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ENVIRONMENTAL TAX REFORM AND THE DOUBLE DIVIDEND:

AN ECONOMETRIC DEMAND ANALYSIS

by

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Abstract

This paper examines the empirical relevance of the double dividend of revenue neutral marginal environmental tax reforms. For this purpose we use an extended version of the Ahmad-Stern model of indirect taxation. This version includes environmental externalities. We estimate the key parameters of the model with different dynamic specifications of the Almost Ideal Demand System. We find no evidence that a revenue neutral environmental tax reform that increases the energy or gasoline tax yields a double dividend.

JEL Classification: D12, H21, H23, H31, Q41

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1. Introduction

There has been a recent academic and public interest in revenue neutral environmental tax reforms. An important question when discussing environmental tax reforms has been the possibility for the government to reap a double dividend. An environmental tax reform yields a double dividend if it (i) creates environmental benefits and (ii) reduces existing tax distortions. The second postulate results from the argument that the magnitude of environmental benefits is largely unknown due to missing markets for environmental quality, see Goulder (1995). Thus, if different welfare components move in opposite direction there is no guarantee that overall welfare changes are positive. Some authors, e. g. FitzRoy (1996), emphasize that a missing double dividend might be a serious obstacle for an environmental tax reform to get ever implemented.

There exist a number of theoretical models that analyze the existence of double dividends. However, to our best knowledge no attempt has been made to test these models empirically. This paper analyzes the empirical possibility of double dividends using an extended version of the indirect tax reform model of Ahmad and Stern (1984). The extension allows for environmental externalities and follows the work of Orosel and Schöb (1995), Schöb (1996), and Pirttil and Schöb (1996). This framework allows us to identify the crucial parameters on which welfare enhancing tax reform proposals are based. These parameters are the marginal cost of public funds and the environmental benefits that will be defined below. In order to calculate these parameters we need to estimate the uncompensated demand elasticities. Hence, the question arises which demand system to use to estimate the elasticities.

One of the major obstacles to the practical application of optimal taxation theory is the dependence of the results on the specification on the demand systems employed to estimate the reactions of the consumers. This problem might be less severe in the context of marginal tax reforms. However, Decoster and Schokkaert (1990) and Madden (1996) have shown that the dynamic specification is of importance for the sensitivity of marginal tax reform proposals based on welfare analysis. These authors estimate various versions of Deaton and Muellbauer's (1980) Almost Ideal Demand System (AIDS), the Rotterdam model of Theil (1975), the CBS model of Keller and van Driel (1985) and Stone's (1954) Linear Expenditure System (LES). With the exception of the LES, the tax proposals of all deterministic specifications yield highly correlated results. Except for the LES all systems have in common that they can be understood as a Taylor approximation of first order to any demand function. Therefore, it is not surprising that these papers find that tax proposals are relatively insensitive to the deterministic specification. In the light of this result we choose the AIDS as a deterministic specification and analyze tax reform proposals using different dynamic specifications. The choice of the AIDS is further justified, since the indirect utility function of the AIDS is known. This is not the case for the Rotterdam model and the CBS model. The indirect utility function is also known in the case of the LES, but as Deaton (1987) has pointed out that its functional form is so restrictive that it predetermines the outcomes of tax proposals independently of the particular parameter estimates.

The data set we use is a sample of German monthly consumption survey data, disaggregated into three household types. The time period we choose is January 1969-December 1995. Therefore, we have substantially more degrees of freedom than other papers that analyze marginal tax reforms through econometric demand analysis. This data set also gives us the possibility to analyze various dynamic specifications, which cannot be estimated in a lot of cases due to the lack of degrees of freedom.[1] Also because we have data by household groups (a sample of elderly persons, low-income and high-income workers, each with their own price indices), the results may indicate how tax reform proposals affect different household groups. In addition the analysis of the tax reform proposals may indicate how sensitive the demand specifications are across different household groups.

Each AIDS specification incorporates a different stochastic and dynamic specification. Our starting point is, as in Anderson and Blundell (1982), a general lag structure from which we derive six versions of the AIDS model along the lines of Wickens and Breusch (1988). These versions enable us to estimate the long run relationship between budget shares of commodity expenditure, prices and income. We also estimate the static AIDS model plus a quadratic and a linear time trend. However, all

[1] We do not present any estimation results in this paper due to space restirctions. However, these are available from the author on request.

these models yield positive own price elasticities. This contradicts neoclassical household theory and has the implausible policy implication that in order to yield environmental benefits the government should cut the energy tax, although energy is assumed to be a polluting commodity!

An explanation for this result might be that the standard demand system completely neglects technological progress. Technological progress has the consequence that the energy efficiency of energy consuming commodities is rising constantly. Therefore, energy demand should react less sensitive to energy price decreases. Energy prices have been falling since the mid 1980's and therefore the neglect of technological progress might be responsible for an estimated positive value of own price elasticity of energy demand. We model technological progress for energy and gasoline efficiency as a restricted time trend. We follow some parts of the literature on computable general equilibrium models and assume that the efficiency of energy and gasoline use grows at the exponential rate of 0,01 (e. g. Burniaux, Martin, et al. (1992) p. 104). We choose this form of modeling technological progress for convenience as it avoids additional nonlinearities in the equation system to be estimated. We do not estimate, as done in Decoster and Schokkaert (1990) and Madden (1996), any difference versions of the AIDS. It is a standard result of time series analysis that difference versions might neglect important long-run information about the levels of the variables. And, indeed, models estimated in differences and in levels typically yield very different results.

The rest of the paper is organized as follows: Section 2 describes the theoretical framework of analysis. Section 3 sets up the econometric framework and section 4 describes the results. Section 5 gives some conclusions.

2. Theoretical framework

Our approach to measure tax distortions and environmental benefits follows previous work on this topic closely. We extend the indirect tax reform model of Ahmad and Stern (1984) along the lines of Orosel and Schöb (1995), Schöb (1996), and Pirttil and Schöb (1996) in order to account for environmental externalities. We will develop the crucial parameters of interest in this section.

We assume that there are constant returns to scale in production and that there are no pure profits, so that tax changes are reflected as consumer price changes only. We assume that the government requires a fixed and exogenous revenue.

Consider a social welfare function of the Bergson-Samuelson type:

$$(2.1) \qquad W\left(q; I^1; I^2; ..; I^h; z\right) = W\left(V^1\left(q; I^1; z\right); V^2\left(q; I^2; z\right); ...; V^h\left(q; I^h; z\right)\right),$$

where

$$(2.2) \qquad V^i\left(q; I^i; z\right) = \max_{x^i}\left\{u^i\left(x^i; z\right): I^i \geq qx^i\right\} \text{ with } i=1;2;...h$$

and where x^i denotes the $n+1$ vector of private commodities, with x_0 as the untaxed numeraire. I^i denotes the income of household i. The variable q denotes the consumer price vector. The consumer price vector q can be written as a function of the producer price vector p and the vector of taxes t, in the following way:

$$q = p + t.$$

If factor incomes and producer prices are fixed we may speak interchangeably of changes in, and derivatives with respect to, q and t. Since we assume that the government is not able to levy lump sum taxes, we can neglect the dependence of the variables on I^i for all $i=1;2;...h$.

