributional statistics like the Theil entropy index are included in the model. National accounts do not usually contain this information, necessary for the macro-model to be a consistent estimator of the parameters of the micro-model. However, in order to be as close as possible to the ideal case, we will add trend and dummy variables, if appropriate, to capture changes in consumer preferences.

Following Nichèle & Robin (1995), we use the same type of minimum distance estimator as in (5) to combine the micro- and macro-estimators. The criterion we minimise is

$$\Psi(\theta) = \begin{pmatrix} \hat{\theta}_m - \theta \\ \hat{\theta}_M - \theta \end{pmatrix}' \begin{pmatrix} \hat{\Sigma}_m & 0 \\ 0 & \hat{\Sigma}_M \end{pmatrix}^{-1} \begin{pmatrix} \hat{\theta}_m - \theta \\ \hat{\theta}_M - \theta \end{pmatrix} \tag{6}$$

where $\hat{\theta}_m$ and $\hat{\theta}_M$ are vectors of stacked homogeneity and symmetry constrained parameters from the micro- and macro-model, whereas $\hat{\Sigma}_m$ and $\hat{\Sigma}_M$ are their corresponding estimated covariance matrices. An estimate of the covariance matrix $\hat{\Sigma}_m$ of the homogeneity and symmetry restricted microeconomic estimator is $(K'\hat{\Sigma}_\mu^{-1}K)^{-1}$. Given the large variation in the expenditure level in the FES and the possibility of aggregation bias in the macro-data that might affect the expenditure parameters (Blundell et al. 1993), we only combine the price parameters from the micro- and macro-models.

4. Estimation results

In this section we present some of the estimation results from the micro- and macroeconomic models. We started the analysis for the microeconomic model by testing the functional form for each expenditure equation, i.e., whether the non-linear expenditure term should enter the model or not. The household characteristics we included in the model were the number of children 0-2, 3-6, and 7-17 years old, number of children over 18 years with and without employment, number of adults, age of the head of the household, and locational variables.

Likelihood ratio (LR) tests indicated that we could reject linearity for all equations, except for the public transport equation with a *p*-value of 0.14. The *p*-values of the LR-test for petrol, other transport, heating and other goods were all 0.00. The imposed restrictions for homogeneity were found to be valid for all equations except for other goods, at a 10% significance level. Symmetry was, however, rejected.

To test for collinearity between the regressors in (4) and the inverse Mill's ratio, we used the adjusted *R*-squared of the auxiliary regression (regressing $\hat{\lambda}_i$ against the explanatory variables in (4)). The adjusted *R*-squared for the four regressions lay in the interval 0.03 to 0.002, which indicate that there are no collinearity problems. One reason for the low correlation is the large range of the explanatory variables in the probit model. For example, if we just include a constant, seasonal dummy variables, and locational dummy variables in the probit model, the adjusted *R*-squared from regressing $\hat{\lambda}$ from the petrol probit model against the explanatory variables in (4) was 0.18.

If there are no collinearity problems, Leung and Yu (1996) show that the *t*-tests on the coefficients of $\hat{\lambda}_i$ are very effective. And from Table 2A in Appendix we see that the *t*-values on φ_i in the petrol, other transport and heating equation are 1.93, 4.57 and –2.64 respectively, indicating that it is appropriate to include the inverse Mill's ratio in the regression to have consistent parameter estimates. However, the *t*-value 1.39 on φ_i in the public transport equation is not significant at any reasonable significance level.

Before we estimated the model on aggregate time series data we pre-tested the series for seasonal unit roots with Hylleberg, Engle, Granger & Yoo's (1990) seasonal unit root test. The test indicated that both the expenditure and price series has a unit root at the zero frequency, i.e., they are integrated of order one. For some of the expenditure series the test indicated roots at some of the seasonal frequencies as well. We have therefore applied the seasonal filter $(1+B+B^2+B^3)$, where B is the back shift operator, i.e., $B^p x_t = x_{t-p}$, to all series in order to filter out any seasonal unit roots and obtain series that are integrated of order I(1,0). In the estimated model no unit roots were found in the residuals. The imposed restrictions of homogeneity and symmetry were rejected, with a LR-test of homogeneity $\chi_4^2 = 67.9$. The model on aggregate data has been estimated with GMM allowing for moving average components.

The parameter estimates[8] in Appendix Table A2 indicate that labour supply has a significant effect on the expenditures on petrol, with an opposite sign for male and female hours of work. For expenditures on public transport and other transport, the individual parameter estimates on labour supply have no significant effect. However, the LR-tests for weak separability between goods and labour supply in Table 1 indicate that neither male nor female labour supply is separable from commodity demand. The only exception for male labour supply is in other transport and for female labour supply in public transport and heating.

Table 1: Separability tests.

Equation	Male hours	Female hours	Total hours
Petrol	12.8 (0.01)	6.8 (0.08)	22.8 (0.00)
Public transport	5.4 (0.07)	4.4 (0.11)	9.4 (0.05)
Other transport	1.8 (0.61)	10.8 (0.01)	13.4 (0.04)
Heating	28.0 (0.00)	4.0 (0.26)	32.0 (0.00)
Other goods	74.0 (0.00)	8.0 (0.05)	80.0 (0.00)

Not: Likelihood ratio tests with p-values within parentheses.

From the macroeconomic model, based on per capita consumption, in Appendix Table A3 we see that the expenditure coefficients are significant, with negative parameter estimates for the quadratic expenditure in the petrol and heating equation. The estimated price coefficients are generally significant at a 5% significance level and rather small in absolute value. The combined price parameters from the micro and macroeconomic model are presented in Table A4. From the table we see that the point estimates are close to the estimates obtained from the

[8] In an initial estimation of the demand system we used the real income level, I^k, to instrument for total expenditure. However, the estimated parameters with real income as instrument differed a great deal from the parameter estimates obtained when we use total expenditure as an instrument for itself. This result is probably due to a weak correlation between the instruments and the endogenous explanatory variable (Bound, Jaeger & Baker, 1995). Regressing $x^k \ln x^k$ on a constant, $\ln I^k$ and $I^k \ln I^k$, i.e. the instrumental setting in the initial estimation, we obtained a R^2 measure of 0.30. Due to the lack of good instruments, the FES also lacks good instruments for hours of work, we have used the variables in the demand system as instruments for themselves.

macroeconomic model. An exception is the own price coefficient in the heating equation that becomes negatively significant, due to the strongly significant negative parameter estimate in the microeconomic model.