The variable z denotes environmental quality, i. e. $\frac{\partial u^i(x^i;z)}{\partial z} > 0$, for all $i=1;2;...h$, which is a public good. The variable X_j for $j=0;1;...;n$ denotes the aggregated demand for commodity j and is given by:

$$X_j = \sum_{i=1}^{h} x_j^i.$$

It is assumed that environmental quality z depends on the consumption of the commodities X_e and X_g in the following way:

$$\text{(2.3)} \qquad z = z(X_e; X_g), \text{ with } \frac{\partial z(X_e; X_g)}{\partial X_e} = \frac{\partial z(X_e; X_g)}{\partial X_g} = z' < 0,$$

where the subscripts e and g stand for energy and gasoline. We also assume that consumption of private goods and environmental quality are weakly separable. Therefore, we have $\frac{\partial x_j^i}{\partial z} = 0$ for all $i=1;2;...h$ and $j=0;1;...;n$. The assumption of weak separability enables us to divide the welfare effect that results from a change of the tax system into welfare effects related only to changes in the consumption of the public good environmental quality (environmental benefits) and those related to changes in the consumption of private goods (private benefits). Under the assumption of weak separability follow the uncompensated demand functions of individual households from (2.2) and (2.3):

$$x_j^i = x_j^i(q; I^i) \qquad \text{for all } i=1;2;...h \text{ and } j=0;1;...;n.$$

The revenue constraint of the government is:

$$(2.4) \qquad R = \sum_{j=1}^{n} t_j X_j(q; I^1; ...; I^h),$$

where R denotes government revenue and t_i denotes the specific tax on commodity i. Now consider a tax reform that changes t_k and adjusts t_l such that the government revenue constraint is fulfilled. Differentiation of (2.1) under consideration of (2.2) and (2.3) yields:

$$(2.5) \qquad \begin{aligned} \frac{dW}{dt_k} = {} & \sum_{i=1}^{h} \frac{\partial W}{\partial V^i} \frac{\partial V^i}{\partial q_k} + \sum_{i=1}^{h} \frac{\partial W}{\partial V^i} \frac{\partial V^i}{\partial z} z' \left(\frac{\partial X_e}{\partial q_k} + \frac{\partial X_g}{\partial q_k} \right) \\ & + \left[\sum_{i=1}^{h} \frac{\partial W}{\partial V^i} \frac{\partial V^i}{\partial q_l} + \sum_{i=1}^{h} \frac{\partial W}{\partial V^i} \frac{\partial V^i}{\partial z} z' \left(\frac{\partial X_e}{\partial q_l} + \frac{\partial X_g}{\partial q_l} \right) \right] \frac{dt_l}{dt_k} \end{aligned}$$

Since the tax reform is revenue neutral we obtain after differentiating (2.4):

(2.6) $$\frac{dt_l}{dt_k} = -\frac{X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k}}{X_l + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_l}}.$$

(2.6) gives the necessary adjustment of t_l in order to keep the government revenue constant. Substituting (2.6) in (2.5) yields under consideration of Roy's Identity:

(2.7) $$\frac{dW}{dt_k} = \left(X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k} \right) \left[\frac{\sum_{i=1}^{h} \beta^i q_l x_l^i}{q_l X_l + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jl}} - \frac{\sum_{i=1}^{h} \beta^i q_k x_k^i}{q_k X_k + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jk}} \right] + \left(X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k} \right) z' \sum_{i=1}^{h} \eta^i \left[\frac{\varepsilon_{ek} X_e + \varepsilon_{gk} X_g}{q_k X_k + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jk}} - \frac{\varepsilon_{el} X_e + \varepsilon_{gl} X_g}{q_l X_l + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jl}} \right],$$

with $\frac{\partial W}{\partial V^i}\frac{\partial V^i}{\partial q_k} = -\frac{\partial W}{\partial V^i}\frac{\partial V^i}{\partial I^i} x_k^i = -\beta^i x_k^i$, and $\frac{\partial W}{\partial V^i}\frac{\partial V^i}{\partial z} = \eta^i$. $\tau_j = t_j / q_j$ is the overall effective tax rate as a proportion of the consumer price. The variable β^i denotes the social marginal utility of income of household i, or the welfare weight. The variable η^i represents the social marginal utility of environmental quality of household i. Note that β^i and η^i are positive. β^i and η^i are value judgments and considered as exogenous. The variable ε_{ab} is the uncompensated cross price elasticity of aggregated demand between goods a and b.[2] Note also that $\sum_{i=1}^{h} \eta^i$ determines social welfare, which results from the public goods characteristic of environmental quality.

The first term in (2.7) describes the change in welfare due to a change in the consumption of private goods. This term neglects environmental quality. In the brackets of the first term stands the difference in marginal cost of public funds of tax t_l and t_k. Therefore, the first term is positive and contributes to a social welfare increase, if the marginal cost of public funds of t_l is greater then the marginal cost of public funds of t_k. This, of course, is a standard result of optimal taxation that neglects environmental externalities. A tax reform yields private benefits if:

$$(2.8) \qquad MCF_l \equiv \frac{\sum_{i=1}^{h} \beta^i q_l x_l^i}{q_l X_l + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jl}} > \frac{\sum_{i=1}^{h} \beta^i q_k x_k^i}{q_k X_k + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jk}} \equiv MCF_k .$$

Inequality (2.8) states that in order to yield private benefits the government should raise taxes with a low *MCF* and should cut taxes with a high *MCF*. The larger the inequality the larger the private benefits that arise from raising t_k and cutting t_l. If (2.8)

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[2] Note the following relationship between the uncompensated cross-price elasticities for aggregated demand, ε_{ab}, and the uncompensated cross-price elasticities for individual household demand, ε_{ab}^i: $\varepsilon_{ab} = \frac{\partial X_a}{\partial q_b}\frac{q_b}{X_a} = \frac{q_b}{X_a}\sum_{i=1}^{h}\frac{\partial x_a^i}{\partial q_b} = \frac{1}{X_a}\sum_{i=1}^{h}\frac{q_b}{x_a^i}\frac{\partial x_a^i}{\partial q_b}x_a^i = \frac{1}{q_a X_a}\sum_{i=1}^{h} q_a x_a^i \varepsilon_{ab}^i$. Also note that $X_j = \frac{1}{q_j}\sum_{i=1}^{h} x_j^i q_j$.

is fulfilled the tax reform yields an increase in the welfare component that is derived from the consumption of private goods. In the numerator of MCF_k stands the marginal reaction of social welfare W that results from a change of the consumption of private goods, neglecting any changes in environmental quality, to a marginal change of t_k. In the denominator we find the marginal tax revenue of t_k. Therefore, MCF_k gives the effect of a change in the consumption of private goods on social welfare per additional unit of government revenue that is raised through an increase in t_k.

For a better understanding of the welfare judgments of various tax proposals and its distributional effects, it is helpful to decompose the inverse of MCF_k, as in Ahmad and Stern (1984):

$$\frac{1}{MCFk} = \frac{q_k X_k}{\sum_{i=1}^{h} \beta^i q_k x_k^i} + \frac{\sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jk}}{\sum_{i=1}^{h} \beta^i q_k x_k^i}.$$

The inverse of MCF_k gives the necessary cut in revenue if welfare is to be increased by one unit through a reduction of t_k. The first part on the right hand side gives the reciprocal of Feldstein's (1972) distributional characteristic of the good k. If the welfare weights β^i for all $i=1;2;...h$ equal unity, that is all individuals are treated the same by the government, then this term would always equal one for all goods and it would not contribute to any differences in the various MCF. If the welfare weights are different for individual households this term plays a role in the ranking of the MCF.

Consider the case where the government favors household j and sets $\beta^j = 1$ and $\beta^i = 0$ for all $i \neq j$. Taking the effect of the first term only, the highest *MCF* would be for the good with the highest consumption share by household j in its total. A government that cares only about household j would therefore raise a tax with a low value for x_k^j and a high value for X_k and cut a tax on a commodity that is consumed disproportionately more by household j than by other households. The second term measures the demand responses on revenue. It is clear that a *MCF* is small if the tax increase causes only little substitutional effects by households.

Since we have data for three different household types, we can investigate the impact of different welfare weights on the *MCF*. Table 1 shows the extreme values we have chosen:

	β^1	β^2	β^3
MCF111	1	1	1
MCF100	1	0	0
MCF010	0	1	0
MCF001	0	0	1

Table 1: Welfare weights.

The welfare indicator *MCF111* allows us to analyze the private welfare benefits of tax reforms according to a Kaldor-Hicks criterion. The government compares losses and gains of the different household groups and calculates whether the gains outweigh the losses. The gains and losses are calculated as Hick's equivalent income variations for each household. The difference between $MCF111_k$ and $MCF111_l$ gives then the income that would be left over after the winners have compensated the losers.

The other three *MCF* allow us to calculate how a tax reform is judged by a single household type. This allows us to asses the winners and losers of a tax reform. Additionally, if all household types judge a tax reform in the same way it is possible to achieve Pareto improvements, since everybody will be better off at least on the basis of private benefits.

The second term in (2.7), analogously to Schöb (1996), describes the difference in the marginal environmental impact of the tax rates t_l and t_k. The marginal environmental impact of t_l is positive if the consumption of the polluting commodities decreases after an increase in t_l. The second term in (2.7) is positive if the marginal environmental impact of t_k exceeds that of t_l. However, the marginal environmental impact of t_k and t_l is not calculable for us, because we do not have any data that allow us to draw conclusions about the magnitude of the terms $\sum_{i=1}^{h}\eta^i$ and z'. Since there is no market for the public good environmental quality, η^i cannot be observed. Also z' is not known in a lot of cases due to a lack of information. All that is known with certainty about η^i and z' are the signs. Therefore, we do not estimate the marginal environmental impact of the various tax rates. We estimate only whether a tax reform might create environmental benefits through a reduction of the consumption of the polluting commodities X_e and X_g.

An environmental tax reform yields environmental benefits as long as:

(2.9) $$EB_k \equiv \frac{\varepsilon_{ek}X_e + \varepsilon_{gk}X_g}{q_k X_k + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jk}} < \frac{\varepsilon_{el}X_e + \varepsilon_{gl}X_g}{q_l X_l + \sum_{j=1}^{n} \tau_j q_j X_j \varepsilon_{jl}} \equiv EB_l .$$

In the numerator of EB_k stands the marginal reaction of the aggregated demand of polluting commodities to a marginal change of t_k. In the denominator we find the marginal tax revenue of t_k. Therefore, EB_k gives the change in aggregated demand for polluting goods per additional unit of government revenue that is raised through an increase in t_k. It is more convenient to express the change in polluting demand per unit of revenue raised through t_k instead of per unit of tax change, since this takes into account the effects of tax changes on the budget constraint of the government. Therefore, the comparison of EB_k and EB_l takes into account that the marginal revenue of a tax rate determines how much a tax rate has to be raised or how much other tax rates can be cut in order to keep government revenue constant. The higher the marginal revenue of a tax rate the better it is for the government to raise this tax since the tax has to be increased only a little to achieve an additional unit of government revenue. Analogously, it is better for the government to cut tax rates that have a relative small marginal revenue.

If the inequality in (2.9) is fulfilled, the aggregated demand of polluting commodities decreases if t_k increases and t_l decreases. Therefore, in order to yield environmental benefits, the government should raise the tax with the lower *EB* and cut the tax with the higher *EB*. The larger the inequality the larger the environmental benefits that arise from raising t_k and cutting t_l. If (2.9) is fulfilled the tax reform yields an increase in the welfare component that is derived from the public good environmental quality.

Our objective is to analyze whether a revenue environmental tax reforms might be able to yield a double dividend. For this purpose we need to calculate the *MCF* and *EB*. These parameters determine the existence of a double dividend. If an environmental tax reform yields environmental benefits and private benefits at the same time, it yields a double dividend. In this case the welfare components that are derived from the consumption of the public good environmental quality and of private goods are both improving. The determination of the *EB* makes sure that there are environmental benefits. although the exact size cannot be determined, because the terms $\sum_{i=1}^{h} \eta^i$ and z' cannot be observed. In order to calculate these parameters we need the uncompensated demand elasticities and the tax rates τ_j, for $j=0;1;...;n$. These are derived in the next section.

3. Econometric framework

In this section we estimate the potential for a double dividend using monthly German data from 1969:01 to 1995:12 on ten commodity groups of consumer expenditure. We consider aggregate consumer behavior for three different types of households. Type 1 is a two-person household of elderly married couples with low income, typically consisting of a pension or other public assistance. Types 2 and 3 are four person households consisting of a married couple and at least one child under 15 years of age.

The difference between household type 2 and 3 is that household type 2 are households of a low income blue- or white collar worker while household 3 consists only of high income white collar workers. The exact classification can be found in the publications of the Statistisches Bundesamt. Household type 2 and 3 are single earner families, so that the assumption of inelastic labor supply may be appropriate. The expenditure data were available in the following categories:

(i)	ex01 = food	food
(ii)	ex02 = clothing	cloth
(iii)	ex03 = housing services	rent
(iv)	ex04 = energy	energ
(v)	ex05 = other expenditures on housekeeping	houseex
(vi)	ex06 = cosmetics and health products	cosm
(vii)	ex07 = transportation and communication services without gasoline	trans
(viii)	ex08 = gasoline	gas
(ix)	ex09 = educational and cultural goods and services	cult
(x)	ex10 = personal goods	pers

Also available were commodity price indices for each of the three household types except the gasoline price index. Here we choose a price index for all German households. The polluting commodities are assumed to be energy and gasoline.

Expenditures on housekeeping consists mostly of expenditure for furniture and household appliances, like washing machines etc. Educational and cultural goods and services include mostly expenditure during leisure time, for expample cinema, theater, and books. Personal goods include services such as travelling.