Although the individual parameter values can be of interest, the economic information of marginal changes in expenditure and prices is most easily summarised in terms of elasticities. From the budget elasticities reported in Table 2 we can see that there are large differences between different household categories. For households without children the demand for petrol will increase more than for households with children, due to a marginal increase in expenditure. It is also apparent that the budget elasticity for petrol and public transport is larger for households with lower disposable income. For petrol there is no large difference in expenditure elasticities between the regions. For public transport and heating there are some differences between the regions. The expenditure elasticity for households living in the three largest cities in Sweden, i.e. Stockholm, Gothenburg and Malmö, is higher, compared to the elasticity for households in other regions. However, for all household categories, petrol, public transport and heating are considered as necessities. The highest budget elasticities are found for other transport. It should, however, be pointed out that some of these estimates have large standard errors.

Table 2: Estimated budget elasticities.

	Petrol	s.e.	Public transport	s.e.	Other transport	s.e.	Heating	s.e.	Other goods	s.e.
					Income quintile					
Lowest	0.75	(0.32)	0.65	(0.16)	3.96	(2.31)	-0.05	(0.36)	1.01	(0.04)
Next lowest	0.73	(0.23)	0.63	(0.11)	3.11	(1.42)	0.09	(0.33)	1.02	(0.03)
Middle	0.65	(0.18)	0.55	(0.19)	2.89	(1.55)	0.15	(0.28)	1.04	(0.03)
Next highest	0.57	(0.20)	0.43	(0.26)	3.14	(2.73)	0.22	(0.23)	1.05	(0.02)
Highest	0.52	(0.23)	0.44	(0.71)	2.43	(3.31)	0.26	(0.32)	1.05	(0.02)
					Number of children below 18 years					
No children	0.69	(0.21)	0.56	(0.23)	2.68	(1.98)	0.17	(0.31)	1.04	(0.03)
One	0.59	(0.21)	0.43	(0.21)	2.21	(2.41)	0.24	(0.34)	1.04	(0.03)
Two or more	0.49	(0.22)	0.45	(0.71)	3.57	(3.46)	0.25	(0.25)	1.05	(0.03)
					Region					
Stockholm	0.60	(0.40)	0.52	(0.17)	2.72	(4.67)	0.27	(0.35)	1.02	(0.03)
Gothenburg/Malmö	0.52	(0.21)	0.57	(0.16)	3.01	(1.98)	0.29	(0.37)	1.03	(0.02)
Major towns	0.64	(0.19)	0.54	(0.71)	2.80	(1.60)	0.15	(0.23)	1.04	(0.02)
Southern areas	0.57	(0.14)	0.40	(0.30)	3.27	(2.06)	0.15	(0.31)	1.05	(0.02)
Major towns northern areas	0.59	(0.20)	0.17	(0.40)	2.51	(2.40)	0.14	(0.17)	1.05	(0.04)
Northern areas	0.60	(0.24)	0.36	(0.31)	3.59	(2.84)	0.14	(0.46)	1.04	(0.04)

Note: Standard deviations within parentheses.

The calculated uncompensated price elasticities reveal small differences between different household categories. The magnitude of the price elasticity is around -1 for petrol, public transport, and other goods, –1.3 for other transports, and –0.6 for heating. Details concerning all compensated and uncompensated price elasticities are available from the authors on request.

5. Simulations

The empirical model from the previous section is used to illustrate response and impact on different households due to non-marginal changes of the carbon dioxide (CO_2) tax. The type of model used here is specifically useful in such an analysis. First of all, the CO_2 tax is essentially a tax on fossil fuels, which means that it hits not only one specific consumer good, but also all other goods containing fossil fuels. In this particular case a CO_2 tax change will obviously affect the consumer price on petrol. But fossil fuels are also used as a primary energy source for heating purposes, both as input in district heating plants and directly by individual households. Thus, it should be apparent that a consistent system of demand equations is called for since it takes into account own-price effects as well as cross-price effects. Secondly, a non-marginal tax change, which has a significant effect on prices, will affect the households' real income. A demand system of the type used here takes this income effect into account. In addition, the model employed includes non-linear income effects, which may be important when large tax changes are considered, and if effects from scenarios with economic growth are to be analysed.

Since the conditioning approach on labour supply does not account for labour supply response due to changes in prices and real income, we have estimated separate labour supply functions for male and females to account for these effects. Due to data limitations in the FES, which only includes information on the household’s total labour income, we have estimated labour supply functions for households with one adult. To make comparisons with other studies on labour supply possible we have restricted our sample to prime aged persons, 25 to 55 years old. In the estimation we have applied a common and simple functional form of the labour supply function. The equation for weekly hours of work, *h*, is specified as

$$h_t = \mu(\mathbf{u}^k) + \rho \ln(w_t / P_t^k) + \kappa(m_t / P_t^k) + \sum_j \theta_j \ln p_{jt}$$

where w_t is the post tax hourly wage rate, m_t is non-labour income, P_t^k is Stones price index and $\mathbf{u}$ is a vector of household characteristics plus a constant term. To this standard labour supply function the price variables in the demand system are added. Following Blomqvist (1996) we linearize the budget constraint and use instrumental variables techniques to estimate the labour supply functions. We let the gross wage rate and non-labour income be exogenous. As instruments for the net wage rate we use the gross wage rate, nonlabour income and the household characteristics included in the vector **u**, see Table A5 in Appendix. In the considered sample all individuals were working.

The results from the labour supply estimation are presented in Table A5 in appendix. The table reveals that price increases for petrol, public transport and other transport have a negative effect on labour supply, whereas price increases on heating and other goods increases labour supply. None of these effects are significant however. The wage elasticity for single men and women is estimated to –0.01 and –0.03 respectively.[9]

The basic motivation for the simulations is the Swedish commitment according to the Kyoto-protocol. As pointed out in the introductory section of the paper, a number of studies have attempted to assess the macroeconomic (Harrison & Kriström, 1999) as well as microeconomic (Hansson-Brusewitz, 1997) impacts on the Swedish economy of various policies to reduce green house gas emissions. The scenarios we consider in this study are to some extent designed to make a rough comparison with these studies possible. The first scenario (C100) includes a 100% increase of the CO_2 tax, with a tax replacement in the form of a lower general VAT. The second scenario (C100PT) includes a 100% increase of the CO_2 tax, but with a tax replacement in the form of lower VAT on public transport. Thus both second scenarios are revenue neutral and have both been considered as options in a green tax reform.