We assume that changes in the vector of budget shares *sh* are responses to anticipated and unanticipated changes in the price vector q and income I in an attempt to maintain a long-run relationship of the form:

$$sh(t) = \Pi \cdot a(t),$$

where $a(t)$ is a vector containing prices, income and an intercept term. Such a model may be written in vector notation, using the lag operator L, as:

$$sh(t) = \sum_{i=1}^{m} y_i L^i sh(t) + \sum_{i=1}^{n} z_i L^i a(t),$$

where y_i and z_i are vectors associated with endogenous and exogenous variables, respectively. The lag operator is such that $sh(t-i) = L^i sh(t)$, $i=1;2;...;n$. In order to obtain the the matrix Π that describes the long run relationship between $sh(t)$ and $a(t)$, we subtrac $sh(t)\sum_{i=1}^{m} y_i$ on both sides. After some rearranging and reparameterization we obtain:

$$(3.10) \qquad sh(t) = \Pi a(t) + \sum_{i=1}^{m} Y_i\left(1 - L^i\right)sh(t) + \sum_{i=1}^{n} Z_i\left(1 - L^i\right)a(t),$$

where

$$\Pi = \left(1 - \sum_{i=1}^{m} y_i\right)^{-1} \sum_{i=1}^{n} z_i,\ Y_i = -\left(1 - \sum_{i=1}^{m} y_i\right)^{-1} \sum_{i=1}^{m} y_i\left(1 - L^i\right) \text{ and } Z_i = -\left(1 - \sum_{i=1}^{m} y_i\right)^{-1} \sum_{i=1}^{n} z_i.$$

For more details on this see Anderson and Blundell (1982) and Wickens and Breusch (1988).

We assume that the long-run relationship takes the form of Deaton and Muellbauer's (1980) almost ideal demand system (AIDS) with:

$$\Pi \cdot a(t) = a + \sum_{i=1}^{10} g_i \, ln q_i + b(ln I - ln PI)$$

and:

$$ln PI = a_0 + \sum_{i=1}^{10} a_i \, ln q_i + \frac{1}{2} \sum_{i=1}^{10} \sum_{j=1}^{10} g_{ij} \, ln q_i \, ln q_j \, .$$

The price index PI is approximated through the Stone price index $ln PI \approx \sum_{i=1}^{10} sh_i \, ln q_i$ in order to obtain linearity of the demand system. This approximation method is common in empirical works estimating the AIDS. See e.g. Deaton Muellbauer (1980).

Since the shares sh_i, $i=1,...,10$ have to add up to one, we have the following restrictions:

$$\sum_{i=1}^{10} g_{ij} = 0, \ \sum_{i=1}^{10} b_i = 0 \text{ and } \sum_{i=1}^{10} a_i = 1.$$

Further we want to impose homogeneity and symmetry in the long-run. Homogeneity yields $\sum_{j=1}^{10} g_{ij} = 0$ and the symmetry of the Slutzky matrix implies $g_{ij} = g_{ji}$.

The equation system (3.10) is specified most generally if Y_i and Z_i are specified as general matrices and high numbers are chosen for n and m. However, due to data limitations, we are restricted to choose rather restrictive versions of demand specification. For example if we specify $m=n=12$ and specify Y_i and Z_i as general matrices we would need about seventy years of monthly data to estimate our ten commodity demand system. Since the data constraint is such that it is impossible for us to estimate nested forms we estimate demand specifications which are contained as special cases in (3.10). This strategy is justified by the following reasoning: Usually, it is stated that the parameter estimates of the long-run economic structure vary substantially with the dynamic specification (see e.g. Anderson, Blundell (1982)). This sensitivity highlights how critical the dynamic specification is in ultimately drawing conclusions about the long-run economic structure. Therefore, we estimate different dynamic specifications of our demand system and we show that at least the policy conclusions do not vary substantially with the dynamic specification. As in Madden (1996) we are not making any inferences regarding what is the best demand system. Since we are not able to estimate the nested dynamic specification, the choice of any particular system as best is problematic. There are non-nested tests, see the literature quoted in Madden (1996), but in general there does not appear to be any well-established procedure which would allow one to unambiguously choose between non-nested models. Thus, the best strategy seems to estimate different specifications of the AIDS and analyze the policy conclusions for all these specifications. We choose the following specifications:

(3.11) $$sh_j(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) + u(t)$$ AIDS,

(3.12) $$sh_j(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) + \sum_{i=1}^{12} \rho_i u(t-i) + u(t)$$ AR,

(3.13) $$sh_i(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) + y_{1j}t + y_{2j}t^2 + u(t)$$ TT2,

(3.14) $$(1-L)sh_j(t) = m\left[a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) - Lsh_j(t)\right] + u(t)$$ PARA,

(3.15) $$sh_j(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) + \sum_{i=1}^{9} y_{ji}(1-L)sh_i(t) + u(t)$$ AB,

(3.16) $$sh_j(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t)) + \sum_{i=1}^{12} y_{ij}\left(1-L^i\right)sh_j(t) + u(t)$$ BEWLEY,

$$sh_j(t) = a_j + \sum_{i=1}^{9} g_{ij} \ln \frac{q_i(t)}{q_{10}(t)} + b_j(\ln I(t) - \ln PI(t))$$

$$(3.17) \qquad + \sum_{i=1}^{9} y_{ji}(1-L) sh_i(t) + \sum_{i=1}^{10} z_{ji}(1-L) \frac{q_i(t)}{q_{10}(t)} \qquad \text{ALLG.}$$

$$+ z_{jtel}(1-L)(\ln I(t) - \ln PI(t)) + u(t)$$

The specification AIDS is the standard static version of the almost ideal demand system as it is found in Deaton, Muellbauer (1980). AR describes the static version plus a autoregressive process of 12th order. TT2 is the only specification which is not a special case of (3.10), but nevertheless it has been estimated frequently, e.g. Ng (1995). PARA is a partial adjustment version of the AIDS and can also be derived as a special case of (3.10). AB includes the first lag of all commodity shares in all equations. BEWLEY includes the static version plus twelve lagged shares of the corresponding endogenous variable in each equation. ALLG includes AB plus the first lag of all exogenous variables in each equation.

All demand systems include monthly dummies so that purely seasonal variation in expenditures is not attributed to the independent variables. According to the German Statistical Office, (Statistisches Bundesamt), the data before 1986 and after 1986 were generated with different methods. This structural break is reflected in an additional dummy. Also one share equation is dropped due to the adding-up restrictions; as shown in Barten (1969) it is irrelevant for estimation which equation is dropped.

From (3.11) and the identity $p_i x_i = sh_i I$ we can derive the uncompensated elasticities,

ε_{ij}:

(3.18) $$\varepsilon_{ij} = -\delta_{ij} + \frac{g_{ij}}{sh_i} - b_i \frac{sh_j}{sh_i},$$

where δ_{ij} is Kronecker's delta, i.e. $\delta_{ii} = 1$ and $\delta_{ij} = 0$, where $i \neq j$. In calculating the elasticities we use the arithmetic mean of the shares sh_i for 1995.

In order to calculate the unobservable tax rates τ_j, for *j=0;1;...;n* we express t_j in proportion to the unobservable producer price for good *j*, p_j. In this case we can write:

(3.19) $$t_j = \tau_j q_j = \tilde{\tau}_j p_j,$$

where $\tilde{\tau}_j$ is the observable value added tax rate on commodity *j*. Since $q_j = (1 + \tilde{\tau}_j) p_j$, (3.19) can be rewritten as:

$$\tau_j (1 + \tilde{\tau}_j) p_j = \tilde{\tau}_j p_j \Leftrightarrow \tau_j = \frac{\tilde{\tau}_j}{1 + \tilde{\tau}_j}.$$

For 1995 we calculate with the following tax rates $\tilde{\tau}_j$, where *j=1,...,10*:

$\tilde{\tau}_{01}$	$\tilde{\tau}_{02}$	$\tilde{\tau}_{03}$	$\tilde{\tau}_{04}$	$\tilde{\tau}_{05}$	$\tilde{\tau}_{06}$	$\tilde{\tau}_{07}$	$\tilde{\tau}_{08}$	$\tilde{\tau}_{09}$	$\tilde{\tau}_{10}$
0.07	0.15	0.15	0.15	0.15	0.15	0.15	2.00	0.15	0.15

Table 2: Tax rates.

One problem we have encountered in estimating the above demand specifications is that all these models yield positive own price elasticities. Especially, the own price elasticity of energy demand is positive, contradicting neoclassical household theory and most empirical studies on energy demand. As a demonstrative example the next table shows the uncompensated ownprice demand elasticities for energy:

	HH1	HH2	HH3	agg
AIDS	0.27	0.22	0.17	0.20
BEWLEY	0.34	0.27	0.03	0.17
TT2	0.13	0.51	0.46	0.51
PARA	0.30	0.15	0.17	0.18
AB	0.43	0.41	0.35	0.38
AR	0.09	-0.13	0.14	0.02
ALLG	0.31	0.45	0.29	0.35
	HH1	HH2	HH3	agg

Table 3: uncompensated ownprice demand elasticities for energy demand

An explanation for this result might be that all of the above demand specifications completely neglect technological progress. Technological progress has the consequence that the energy efficiency of energy and gasoline consuming commodities is rising constantly. Therefore, energy demand should react less sensitive to energy price decreases. Energy prices have been falling since the mid nineteen eighties and therefore, the neglect of technological progress might be responsible for an estimated positive value of own price elasticity of energy demand. Indeed, preliminary research has shown that estimation of the demand system AIDS from 1969:01 until 1985:12 yields negative uncompensated own price demand elasticities for energy. Therefore, we provide a simple attempt to model technological progress.

The commodities energy and gasoline have the characteristic that they are not consumed directly, but used as an input to use other consumption goods. Energy, for example, is not consumed directly, but serves as a commodity to use electrical household appliances. Also gasoline functions as an input to derive a service stream from the commodity automobile. Therefore, we assume that not the commodities itself, but a service stream c of the commodities generates utility. We assume a household production function $\gamma_i(\cdot)$ that uses energy, gasoline and commodity i to produce a service c_i:

$$c_i = \gamma_i\left(x_i; E_{04}x_{04}; E_{08}x_{08}\right) \qquad i = 1,\ldots;n, i \neq 4,8 \text{ and } u(c;z).$$

The variable E_i reflects the effects of technological progress. We assume that E_i, i=*04; 08*, grows at rate 0,01. The maximization problem of the household is now:

$$(3.20) \qquad V^i\left(q;I^i;z\right) = \max_{x^i}\left\{u^i\left(x;E_{04}x_{04};E_{08}x_{08};z\right): I^i \geq qx^i\right\}, \text{ where } i=1;2;\ldots h.$$

The utility function reflects not only preferences but also technological characteristics of the household production function. From the first order conditions of the maximization problem in (3.20) and the assumption of weak separability between private and public goods follows that the long-run relationship between shares, prices and income can be written as:

$$sh = f\left(q;\frac{q_{04}}{E_{04}};\frac{q_{08}}{E_{08}};I\right),$$

where $f(\cdot)$ is a continuous function. Assuming now that $f(\cdot) = \Pi \cdot a(t)$, where $a(t)$ is a vector containing prices, q, income I, $\frac{q_{04}}{E_{04}}, \frac{q_{08}}{E_{08}}$ and an intercept term. If Π takes the functional form of the almost ideal demand system (AIDS), we obtain the following equation system in vector notation:

$$\Pi \cdot a(t) = a + \sum_{i=1}^{10} g_i \, ln \frac{q_i}{q_{10}} + b(ln I - ln PI) - g_{04} \cdot 0{,}01 \cdot t - g_{08} \cdot 0{,}01 \cdot t,$$

and:

$$ln PI \approx \sum_{i=1}^{10} sh_i \, ln q_i - sh_{04} \cdot 0{,}01 \cdot t - sh_{08} \cdot 0{,}01 \cdot t.$$

This form of modeling technological progress has the convenient property that it does not add any nonlinearities to the demand system.

Except for the demand system TT2 we extend all of the above demand specifications to include technological progress. Demand specifications including technological progress are labeled with the prefix *tp*. The uncompensated own price demand elasticities are all negative when technological progress is considered. The next table shows the uncompensated ownprice demand elasticties for energy, estimated with the inclusion of technological progress:

	HH1	HH2	HH3	agg
tpAIDS	-0,61	-0,7	-0,36	-0,53
tpPARA	-0,52	-0,68	-0,40	-0,53
tpALLG	-0,71	-0,001	-0,25	-0,21

tpBEWLEY	-0,79	-0,69	-0,47	-0,60
tpAR	-0,53	-0,58	-0,12	-0,36
tpAB	-0,68	-0,71	-0,27	-0,50
	HH1	HH2	HH3	agg

Table 4: uncompensated ownprice demand elasticities for energy demand

In the next section we analyze different tax reforms and their welfare effects as implied by the demand elasticities that we calculate from different demand systems estimated for Germany.

4. Empirical results

In this section we give a summary of the estimation results and discuss some of their political implications.

4.1. Summary of the estimation results

The following statements are referring only to the demand systems that include technological progress. The smallest demand system specifications contains 171 parameters. Due to space restrictions it is impossible to present all estimation results. However, they are available from the author on request. In this section we merely summarize the estimation results. In a ten commodity AIDS demand system with imposed homogeneity and symmetry there are 63 parameters that describe the long-run behavior of households. In the following table we list the number of these parameters that are statistically significant at a 5% and 10% level, respectively.

	5%			10%		
	HH1	HH2	HH3	HH1	HH2	HH3
tpAIDS	31	27	35	37	32	38
tpPARA	34	24	30	35	28	34
tpALLG	30	27	40	38	32	42
tpBewley	45	53	43	49	56	45
tpAR	24	25	19	30	28	24
tpAB	28	21	33	36	25	37

Table 5: Number of statistically significant parameters that describe long-run behavior

At the 10% level these results are in accordance with the studies of demand systems that can be found in the literature. The residuals seem at least partially to show some systematic movement which indicates serial correlation and heteroscedasticity. Regarding this aspect this paper cannot draw any comparisons with the literature, since these results are usually not given, or statistics are presented that are designed to detect only first order serial correlation. In the next section we discuss the policy implications of the statistical results.

4.2. Policy implications

In this section we discuss some policy implications of the results. After calculating all *MCF* and *EB* we can order them according to their rank. Comparing the ranks of the *MCF* and *EB* gives the effects of tax reforms on the various welfare indicators. For example if the rank of *MCF* of the energy tax is higher than the rank *MCF* of the gasoline tax, then the energy tax should be cut in order to yield an increase in the private welfare. Analogously, environmental quality improves if the tax on a commodity with a high rank of the *EB* is cut and in exchange the tax of a commodity with a lower ranking *EB* should increased. In the appendix we have provided the complete ranking of all commodities for the various *MCF* and *EB* and demand systems.