5.1 Simulation method

The simulation method can be described as follows. The percentage price change on good *i* is calculated according to the following formula:

$$\frac{\Delta p_i}{p_i^0} = \frac{(t_i^1 + \tau_i^1 + t_i^1 \cdot \tau_i^1) - (t_i^0 + \tau_i^0 + t_i^0 \cdot \tau_i^0)}{1 + t_i^0 + \tau_i^0 + t_i^0 \cdot \tau_i^0}, \tag{7}$$

where the superscript denotes tax regime (0 is baseline tax), t is the VAT rate for good i, and τ is the excise duty on good i. It should be noted that τ shows the excise duties share of the producer price (price exclusive of taxes), and that it includes all energy related indirect taxes. Furthermore, it is assumed that all households face the same prices. The price level for good i after the tax change is then equal to:

$$p_i^1 = (1 + \frac{\Delta p_i}{p_i^0}) \cdot p_i^0, \tag{8}$$

[9] Based on a meta-analysis Wikström (1999) estimate the median wage elasticity for married men and women in Sweden to 0.08 and 0.3 respectively.

which means that the after-tax change Stone price index for household *k* (or expenditure deflator) equals:

$$\ln P^{k1} = \sum_i s_i^k \ln p_i^1 , \tag{9}$$

where, as previously, s_i^k is household *k*'s initial expenditure share on good *i*. It should be noted that we do not allow for possible general equilibrium effects. That is, we assume that taxes are shifted completely on consumer prices. For at least energy goods, such as petrol, this may not be an unreasonable assumption since these goods are traded on international competitive markets.

Substituting expression (8) and (9) into the demand system for household *k* then gives us the new consumption vector according to:

$$\begin{aligned} y_i^{k1} &= \hat{\alpha}_i \tilde{\mathbf{d}}^k \times x^{k0} + \left(\sum_j \hat{\gamma}_{ij} \ln p_j^1\right) x^{k0} + \hat{\beta}_i \tilde{\mathbf{d}}^k \times \ln[x^{k0} / P^{k1}] x^{k0} \\ &\quad + \hat{\delta}_i \tilde{\mathbf{d}}^k \times \left(\ln[x^{k0} / P^{k1}]\right)^2 x^{k0} + \hat{\varepsilon}^{k0} , \end{aligned} \tag{10}$$

where a ^ denotes an estimate and $\tilde{\mathbf{d}}^k$ is the vector of household characteristics, including labour supply. The superscript 0 indicates the point of reference. In both scenarios we keep all characteristics (such as number of children) as well as nominal expenditure (*x*) unchanged. The last term in equation (10), $\hat{\varepsilon}^{k0}$, represents unexplained household-specific effects not accounted for in the estimations, and the effect of infrequent purchase. The latter are assumed to remain constant over simulations.[10]

Each household's tax payment on good *i*, before ($m = 0$) and after ($m = 1$) the tax change, is calculated as:

$$\begin{aligned} VAT^{km} &= \sum_i \frac{t_i^m}{(1 + t_i^m)} s_i^{km} x^{km} \\ T^{km} &= \sum_i \frac{\tau_i^m}{(1 + t_i^m)(1 + \tau_i^m)} s_i^{km} x^{km} , \end{aligned}$$

where *VAT* denotes value added tax payment, and *T* indirect taxes, or excise duties, on energy goods.

To evaluate the welfare effects from the tax reform we use compensated variation, $CV = e(\mathbf{p}^1, v^0) - e(\mathbf{p}^0, v^0)$, i.e., the amount of money the household needs to be given at the new set of prices in order to attain the pre-reform level of utility v^0. The CV is calculated as

[10] The last term can be omitted if we just want to analyse relative (percentage) changes. If we want to compare consumption or tax levels after the tax with the levels at the reference point, this term should be included.

a second order Taylor expansion for each household as:

$$CV = \frac{\partial CV}{\partial \mathbf{p}}\bigg|_{p^0} (\mathbf{p}^1 - \mathbf{p}^0) + \frac{1}{2}(\mathbf{p}^1 - \mathbf{p}^0)' \frac{\partial^2 CV}{\partial \mathbf{p}^2}\bigg|_{p^0} (\mathbf{p}^1 - \mathbf{p}^0)$$

$$= \mathbf{x}_c(\mathbf{p}^0, v^0)(\mathbf{p}^1 - \mathbf{p}^0) + \frac{1}{2}(\mathbf{p}^1 - \mathbf{p}^0)' \frac{\partial \mathbf{x}_c}{\partial \mathbf{p}}\bigg|_{p^0} (\mathbf{p}^1 - \mathbf{p}^0)$$

where $\mathbf{x}_c$ is a vector of Hicksian demand functions and $(\partial \mathbf{x}_c / \partial \mathbf{p})|_{p^0} = \mathbf{S}_{ij}$ is a matrix of compensated own- and cross-price effects.

5.2 Simulation results

Baseline taxes

We use the tax rates valid for 1998 as a baseline tax system. Since the last year in the micro data set is 1992, we have multiplied all expenditures by the growth rate in private consumption from 1992 to 1998, and the resulting consumption pattern will therefore serve as the reference point (0). The baseline taxes are displayed in Table 3, where τ^0_{CO2} shows the CO_2 share of the producer price. The first column displays the baseline VAT rate. Here it can be noticed that the VAT on public and other transports are 12% (levied on producer price plus excise duty). The second column displays the baseline excise duty, as the share of the producer price, and column three the corresponding CO_2 tax. The number 2.23 for petrol in the second column means then that the excise duty on petrol (energy plus CO_2 tax) in 1998 amounted to 3.61 SEK/litre (0.42 USD). The corresponding number in column three, 0.43, implies a CO_2 tax of 0.86 SEK/litre (0.10 USD).

Results C100

In Table 3 it can be seen that C100 implies an increase of the implicit tax rate, τ, on petrol from 2.23 to 2.65, which corresponds to a 13% petrol price increase. Furthermore the reform implies that the general VAT level can be reduced by only 2%, from 25% to 24.5%. The latter illustrates the problem with replacing a broad-based tax with a narrow based tax. The reform implies a 32% consumer price increase on oil, while the price on electricity decreases with 0.4% due to the lower VAT. There is no CO_2 tax on electricity in Sweden. The tax change have a more pronounced effect on the consumer price for oil than for petrol due to the fact that the baseline tax on oil is lower than on petrol. Furthermore, the price change on district heating is rather moderate (3%) due to the fact that only 20% of primary energy inputs consist of energy goods that are subject to excise duties. It should also be noted that the average effect on the overall “consumer price index” (StoneP) is small, approximately 0.6%. The reason is that the average budget shares for the various energy goods are small.

According to the labour supply function in Section 5 these price changes would result in lower labour supply for both men and women with approximately 3%. For men there is a decrease from 40.8 hours per week to 39.8, and for women there is a reduction from 35.8 hours per week to 34.6. Since the price coefficients in the labour supply function are not significant and the fact that it was only possible to estimate labour supply functions for a small part of the individuals in the sample, we have not considered the labour supply changes in the simulations.