Regarding an environmental tax reform, the energy tax and the gasoline tax are the most interesting ones. Therefore in the next table we present the ranks of the *MCF* and *EB* for the commodities energy and gasoline.

	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
energy						
EB	9	9	9	9	9	9
MCF111	2	2	3	3	3	2
MCF100	1	1	1	1	1	1
MCF010	2	2	3	2	3	2
MCF001	4	4	6	3	6	4
gasoline						
EB	10	10	10	10	10	10
MCF111	1	1	1	1	1	1
MCF100	3	4	5	5	7	3
MCF010	1	1	1	1	1	1
MCF001	1	1	1	1	2	1
	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 6: Rankings of welfare indicators for energy and gasoline.

There seem to be two remarkably stable results. Regarding the energy tax in all household demand systems household type 1 prefers the energy tax to be cut before all other tax rates. A similar result holds for household type 2 and the welfare indicator

MCF111 regarding the gasoline tax. Therefore, a tax reform that wants to create private benefits for all household types, should not raise the tax on energy or gasoline. Therefore, an environmental tax reform that yields a double dividend in a strictly Pareto improving sense must be one without increases in the energy tax or gasoline tax. A gasoline tax increase can be also rejected in a Kaldor Hicks improving sense.

The intuition for this result is easier understood when we look at the inverse of the distributional characteristics of the commodities energy and gasoline that can be observed directly given our choices of β^i for *i=1;2;3*.

commodity	X_i/x_i^1	X_i/x_i^2	X_i/x_i^3
food	9,84	2,54	1,98
clothing	16,94	2,65	1,78
rent	8,86	2,57	2,01
energy	**7,53**	**2,47**	**2,17**
housekeeping	14,21	2,87	1,72
cosmetics and health	11,31	4,15	1,49
transportation	14,58	2,60	1,83
gasoline	**20,57**	**2,35**	**1,90**
cultural	19,53	2,68	1,74
personal	13,84	2,86	1,73
variance	**17,48**	**0,23**	**0,03**
commodity	X_i/x_i^1	X_i/x_i^2	X_i/x_i^3

Table 7: Inverse of the distributional characteristics.

For household 1 and 2 energy and gasoline, respectively, have the highest distributional characteristic. This means that when these two goods are taxed, household 1 and household 2, respectively, carry the highest burden. Another argument against higher taxation of energy and gasoline are their comparably low marginal revenues as can be seen from their ranking in the next table.

R_{t_i}	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
$R_{t_{01}}$	1	2	2	1	2	1
$R_{t_{02}}$	6	6	7	6	6	6
$R_{t_{03}}$	2	1	1	2	1	2
$R_{t_{04}}$	8	8	9	8	8	9
$R_{t_{05}}$	5	5	5	5	5	5
$R_{t_{06}}$	7	7	6	7	7	7
$R_{t_{07}}$	4	4	4	3	4	4
$R_{t_{08}}$	10	10	10	10	10	10
$R_{t_{09}}$	3	3	3	4	3	3
$R_{t_{10}}$	9	9	8	9	9	8
R_{t_i}	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 8: Ranking of the marginal government revenue.

Raising the energy and gasoline taxes leads only to a relatively small additional tax revenue. Thus, the government is not able to sufficiently compensate households in form of tax cuts. Tax rates with a small marginal tax revenue are good candidates for a tax cut, since the effects on the government budget are only small. Hence, the last table tells us that also the tax rate on personal goods is a good candidate for a tax cut. This view is confirmed below.

From the variances in table 4 it follows that for household type 3 distributional characteristics matter the least. Therefore, the correlation between *MCF111* should be the highest with *MCF001*, followed by *MCF010*. For household type 2 and 3 efficiency is more important than for household type 1, since for these two household types distributional characteristics are quite uniform. Thus, they judge tax reform proposals more on the basis of government revenue effects.

Now consider how sensitive the rankings are to the specification of the demand system. In appendix C we have listed the Spearman rank coefficient that gives the correlation between the rankings given by each demand system for the *EB* and the four *MCF*. The Spearman rank coefficient r is significant at the 5% level and at the 10% level, if $|r| \geq 0{,}754$ and $|r| \geq 0{,}611$, respectively.[3] As can be seen from the appendix C, correlation is significant between the various demand specifications. In general we find that the demand specification seems to be the most important for household type 3. For this household type the correlation coefficient is the lowest. We find high correlation between tpAIDS and tpPARA, tpAIDS and tpBEWLEY, tpAIDS and tpAB, tpPARA and tpAB and tpBEWLEY and tpAB. Thus, we can confirm the result of Madden

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[3] The Spearman rank coefficient r is is significant at the 5% level, if $|r|\sqrt{n-1} \geq t$. Where t is the value of the t-statistic and n is the number of observations. See Dougherty (1992), p. 206.

(1996) that the correlation between the static AIDS, tpAIDS, and its partial adjustment version, tpPARA, is very high.

The sensitivity of the rankings are summarized in the next table, where we calculated the arithmetic correlation coefficient for each welfare indicator.

EB	*MCF111*	*MCF100*	*MCF010*	*MCF001*
0,75	0,87	0,92	0,92	0,82

Table 9: Sensitivity of the rankings to the demand specifications.

In this section we have shown that a revenue neutral environmental tax reform that raises the energy tax cannot yield a double dividend according to the Pareto-criterion. A revenue neutral environmental tax reform that raises the gasoline tax fails to yield a double dividend according to the Pareto- and also according to Kaldor-Hicks criterion. However, due to the substitution- and complementary- relationships between the commodities it might be possible that revenue neutral tax reform might yield a double dividend by raising other taxes than the energy or gasoline tax. This question is analyzed in the next two sections. In the third section we analyze whether it is possible to achieve private benefits if the energy and gasoline tax is recycled in a lump-sum fashion.

4.2.1. Pareto-improving tax reforms

In this section we describe marginal revenue neutral tax reforms that tax create an environmental benefit and are judged as welfare improving from all three household types. Thus a Pareto-improving tax reform is based on the welfare indicators *MCF100*, *MCF010*, *MCF001*, and *EB*. We label these tax reforms as Pareto-improving since they fulfill the sufficient condition that guarantees all three household types to be better off.

	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
110					ud	
25	du		du			du
29	du		du	du		du
210		ud			ud	
57					ud	
510		ud			ud	
67	ud	ud				ud
610	ud	ud	ud		ud	ud
79	du	du		du	du	du
710	ud				ud	
910	ud	ud			ud	ud
	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 10: Pareto-improving tax reforms.

14 ud means tax on commodity 1 up and tax on commodity 4 down.

There is some degree of consistency in the tax reforms that are suggested by the different demand systems. All demand systems that suggest tax changes for the same pair of commodities also suggest tax changes in the same direction.

Note that no strictly improving tax reform involves changes in the gasoline tax. Raising a gasoline tax would create environmental benefits, but at the same time it increases also the inefficiency of the tax system from a non-environmental point of view. Therefore, a trade-off would occur between private and environmental benefits.

Therefore, the evidence should be rather interpreted that an increase of the energy tax yields environmental benefits, but lowers private benefits. The main conclusion that we would like to draw is that it is very likely that an environmental tax reform that raises the energy or gasoline tax does not yield a double dividend in a strictly Pareto improving sense. As indicated above, the losers from an energy and gasoline tax increase would be household type 1 and household type 2, respectively.

Candidates for an environmental tax reform that yield a double dividend and are mentioned at least four times are the following pairs:

taxcut	taxincrease
(10) personal goods	(6) cosmetics and health products
(10) personal goods	(9) educational and cultural goods
(2) clothing	(9) educational and cultural goods
(7) transportation and communication	(9) educational and cultural goods

After having shown that an environmental tax reform that involves increases in the energy or gasoline tax is unlikely to make everybody better off, we might ask whether the losses of the losers could be (over)compensated by the gains of the winners. The purpose of the next section is to apply the Kaldor-Hicks welfare criterion as a measure for welfare comparisons.

4.2.2. Kaldor-Hicks-improving tax reforms

Welfare comparisons on the basis of the Kaldor-Hicks welfare criterion are possible if we set the welfare weights of the government $\beta^i = 1$, for all *i=1;2;3*. The welfare indicators that have to be analyzed in this section are *MCF111* and *EB*.

	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
12	ud		ud	ud		ud
15					du	
16	du	du	du	du	ud	du
17	ud	ud			ud	ud
19	du			du	du	du
110	ud	ud	ud		ud	ud
25	du	du	du	du		du
26	du	du	du	du		du
29	du		du	du	du	du
210		ud			ud	
35					du	
36			du		ud	
37	ud	ud			ud	ud
310	ud	ud		ud	ud	
47			**ud**			
410				**ud**	**ud**	
56	du	du	du	du	ud	
57					ud	

59			ud			
510		ud	ud		ud	
67	ud	ud			ud	ud
<u>*69*</u>	ud	ud	ud		du	ud
610	ud	ud	ud		ud	ud
79	du	du		du	du	du
710	ud	ud			ud	
910	ud	ud			ud	ud
	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 11: Kaldor-Hicks-improving tax reforms.

The tax reform proposals that yield a double dividend when the Kaldor-Hicks criterion is employed does not show the consistency that the Pareto improving tax proposals show. For some pairs of tax changes that are suggested by more than one demand specification it is not clear in which direction the tax changes should go. For example, tpALLG suggests to cut the tax on housing services and to raise the tax on cosmetics and health products. The demand specification tpAR suggests the opposite. All tax pairs that show this inconsistency are in italics and are underlined.

Three demand specifications suggest to raise the energy tax. To cut the tax on personal goods and to raise the tax on energy is suggested by two specifications, tpBewley, tpAR. tpALLG suggests to raise the energy tax and to cut the tax on transportation and communication services. All other demand specification suggest that the energy and gasoline tax should not be changed at all.

Therefore, the evidence is rather weak that a revenue neutral environmental tax reform might yield a double dividend according to the Kaldor-Hicks criterion, when the energy or gasoline tax is changed. This point is further supported by the next table. The next table gives the Spearman rank coefficient for the *MCF* and the *EB*.

	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
$r_{111;EB}$	-0,39	-0,38	-0,62	-0,75	-0,15	-0,47
$r_{100;EB}$	-0,65	-0,65	-0,71	-0,61	-0,08	-0,65
$r_{010;EB}$	-0,44	-0,50	-0,60	-0,77	-0,15	-0,47
$r_{001;EB}$	-0,25	-0,19	-0,42	0,61	0,09	-0,27
	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 12: Spearman for *EB* and the various *MCF*.

This table gives the Spearman rank coefficient for environmental benefits and the marginal cost of public funds. The first row gives Spearman rank coefficients for *EB* and *MCF111*. In this row all of the coefficients are negative. The same is true for the row that gives Spearman rank coefficients for *EB* and *MCF100* and *MCF010*. For the row that gives Spearman rank coefficients for *EB* and *MCF001* there are only two positive values. Thus, the objectives to raise the private welfare of households and to improve environmental quality are rather contradictory. From this evidence we would like to draw the conclusion that it is rather difficult to achieve a double dividend, since the coefficients indicate that the aim of increasing environmental benefits contradicts the aim of decreasing distortions of the tax system. Table 12 also indicates that the lower the income the more difficult it is to yield a double dividend.

4.2.3. Recycling the revenue in a lump sum fashion

In this section we analyze if it is possible if the additional revenue of an energy tax or gasoline tax is recycled through tax cuts in the income tax. Considering that household types 2 and 3 have only one working family member it seems quite reasonable to assume that the labor supply of these two household types is inelastic. In this case an income tax cut might be considered as a labor income tax cut. This interpretation is not appropriate for household type 1 since the household receives only transfer income.

If the marginal revenue of a tax increase is used for lump sum transfers we get the following expression for the welfare effects of a revenue neutral environmental tax reform from (2.1), (2.2), (2.3) and (2.4):

$$\frac{dW}{dt_k} = \sum_{i=1}^{h} \beta^i \frac{dI^i}{dt_k} \left(1 - \frac{\sum_{i=1}^{h} \beta^i x_k^i}{\sum_{i=1}^{h} \beta^i \frac{dI^i}{dt_k}} \right) + \left(\sum_{i=1}^{h} \eta^i \right) \left(\frac{\partial X_e}{\partial t_k} + \frac{\partial X_f}{\partial t_k} + \sum_{i=1}^{h} \left(\frac{\partial X_e}{\partial I^i} + \frac{\partial X_g}{\partial I^i} \right) \frac{dI^i}{dt_k} \right)$$

From the budget restriction of the government follows $\sum_{i=1}^{h} \frac{dI^i}{dt_k} = X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k}$. For the welfare weights β^i we consider only cases where it equals either zero or one. A welfare weight of zero indicates that the government does not care about the corresponding household. Therefore, it is reasonable to assume that in this case the household with welfare weight zero does not receive any additional lump sum transfer, so that $\sum_{i=1}^{h}\beta^i \frac{dI^i}{dt_k} = X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k}$. From this follows the necessary condition for a double dividend:

$$MEB_k = \left(X_k + \sum_{j=1}^{n} t_j \frac{\partial X_j}{\partial q_k} \right)(MCFk - 1) > 0 .$$

This expression is well known in public finance as marginal excess burden *MEB*. Multiplication with the q_k gives the additional DM amount that the government would need in order to fulfill the necessary condition for a double dividend. This amount is calculated in the next table for the energy and gasoline tax and for the four specifications of welfare weights.

DM	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB
$q_{04}MEB_{04}^1$	-120,51	-121,63	-134,21	-111,77	-131,23	-116,63
$q_{04}MEB_{04}^2$	-62,18	-63,30	-75,89	-53,44	-72,90	-58,30
$q_{04}MEB_{04}^3$	-50,11	-51,23	-63,81	-41,37	-60,83	-46,23
$q_{04}MEB_{04}$	65,00	63,88	51,30	73,74	54,28	68,88
$q_{08}MEB_{08}^1$	-50,36	-50,48	-58,19	-62,33	-78,14	-54,62
$q_{08}MEB_{08}^2$	4,44	4,32	-3,40	-7,54	-23,35	0,18
$q_{08}MEB_{08}^3$	19,15	19,03	11,31	7,17	-8,64	14,89
$q_{08}MEB_{08}$	88,10	87,98	80,26	76,12	60,31	83,83
DM	tpAIDS	tpPARA	tpALLG	tpBEWLEY	tpAR	tpAB

Table 13: *MEB* of an energy and gasoline tax increase.