Table 3: Baseline (1998) prices and taxes, and price changes (%) in scenario C100.

Commodity	t^0	τ^0	τ^0_{co2}	τ^1	$\Delta p/p$	
Petrol	0.25	2.23	0.43	2.65	13	
Electricity	0.25	0.31		0.31	-0.4	
Heating oil	0.25	1.24	0.73	1.96	32	
Public transport	0.12	0.20[a]	0.06[a]	0.26	5	
Other transport	0.12	0.30[a]	0.10[a]	0.40	8	
District heating	0.25	0.16[b]	0.07[b]	0.23	3	
Heating					3	(7.00)[c]
StoneP					0.6	(0.009)[c]

Notes: [a] Due to missing data these numbers are "best guesses". [b] In 1998 approximately 10% of primary energy input in district heating consists of oil and 10% of electricity. Accordingly we have that $\tau^0 = 0.1\cdot 1.24+0.1\cdot 0.31$. Other primary energy inputs such as biofuels are untaxed. [c] Standard deviation within parentheses.

Table 4 displays the effect from C100. The numbers in columns 1 to 4 display the change in real consumption (quantity) due to the tax increase. Table 4 reveals a reduction of petrol demand by approximately 11% for all household categories. For public transport the average decrease in demand is about 5%, without any clear pattern between the different income groups. For other transport the results indicate that households with the lowest income make the smallest adjustment.

When it comes to the number of children below 18, the simulation results indicate no differences between the households for petrol. For public transport, households with two or more children adjust more to the higher price than households with no or one child. Other transport shows the same pattern as public transport, with larger demand changes for households with children. According to the results the demand for heating is altered most for households without children. The simulation also indicates that the adjustment in real demand for heating decreases as the number of children increases.

Concerning household location the results in Table 4 reveal that the effects on petrol demand are similar in all regions. This is also an anticipated result considering the estimation results, although the conventional wisdom is that households in the northern part of Sweden are less sensitive to price changes. According to the simulation, households in the northern areas will adjust their real demand for public transport less than households in other regions will. For other transport the adjustment is smallest for the households living in the three big cities (Stockholm, Gothenburg and Malmö). Concerning heating the results indicate that real heating consumption will decrease less for households in the three big cities and major towns compared to households in the other regions.

Table 4: Tax payment and welfare effects on different households, C100.

	ΔQ petrol %	ΔQ public tran. %	ΔQ other tran. %	ΔQ heating %	Δ(T+VAT) (SEK)	ΔT%	CV (SEK)	CV / Disp income (%)
					Income quintile			
Lowest	-10.5	-5.5	-8.5	-2.4	-28	9.2	465	0.5
Next lowest	-11.0	-4.7	-11.2	-6.2	-2	7.6	1077	0.4
Middle	-10.9	-5.2	-10.6	-1.2	-19	7.6	889	0.5
Next highest	-10.9	-4.7	-10.7	-0.6	12	7.3	1231	0.5
Highest	-10.9	-6.5	-10.0	-2.1	-55	7.1	1305	0.3
					Number of children below 18 years			
No children	-11.0	-5.2	-9.2	-1.7	12	7.8	944	0.4
One	-10.9	-5.2	-10.8	-1.5	-48	7.2	1121	0.4
Two or more	-10.8	-6.2	-10.6	-1.0	-47	7.1	1171	0.4
					Region			
Stockholm	-10.7	-4.8	-8.7	-0.3	-147	8.4	579	0.2
Gothenburg/Malmö	-10.9	-5.5	-9.6	-1.3	-50	7.8	972	0.4
Major towns	-10.9	-6.6	-10.3	-1.3	-9	7.2	1100	0.4
Southern areas	-10.9	-5.5	-10.6	-3.0	28	7.2	1189	0.5
Major towns n.a.	-11.0	-3.5	-11.3	-3.9	59	7.3	1409	0.5
Northern areas	-10.9	-4.6	-10.6	-2.1	76	7.0	1423	0.6

Notes: ΔQ_i = percentage change in real consumption (quantity) on good *i*, Δ(T+VAT) = total change in tax payment, ΔT% = percentage change in indirect tax payment. n.a. = northern areas.

The results in column 5 reveals that the total tax payment effects are small. The reason for this is of course that the reform is revenue neutral, and that the tax replacement is in the form of a cut in the general VAT.

The welfare effect, measured as compensation variation (CV), differs substantially between household categories. According to column 7 in table 4, low-income households will face a welfare loss amounting to SEK 465, whereas it is SEK 1,305 for the high-income households. However, relative to disposable income the welfare loss will be greater for low-income households indicating that the tax is regressive. The CV increases in absolute value with the number of children, as expected, while it seems to be independent of the number of children if we set the loss in relation to disposable income. Finally we observe that the welfare loss is largest for households in the northern part of Sweden, both in monetary terms and relative to disposable income.

In summary the results in table 4 reveals that the reform implies a cost for the Swedish households. Thus it is apparent that the overall welfare change due to the reform depends on the emission reduction and the value the households attribute to this reduction. In addition we can conclude that distributional differences are most pronounced in the regional dimension.

Compared with Hansson-Brusewitz's (1997) findings, the 11% reduction in petrol demand in the household sector seems surprisingly high. Hansson-Brusewitz (1997) found that expenses related to car ownership would decrease by only 1.7%. However, the result in this study is not exactly comparable with that number, since we estimate the effect on petrol demand, and not expenses related to car ownership.[11] In a survey by Goodwin (1992) it was found that the average long-run elasticity for petrol is -0.84 for cross-section studies and -0.71 for time-series studies.[12] Thus, previous studies support the findings in this study to some extent.

Results C100PT

The second scenario is a revenue neutral tax reform in which the CO_2 tax is doubled and where the tax revenues are returned to the households in the form of a cut in the VAT for public transport. The baseline VAT rate on public transport is 12% and the revenues from the doubling of the CO_2 tax are more than sufficient to cover a total removal of the VAT on public transport. According to the results the increase in CO_2 tax revenues suffices not only to remove the VAT on public transport, but also allows an ad valorem subsidy of 23% on public transport. As a result the reform gives rise to a 28% decrease in the effective consumer price on public transport.

Table 5 reveals that the differences between different types of households are very small. Petrol consumption will decrease by approximately 12%, irrespective of type of household. According to the results the tax reform gives rise to a sharp increase in the demand for public transport. On average the increase is about 43%. Demand for other transport will decrease by approximately 5% on average. One conclusion then is that the tax reform will induce a strong substitution from individual transports by car to public transport. The environmental effects from the reform, in terms of CO_2 emissions, cannot be determined without further assump-

[11] Expenses related to car ownership are defined as purchase of petrol, repair expenses, parking fees, garage costs, yearly vehicle control, etc.

[12] In a study on Swedish data by Jansson & Wall (1994), the price elasticity for petrol was estimated at -0.21 in the short run and -0.71 in the long run. Similar results can be found in Franzén (1994).

tions. Obviously there will be a positive effect due to the decrease in petrol consumption. On the other hand the sharp increase in public transport may lead to an increase in emissions. The effect on emissions due to the increase in public transports depends on the capital utilization in the sector, as well as the "production function" for public transports. A low utilization rate implies that more people can travel without increased emissions, whereas a high utilization rate may lead to more emissions from the public transport sector. The net effect on emissions is therefore ambiguous.

Table 5: Tax payment and welfare effects on different households, C100PT.

	ΔQ petrol %	ΔQ public tran. %	ΔQ other tran. %	ΔQ heating %	Δ(T+VAT) (SEK)	ΔT%	CV (SEK)	CV / Disp income (%)
					Income quintile			
Lowest	-12.1	40.5	-5.3	-5.0	-166	12.6	416	0.5
Next lowest	-11.8	40.1	-4.8	-4.0	50	8.9	1292	0.5
Middle	-11.8	42.1	-6.2	-3.2	14	9.0	1064	0.5
Next highest	-12.0	51.1	-5.5	-3.6	118	8.3	1514	0.6
Highest	-11.7	31.7	-3.3	-3.7	1	8.5	1571	0.4
					Number of children below 18 years			
No children	-11.7	43.9	-5.1	-3.9	-11	9.4	1061	0.5
One	-11.8	54.4	-3.4	-3.4	-14	8.6	1340	0.5
Two or more	-12.0	29.5	-5.4	-3.5	117	8.2	1519	0.5
					Region			
Stockholm	-12.7	42.0	-4.9	-3.4	-713	13.2	191	0.1
Gothenburg/Malmö	-11.7	45.6	-4.3	-4.4	-155	9.9	1037	0.4
Major towns	-11.8	31.9	-4.8	-3.2	129	8.1	1396	0.6
Southern areas	-11.5	49.2	-5.5	-4.3	372	7.4	1682	0.7
Major towns n.a.	-11.6	50.3	-3.9	-4.0	246	8.0	1763	0.7
Northern areas	-11.5	47.0	-6.1	-2.8	438	7.2	1941	0.8

Notes: ΔQ_i = percentage change in real consumption (quantity) on good *i*, Δ(T+VAT) = total change in tax payment, ΔT% = percentage change in indirect tax payment. n.a. = northern areas.

The tax payment effects on different households are presented in column 5. As expected, households living in the most urbanised areas are overcompensated in the sense that they receive a net subsidy amounting to SEK 713 per year, whereas households in areas where public transport is less developed get a net tax payment. In the most northern part of Sweden the tax payment increases by SEK 438 per year. This corresponds to an increase in tax payment relative to disposable income of approximately 0.1%. The results also reveal that the tax burden is smaller for low-income households than for high-income households. However, the distribution of the tax burden seems to be less sensitive between income groups than between different regions, which is expected to some extent. For households with many children the result is a net tax payment while for households with no children or only one child there is only small changes in their net tax payment.

Although the low-income households and those living in the Stockholm area receive a subsidy, the revenue-neutral reform implies a welfare loss in terms of CV for these households. Compared with the first scenario, the welfare loss relative to disposable income is distributed in a similar manner.

To conclude we have found that a tax reform where the CO_2 tax revenues are used to subsidise public transport does have rather strong distributional effects, especially in the regional dimension. Households with many children living in areas where public transport is less developed cannot reap the benefits of the reform in the same way as households in the most urban areas can. Furthermore we can conclude that the environmental effect of such a reform, in terms of CO_2 emissions, is not clear-cut. The reason is that it can't be ruled out that the subsidy to public transport boost total travelling, hence counteracting the effect of reduced car driving. From a social welfare point of view we can also conclude that a net subsidy on public transport cannot be a first best alternative, unless it generate positive externalities.

6. Concluding remarks

One conclusion from the first scenario is that the CO_2 tax has regional distribution effects, in the sense that household living in sparsely populated areas carry a larger share of the tax burden. This result is in line with other similar Swedish studies. Concerning the number of children within the household and household income quintile, we found no significant differences for the change in tax payments in relation to disposable income. Although the tax burden in absolute value is larger for households with many children and high-income households. However, in a simulation[13] where we do not return the revenues to the households, we found no significant regional differences in tax payments in relation to income. The CO_2 tax was instead found to be regressive, in the sense that low-income households carried a larger share of the tax burden.

The environmental effects, in terms of CO_2 emissions, are unambiguous in the first scenario since demand for all fossil fuel related goods is decreasing. Petrol demand will decrease by approximately 11%, which means that the reduction in CO_2 emissions from the Swedish household sector will be slightly above 11%. This corresponds to an approximately 2% reduction in total emissions of CO_2 in Sweden.

The distribution of the tax burden and the welfare loss is more uneven in the second scenario where the tax revenue is returned in the form of a subsidy to public transport. The second scenario implies that households in the most urbanised areas receive a net subsidy, whereas those in less urbanised areas have to pay a net tax. A household in the Stockholm area, for example, receives SEK 713 annually; while a similar household in the most sparsely

[13] Due to space limitations this simulation is not shown.

populated area in northern Sweden would have to pay SEK 438. The environmental effect is less easy to derive in the second scenario. Although there is a sharp decrease in petrol demand, this may to some extent be counteracted by a strong increase in the demand for public transport. The net effect on the environment will depend on capacity utilization and the "production function" for public transport.

A study like the present one suffers from a number of potential shortcomings, some emerging from data limitations and some from assumptions that may be unreasonable. The description of environmental effects due to tax changes belongs to the first group. For example, environmental effects other than CO_2 emissions may be important for peoples' well being. Acidification, eutrophication, and effects on local air quality are examples of environmental effects that are not considered, but which are very important. To cope with these types of effects we would need a much more detailed "environmental module" that links changes in consumption pattern to changes in emissions of sulphur, particulates, and so on, and which in turn can be translated into actual environmental problems such as acidification and effects on human health. At present, however, we cannot perform such an analysis due to data limitations, but it is of course ranked high on the research agenda.