As expected from standard results of optimal taxation, when the proceeds of an energy or gasoline tax are recycled in a lump sum fashion, it is impossible to compensate all households. This can be seen in rows 5 and 9. For the energy tax the additional amount that the government needs to compensate all households, lies between DM 51,30 and 73,74. For the gasoline tax this amount lies between DM 60,31 and 88,10. It is important to note that the number of all households has been normalized to one when these numbers were calculated. For the energy tax it is always possible to compensate a single household type. This is not so for the gasoline tax. In the demand specifications that model technological progress there exist cases where it is not possible to compensate household types 2 and 3 even if all the marginal revenue from a gasoline tax increase is returned to them. It can be also seen that the gasoline tax is more distortionary than the energy tax. In fact, the table in appendix A suggests that the gasoline tax is the most distortionary indirect tax in the German tax system, when only private welfare is considered.

5. Conclusions

The main result of this paper is the lack of empirical evidence supporting the double dividend hypothesis of a marginal revenue neutral environmental tax reform, when the energy or gasoline tax is raised. Good candidates for an environmental tax reform that yields a double dividend are the following pairs: cut the tax on personal goods and raise the tax on cosmetics- or cultural expenditures, respectively. Other pairs are to raise the tax on cultural goods and to cut the tax on clothing or transportation expenditures. One can also conclude that the least expensive way to raise the energy or gasoline tax in terms of private welfare is to recylce the additional revenue in form of tax cuts on personal goods. This is so, because personal goods have the highest marginal cost of public funds next to energy and gasoline and also a comparable high ranking of the measure for environmental benefits. Analogous arguments apply for increases of the tax on cultural goods. Hence, we have found evidence that an environmental tax reform could yield a double dividend if taxes on personal goods and cultural goods are changed.

In order to derive these results we have estimated six dynamic specifications of the Almost Ideal Demand System (AIDS). This gives us also the possibility to see how stable the policy suggestions are and to which degree they depend on the dynamic specification. In general we find that the demand specification seems to be the most important for household type 3. For this household type the correlation coefficients are the lowest.

At least for the Pareto improving tax reforms our suggestions show a certain degree of consistency. All demand systems that suggest tax changes for the same pair of commodities also suggest tax changes in the same direction.

One of the major obstacles to the practical application of optimal taxation theory is the dependence of the results on the specification on the demand systems used to estimate the reactions of the consumers. Previous work has shown that especially the dynamic specification seems to play a role. Therefore, our strategy was to estimate different dynamic specifications of a demand system and to show that at least the major policy conclusions can be considered as stable.

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Appendix A.

Rankings of the *MCF* and *EB* for all commodities and demand specifications

	tpaids	tppara	tpallg	tpbewley	tpar	tpab
food/EB	5	6	5	3	5	5
MCF111	7	6	7	7	7	7
MCF100	4	4	3	4	4	4
MCF010	6	6	6	7	6	7
MCF001	9	9	9	10	10	9
cloth/EB	1	2	1	1	2	1
MCF111	6	8	6	6	9	6
MCF100	8	9	8	9	9	8
MCF010	7	8	5	6	7	6
MCF001	5	7	4	6	8	5
rent/EB	8	8	6	8	7	8
MCF111	5	5	4	4	6	5
MCF100	2	2	2	2	2	2
MCF010	5	4	4	4	5	4
MCF001	8	6	8	8	9	7
energ/EB	9	9	9	9	9	9
MCF111	2	2	3	3	3	2
MCF100	1	1	1	1	1	1
MCF010	2	2	3	2	3	2
MCF001	4	4	6	3	6	4
house/EB	2	3	3	2	8	2
MCF111	9	9	9	9	8	10
MCF100	9	8	9	8	8	9
MCF010	9	9	9	9	9	9
MCF001	10	10	10	9	5	10
cosm/EB	7	7	7	4	4	7
MCF111	10	10	10	10	5	9
MCF100	7	7	7	6	5	7
MCF010	10	10	10	10	10	10
MCF001	6	8	5	4	3	6
trans/EB	4	4	8	5	3	4
MCF111	4	4	2	5	4	3
MCF100	6	6	5	7	6	6
MCF010	4	3	2	5	4	3
MCF001	3	3	2	5	4	3

gas/EB	10	10	10	10	10	10
MCF111	1	1	1	1	1	1
MCF100	3	3	4	5	7	3
MCF010	1	1	1	1	1	1
MCF001	1	1	1	1	2	1
cult/EB	6	5	2	6	6	6
MCF111	8	7	8	8	10	8
MCF100	10	10	10	10	10	10
MCF010	8	7	8	8	8	8
MCF001	7	5	7	8	7	8
pers/EB	3	1	4	7	1	3
MCF111	3	3	5	2	2	4
MCF100	5	5	6	3	3	5
MCF010	3	5	7	3	2	5
MCF001	2	2	3	2	1	2
	tpaids	tppara	tpallg	tpbewley	tpar	tpab

Appendix B.

Inverse of the distributional characteristisc

commodity	X_i/x_i^1	X_i/x_i^2	X_i/x_i^3
food	9,84	2,54	1,98
cloth	16,94	2,65	1,78
rent	8,86	2,57	2,01
energ	7,53	2,47	2,17
houseex	14,21	2,87	1,72
cosm	11,31	4,15	1,49
trans	14,58	2,60	1,83
gas	20,57	2,35	1,90
cult	19,53	2,68	1,74
pers	13,84	2,86	1,73

Ranking of the inverse of the distributional characteristisc

	X_i/x_i^1	X_i/x_i^2	X_i/x_i^3
food	3	3	8
cloth	8	6	5
rent	2	4	9
energ	1	2	10
houseex	6	9	2

cosm	4	10	1
trans	7	5	6
gas	10	1	7
cult	9	7	4
pers	5	8	3

Appendix C.

Sensitivity to demand specification-Spearman rank correlations

	tpAIDS	tpPARA	tpALLG	tpBewley	tpAR
tpPARA/EB	0,95				
MCF111	0,96				
MCF100	0,99				
MCF010	0,95				
MCF001	0,90				
tpALLG/EB	0,77	0,76			
MCF111	0,94	0,90			
MCF100	0,98	0,96			
MCF010	0,84	0,90			
MCF001	0,95	0,81			
tpBewley/EB	0,82	0,65	0,68		
MCF111	0,98	0,94	0,89		
MCF100	0,93	0,94	0,89		
MCF010	0,98	0,92	0,83		
MCF001	0,93	0,81	0,84		
tpAR/EB	0,68	0,77	0,48	0,50	
MCF111	0,75	0,76	0,66	0,73	
MCF100	0,84	0,85	0,84	0,96	
MCF010	0,99	0,92	0,79	0,96	
MCF001	0,68	0,56	0,66	0,79	
tpAB/EB	1,00	0,95	0,77	0,82	0,68
MCF111	0,98	0,94	0,96	0,93	0,76
MCF100	1,00	0,99	0,98	0,93	0,84
MCF010	0,95	0,96	0,95	0,95	0,92
MCF001	0,99	0,89	0,94	0,92	0,66