There are (at least) two assumptions that may be questioned. The first one is that we do not model labour supply explicitly in the simulations, but use it as a conditioning good. This is the correct approach if we believe that labour supply is "restricted", or fixed for the individual. Thus, in the short run the approach taken may be relevant, as we obviously have labour supply restrictions due to involuntary unemployment, but also due to more or less fixed working hours for those who are employed. In the long run, however, this assumption is more dubious. Related to this short-run versus long-run problem is the assumption in the scenarios that there is no substitution between primary energy sources in residential heating. In the short run this is probably an accurate description of reality, since a change of heating system is coupled with large fixed costs for the household. In the long run, however, we can observe changes in heating systems, which means that we may understate the total effect in fossil fuel consumption due to CO_2 tax changes. Finally, we have assumed that there are no "general equilibrium" effects since the producer prices of all goods are assumed to be unaffected by the tax change. The basic reason for this are the assumptions of Sweden as a small open economy and that markets are competitive. However, many commodity markets may not fit this description, and we can therefore not rule out the possibility of price effects.

References

Amemiya, T. (1974), Multivariate Regression and Simultaneous Equation Models when the Dependent Variables are Truncated Normal, *Econometrica*, 42, 999-1012.

Amemiya, T. (1984), Tobit Models: A Survey, *Journal of Econometrics*, 24, 3-61.

Baker, P., McKay, S., and Symons, E. (1990), The Simulation of Indirect Tax Reforms: The IFS Simulation Program for Indirect Taxation (SPIT), IFS Report Series No. W90/11, Institute for Fiscal Studies, London.

Banks, J., Blundell, R. and Lewbel, A. (1997), Quadratic Engel Curves and Consumer Demand, *The Review of Economics and Statistics*, 527-539.

Blomqvist, S. (1996), Estimation methods for male labor supply functions, How to take account of nonlinear taxes, *Journal of Econometrics*, 70, 383-405.

Blundell, R. and Meghir, C. (1987), Bivariate Alternative to the Tobit Model, *Journal of Econometrics*, 34, 179-200.

Blundell, R., Pashardes, P. and Weber, G. (1993), What Do we Learn About Consumer Demand Patterns from Micro Data? *The American Economic Review*, 83, 570-597.

Blundell, R. and Walker, I. (1982), Modeling the Joint Determination of Household Labour Supplies and Commodity Demands, *Economic Journal*, 92, 351-364.

Bound, J., Jaeger, D.A. and Baker, R.M. (1995), Problems With Instrumental Variable Estimation When the Correlation Between the Instruments and the Endogenous Explanatory Variable Is Weak, *Journal of the American Statistical Association*, 90, 443-450.

Bovenberg, A. L. and Goulder, L.H. (1996), Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses, *American Economic Review*, September 1996, 86 (4), 985-1000.

Browning, M. and Meghir, C. (1991), The Effects of Male and Female Labour Supply on Commodity Demands, *Econometrica*, 59, 925-951.

Brännlund, R. and Gren, I-M. (1999), Green Taxes in Sweden: A Partial Equilibrium Analysis of the Carbon Tax and the tax on Nitrogen and Fertilizers, in *Green Taxes, Economic Theory and Empirical Evidence from Scandinavia,* ed. by Brännlund, R. and Gren, I-M., New Horizons in Environmental Economics, Edward Elgar, Cheltenham, UK.

Brännlund, R. and Kriström, B. (1999), Energy and Environmental Taxation in Sweden: Some Experience from the Swedish Green tax Commission. Forthcoming in *Environmental Implications of Market-based Policy Instruments*, ed. by Sterner, T., Edward Elgar Publishing Company, 1999

Deaton, A. (1981), Theoretical and Empirical Approaches to Consumer Demand Under Rationing, in *Essays in the Theory and Measurement of Consumer Behaviour*, ed. by Deaton, A.: Cambridge University Press, Cambridge.

Deaton, A. and Irish, M. (1984), Statistical Models for Zero Expenditures in Household Budgets, *Journal of Public Economics*, 23, 59-80.

Deaton, A. and Muellbauer, J. (1980), An Almost Ideal Demand System, *The American Economic Review*, 70, 312-326.

Ferguson, T. (1958), A Method of Generating Best Asymptotically Normal Estimates with Application to the Estimation of Bacterial Densities*, Annals of Mathematical Statistics*, 29, 1046-61.

Franzén, M (1994), Gasoline Demand - A Comparison of Models. Ekonomiska studier nr. 49, Handelshögskolan vid Göteborgs Universitet.

Goodwin, P.B. (1992), A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes, *Journal of Transport Economics and Policy*, 1992:2, 155-169.

Hansson-Brusewitz, U. (1997). Höjd koldioxidskatt och höjd skatt på elektrisk kraft: effekter på hushållens välfärd och konsumtion, in Skatter, miljö och Sysselsättning, SOU 1997:11, underlagsrapporter till Skatteväxlingskommitténs slutbetänkande (In Swedish).

Harrison, G. W. and Kriström, B. (1999), General Equilibrium Effects of Increasing Carbon Taxes in Sweden, in *Green Taxes, Economic Theory and Empirical Evidence from Scandinavia,* ed by Brännlund, R. and Gren, I-M., New Horizons in Environmental Economics, Edward Elgar, Cheltenham, UK.

Heckman, J. (1979), Sample Selection Bias as a Specification Error, *Econometrica*, 47, 153-161.

Hylleberg, S., Engle, R.F., Granger, C.W.J. and Yoo, S.B. (1990), Seasonal Integration and Cointegration, *Journal of Econometrics*, 44, 215-238.

Imbens, G.W. and Lancaster, T., (1994), Combining Macro Data in Microeconometric Models, *Review of Economic Studies*, 61, 655-680.

Jansson, J.O. and Wall, R. (1994), Bensinskatteförändringars effekter. Rapport till Expertgruppen för Offentliga Studier (ESO), Ds 1994:5.

Jorgenson, D.W. and Stoker, T.M. (1997), Non-linear Three-Stage Least Squares Pooling of cross-section and Time-Series Observations, in *Welfare, Volume 1: Aggregate Consumer Behaviour*, ed by Jorgenson, D.W, The MIT Press, Cambridge.

Leung, S.F. and Yu, S. (1996), On the Choice Between Sample Selection and Two-Part Models, *Journal of Econometrics*, 72, 197-229.

Lewbel, A. (1996), Demand Estimation with Expenditure Measurement Errors on the Left and Right Hand Side, *The Review of Economics and Statistics*, 78, 718-725.

Nichèle, V. and Robin, J-M. (1995), Simulation of Indirect Tax Reforms Using Pooled Micro and Macro French Data, *Journal of Public Economics*, 56, 225-244.

Oates, W. E. (1995), Green Taxes: Can We Protect the Environment and Improve the Tax System at the Same Time? *Southern Economic Journal*, April 1995, 61 (4), 915-922.

Pollak, R.A. (1969), Conditional Demand Functions and Consumption Theory, *Quarterly Journal of Economics*, 83, 70-78.

SOU 1990:59. *Sätt värde på miljön. Miljöavgifter och andra ekonomiska styrmedel*. Slutbetänkande från miljöavgiftsutredningen, Allmänna förlaget, Stockholm (In Swedish).

Starret, D. (1999), Double Dividend: Just Desserts or Pie in the Sky? in *Green Taxes, Economic Theory and Empirical Evidence from Scandinavia,* ed. by Brännlund, R. and Gren, I-M., New Horizons in Environmental Economics, Edward Elgar, Cheltenham, UK.

Tobin, J. (1958), Estimation of Relationships for Limited Dependent Variables, *Econometrica*, 26, 24-36.

White, H. (1980), A Heteroscedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroscedasticity, *Econometrica*, 48, 817-838.

Wikström, M. (1999), Taxes and Labour Supply in Sweden - A Meta Analysis, In Brännlund, R. and Gren, I-M. (eds) *Green Taxes: Economic Theory and Empirical Evidence*, Edward Elgar Publishing Company.

Appendix

Table A1. Sample statistics by region.

Variable	Stockholm	Gothenburg/ Malmö	Major towns	Southern areas	Major towns northern areas	Northern areas
Petrol share	0.029 (0.029)	0.041 (0.037)	0.049 (0.041)	0.052 (0.039)	0.051 (0.038)	0.059 (0.042)
Public transport share	0.018 (0.023)	0.010 (0.016)	0.008 (0.016)	0.005 (0.013)	0.008 (0.020)	0.005 (0.012)
Other transport share	0.008 (0.023)	0.006 (0.021)	0.005 (0.020)	0.005 (0.017)	0.007 (0.028)	0.004 (0.018)
Energy share	0.035 (0.049)	0.041 (0.047)	0.051 (0.055)	0.055 (0.058)	0.061 (0.067)	0.064 (0.065)
Other non-durable Goods	0.910 (0.066)	0.902 (0.064)	0.887 (0.073)	0.883 (0.072)	0.873 (0.079)	0.868 (0.079)
Number of adults	1.74 (0.46)	1.77 (0.47)	1.79 (0.45)	1.83 (0.41)	1.82 (0.43)	1.84 (0.44)
Children aged 0-2	0.15 (0.40)	0.15 (0.40)	0.15 (0.38)	0.16 (0.41)	0.17 (0.41)	0.14 (0.38)
Children aged 3-6	0.22 (0.48)	0.23 (0.50)	0.24 (0.51)	0.26 (0.54)	0.26 (0.51)	0.26 (0.54)
Children aged 7-17	0.59 (0.87)	0.62 (0.91)	0.64 (0.91)	0.68 (0.94)	0.67 (0.91)	0.68 (0.94)
Children aged 18- working	0.06 (0.26)	0.08 (0.30)	0.08 (0.30)	0.08 (0.31)	0.07 (0.28)	0.10 (0.35)
Children aged 18- non working	0.09 (0.32)	0.09 (0.33)	0.11 (0.33)	0.09 (0.31)	0.10 (0.32)	0.11 (0.34)
Age of head	43.77 (13.49)	43.23 (13.76)	44.13 (13.81)	45.05 (14.27)	44.56 (14.00)	45.65 (14.15)
Male hours	29.79 (19.03)	30.65 (18.84)	31.09 (18.49)	32.45 (18.17)	31.36 (18.19)	31.69 (18.71)
Female hours	26.86 (16.58)	24.14 (16.79)	24.05 (16.55)	22.93 (16.73)	24.39 (16.50)	22.56 (17.20)
Total expenditures	172 300	166 700	154 300	148 300	152 200	147 000
Sample size	1 988	1 586	4 029	2 610	933	776

Notes: Standard deviations within parentheses. Source: The Family Expenditure Survey 1985, 1988 and 1992.

Table A2: Parameter estimates from the microeconomic model.

Var.	Petrol	*t*-value	Public transport	*t*-value	Other tran-sport	*t*-value	Heating	*t*-value	Other goods	*t*-value
					Intercept of the expenditure equations					
Constant	-.689	-.89	.101	2.10	-2.089	-2.19	-.050	-.07	3.251	3.79
Stockholm	.050	.12	.020	.78	.559	.74	.314	.55	-.530	-.94
GB/Malmö	.800	1.93	-.016	-.61	-.456	-.60	.877	1.59	-1.345	-2.32
Major towns	.434	1.18	-.013	-.50	-.068	-.09	.767	1.50	-1.210	-2.25
Southern areas	1.030	1.63	-.010	-.38	-.390	-.48	1.938	2.99	-2.361	-3.36
Major towns n.a.	.520	.95	.033	1.06	-1.872	-1.91	.958	1.59	-.088	-.12
Ch 0-2	-.248	-.90	-.007	-.56	1.303	.94	.231	.70	.327	.90
Ch 3-6	-.061	-.26	-.008	-.77	-.282	-.68	-.811	-2.50	.606	1.73
Ch 7-17	-.185	-1.58	-.007	-1.34	.200	.66	-.000	-.00	.538	2.23
Ch 18- w	-.808	-1.69	-.002	-.10	.201	.36	-.005	-.010	1.493	2.31
Ch 18-nw	-.220	-.72	.020	1.42	.869	2.70	-.342	-1.08	.215	.50
Adult	.183	.56	.014	1.33	.096	.25	.747	2.59	-.549	-1.28
Years old	-.001	-.17	-.001	-1.81					-.003	-.31
Male hours	.020	2.56	-.001	-.78	-.003	-.28	-.021	-2.69	-.017	-1.56
Female hours	-.014	-2.81	.001	1.08	-.002	-.38	-.004	-.62	.003	.33
d2	.001	.26	.000	.23	.006	2.15	.001	.40	-.000	-.03
d3	-.0001	-.29	.000	.36	-.008	-2.36	-.002	-.60	.005	1.39
d4	-.003	-1.72	.002	1.48	-.003	-1.13	.000	.14	.006	2.20
Trend	-.000	-.38	.000	.29	.000	.86	.000	.66	-.001	-1.29
Mills	1467	1.93	351	1.39	3586	4.57	-4005	-2.64		
					Linear expenditure coefficients					
Constant	.225	1.11	-.012	-1.94	.515	2.05	.042	.21	-.598	-2.58
Stockholm	-.027	-.25	-.001	-.45	-.132	-.66	-.115	-.77	.173	1.17
GB/Malmö	-.215	-1.97	.002	.70	.131	.65	-.264	-1.80	.384	2.50
Major towns	-.122	-1.26	.002	.52	.031	.16	-.220	-1.62	.330	2.32
Southern areas	-.277	-1.63	.001	.32	.113	.53	-.530	-3.06	.639	3.38
Major towns n.a.	-.140	-.95	-.004	-1.02	.512	1.97	-.261	-1.63	.021	.11
Ch 0-2	.065	.91	.001	.37	-.359	-.98	-.059	-.68	-.091	-.96
Ch 3-6	.019	.31	.001	.65	.069	.64	.212	2.51	-.165	-1.81
Ch 7-17	.049	1.63	.001	1.40	-.060	-.77	.003	.052	-.140	-2.25
Ch 18- w	.221	1.80	.000	.23	-.053	-.37	.006	.052	-.389	-2.35
Ch 18-nw	.058	.76	-.002	-1.13	-.227	-2.83	.087	1.08	-.047	-.43
Adult	-.041	-.47	-.002	-1.38	-.027	-.27	-.173	-2.29	.126	1.11
Years old	.000	.00	.000	1.79					.000	.14
Male hours	-.005	-2.50	.000	.63	.001	.28	.006	2.69	.004	1.33
Female hours	.004	2.77	-.000	-.96	.001	.38	.001	.53	-.001	-.42

Notes: *t*-values computed from heteroscedastic-consistent matrix (Robust-White). GB = Gothenburg, n.a. = northern areas, Ch = children, w = working, nw = non working. In the regression northern areas has been used as reference region.

Table A2 continued: Parameter estimates from the microeconomic model.

Var.	Petrol	*t*-value	Public transport	*t*-value	Other tran-sport	*t*-value	Heating	*t*-value	Other goods	*t*-value
					Quadratic expenditure coefficients					
Constant	-.017	-1.26			-.031	-1.88	-.004	-.30	.039	2.47
Stockholm	.002	.34			.008	.59	.009	.95	-.013	-1.35
GB/Malmö	.014	1.98			-.009	-.70	.019	1.98	-.027	-2.65
Major towns	.008	1.31			-.003	-.22	.015	1.71	-.022	-2.35
Southern areas	.018	1.62			-.008	-.57	.036	3.10	-.043	-3.38
Major towns n.a.	.009	.95			-.035	-2.01	.018	1.67	-.001	-.09
Ch 0-2	-.004	-.93			.025	1.02	.004	.67	.006	1.02
Ch 3-6	-.001	-.36			-.004	-.60	-.014	-2.51	.011	1.88
Ch 7-17	-.003	-1.66			.004	.88	-.000	-.08	.009	2.24
Ch 18- w	-.015	-1.90			.003	.37	-.001	-.08	.025	2.36
Ch 18-nw	-.003	-.78			.015	2.98	-.005	-1.06	.002	.33
Adult	.002	.41			.002	.28	.010	2.02	-.007	-.96
Years old	.000	.14							-.000	-.03
Male hours	.0003	2.44			-.000	-.28	-.0004	-2.68	-.0002	-1.15
Female hours	-.0002	-2.71			-.000	-.40	-.0001	-.44	.0001	.50
					Price coefficients					
Petrol	.010	.72	.003	.31	-.020	-.85	.332	12.38	-.231	-8.67
Public tran.	.017	.90	.012	1.00	-.075	-2.29	-.027	-.76	-.005	-.13
Other tran.	.025	2.03	-.009	-1.11	.040	1.17	.056	3.21	-.089	-4.20
Heating	.002	.23	-.003	-.69	.012	1.08	-.159	-14.05	.146	10.28

Notes: *t*-values computed from heteroscedastic-consistent matrix (Robust-White). GB = Gothenburg, n.a. = northern areas, Ch = children, w = working, nw = non working. In the regression northern areas has been used as reference region.

Table A3. Parameter estimates from the macro model.

Commodity.	Constant	Price petrol	Price public transport	Price other transport	Price heating	Linear expendi-tures	Quadratic expendi-tures
Petrol	-6.246	0.001	0.0008	0.002	-0.008	1.75	-0.12
	(-1.90)	(0.55)	(1.40)	(2.97)	(-3.53)	(1.93)	(-1.93)
Public transport	0.053	0.0008	-0.0005	-0.008	0.0003	-0.006	
	(10.19)	(1.40)	(-2.49)	(-1.66)	(0.46)	(-8.04)	
Other transport	6.962	0.002	-0.008	-0.006	0.001	-1.94	0.14
	(4.36)	(2.97)	(-1.66)	(-3.23)	(2.79)	(-4.38)	(4.41)
Heating	-85.94	-0.008	0.003	0.001	0.0005	23.94	-1.67
	(-10.29)	(-3.53)	(0.46)	(2.79)	(0.12)	(10.33)	(-10.37)

Not: *t*-values within parentheses.

Table A4. Parameter estimates from the combined micro and macro model.

Commodity.	Price petrol	Price public transport	Price other transport	Price heating
Petrol	-8.6×10^{-4} (-0.03)	4.9×10^{-3} (0.84)	1.5×10^{-2} (1.93)	-1.5×10^{-2} (-0.75)
Public transport		-4.8×10^{-3} (-2.34)	-1.5×10^{-2} (-3.48)	8.2×10^{-3} (1.26)
Other transport			-5.2×10^{-2} (-3.31)	3.9×10^{-2} (3.74)
Heating				-1.3×10^{-1} (-3.92)

Not: *t*-values within parentheses.

Table A5. Parameter estimates from the labour supply functions

Variable	Male labour supply	Female labour supply	Elasticity male labour supply	Elasticity female labour supply
Constant	35.08 (1.16)	18.52 (0.43)		
Price petrol	-4.29 (-0.60)	-4.33 (-0.46)	-0.10	-0.12
Price public transport	-3.50 (-0.60)	-4.36 (-0.46)	-0.09	-0.12
Price other transport	-6.18 (-0.97)	-6.46 (-0.91)	-0.15	-0.18
Price heating	4.84 (0.99)	5.89 (0.78)	0.11	0.16
Price other goods	10.66 (0.92)	14.54 (0.91)	0.26	0.41
Wage rate	-0.44 (-1.91)	-1.15 (-4.10)	-0.01	-0.03
Non labour income	-0.01 (-0.78)	-0.01 (-0.63)	-0.00	-0.00
Children aged 0-2	-0.72 (-1.09)	-1.87 (1.58)		
Children aged 3-6	-3.45 (-2.27)	-4.40 (-6.04)		
Children aged 7-17	0.72 (1.25)	-1.52 (-4.46)		
Children aged 18- non working	1.69 (1.52)	-0.59 (-0.49)		
Age	-0.013 (-0.42)	-0.03 (-0.77)		

Not: *t*-values within parentheses.