Income, Energy Taxation, and the Environment

An Econometric Analysis

by

Tarek Ghalwash

Abstract

This thesis consists of four papers: two of them deal with the relationship between consumption, energy taxation, and emissions on macro level, and two of them focus on the effects of changes in consumption and income on the environmental quality on a micro level.

The main objective of **paper [I]** is to examine how exogenous technological progress, in terms of an increase in energy efficiency, affects consumption choice by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x). The aim of the paper is closely related to the discussion of what is known as the "rebound effect". To neutralize the rebound effect, we estimate the necessary change in CO_2 tax, i.e. the CO_2 tax that keeps CO_2 emissions at their initial level. In addition, we estimate how this will affect emissions of sulphur dioxide and nitrogen oxides. The results indicate that an increase in energy efficiency of 20 percent will increase emissions of CO_2 by approximately 5 percent. To reduce the CO_2 emissions to their initial level, CO_2 tax must be raised by 130 percent. This tax increase will reduce the emissions of sulphur dioxide to below their initial level, but will leave the emissions of nitrogen oxides at a higher level than initially.

One of the premises implied in **paper [II]** is that the changes in consumer prices, as a result of changes in environmental taxes, may send a different signal to the consumer compared with other changes in consumer prices, such as changes in producer price. In addition, this assumed difference in the signaling effect of the changes in environmental taxes, compared to changes in the producer price, may also differ between different commodities. To achieve the objectives a system of demand functions for Swedish households is estimated. To test for the signaling effect of environmental taxes the consumer price for energy goods is partitioned into a producer price part and a tax part.

In **Paper [III]**, we estimate the income elasticity of demand for recreational services and other traditional groups of goods in Sweden and we test for potential changes in such estimates over the twentieth century. The paper uses Swedish household surveys for the years 1913, 1984, 1988, and 1996. Because of the difficulty of directly observing the demand for recreational services, we employ an indirect methodology by using the demand for some outdoor goods as proxies for the recreational services demand.

In **paper [IV]**, we investigate the relationship between pollution and income at the household level. Here we want to investigate, and hence contribute to the existing literature, under what conditions concerning individual preferences and the link between consumption and pollution a linear relationship is to be expected, but also to empirically assess the relationship. To achieve our objective we formulate a model determining different type of households' choice of consumption for goods. Furthermore we link the demand model to emission functions for the various goods. The results from the empirical analysis show that, at least in a close neighborhood of observed income/pollution, we can reject linearity for all three types of pollutions, CO_2, SO_2, and NO_x. According to our results the pollution/income relationships are all strictly concave. Thus the implication is that the income distribution seems to matter in the sense that equalization of income will lead to higher emissions. Furthermore it is shown that the slope as well as the curvature differ between different types of households, which means that preferences differ across households.

Keywords: Household consumption, energy demand, emissions, rebound effect, energy taxation, tax elasticities, environmental services, income elasticities, Engel Curves, income distribution.

Acknowledgment

Completing this thesis, a product of several years' work, I feel deeply indebted to a great many people who have greatly inspired and supported me during my Ph.D study at the Department of Economics, Umeå University and the writing of this thesis.

I would first like to thank my supervisor *Runar Brännlund*. I am very grateful to *Runar* for accepting to become my advisor, and for all the help and encouragement during these years. His expertise, continuous support and invaluable criticism were the foundations of this thesis. Despite his busy schedule, he always created the necessary time to receive me, provide me with new insights and discuss the progress of this work. Besides, he always responded quickly the multiple e-mails and different versions of the manuscript. It is a real honour for me to complete this work under his supervision.

I want to express my sincere gratitude to *Jonas Nordström*, my co-author on one paper in the thesis. Working with *Jonas* has been a true privilege, and a fruitful learning experience. *Jonas* has kindly read various parts of my work and has given valuable praise and criticism. I am also grateful to *Karl-Gustaf Löfgren* and *Kurt Brännäs,* for their careful and precise work with helpful comments and suggestions to improve the form and contents of the manuscript. *Karl-Gustaf* was the discussant at my final seminar and his expertise and thoughtful reading of my last two papers were very helpful. *Kurt* deserves special thanks for reading various drafts of my papers, and providing comments that improved the work substantially.

I think that even though being a Ph.D. student is stressful and difficult, every day during the last five years I have been happy to go to work. The atmosphere in the department of economics has made all the difference. There are so many friends and colleagues to thank for that. I am sincerely grateful to all my colleagues for all your help during the difficult first year. I wish also to thank my old friend *Ahmed Ebrahim* for keeping in touch, and being interested in my work when it was in my mind. I am also greatly thankful to *Marie Hammarstedt* and *Eva Cederblad* for all their help throughout the years.

There is not enough space to mention all my friends who indirectly contributed to this thesis, even if I had a complete record of their contributions.

Finally, a very special thanks and recognition for my wife, *Reham* for putting up with the long hours, for listening to my complaining, and most of all, for always believing that I could do it. *Nouran* and *Mariam*, when you grow up and are able to realize the meaning of love, you will know that you were, still and will always be the best and most important part of my life. Thank you for making me the happiest father.

This thesis consists of an introduction part and four self- contained papers. In the introduction the papers will be referred to by the numbers in brackets.

[I] Brännlund, R., Ghalwash, T. and Nordström, J. (2005). Increased Energy Efficiency and the Rebound Effect: Effects on Consumption and Emissions. *Energy Economics*. (Article in press.)

[II] Ghalwash, T. (2005). Energy Taxes as a Signaling Device: An Empirical Analysis of Consumer Preferences. *Energy Policy*. (Article in press.)

[III] Ghalwash, T. (2006). Demand for Environmental Quality: An Empirical Analysis of Consumer Behavior in Sweden. *Umeå Economic Studies* 676.

[IV] Brännlund, R. and Ghalwash, T. (2006). The Income-Pollution Relationship and the Role of Income Distribution: Evidence from Swedish Household Data. *Umeå Economic Studies* 677.

1. Introduction

The four papers included in this thesis can be divided into two main parts. The first part consists of papers [I] and [II] and deals with the relationship between consumption, energy taxation, and emissions on the macro level. The second part focuses the role of income on changes in consumption environmental quality, and includes paper [III] and [IV]. This introduction presents the two parts and summarizes the corresponding papers along with a general discussion of the related research topics and relevant literature.

1.1 The relationship between energy taxation, consumption and emissions.

One of the most serious problems that the humanity faces today is the continuous deterioration of the natural environment. Environmental protection has been an intriguing and tough issue to most economists. In the development of economic theory environmental issues have mostly been viewed as market failures due to missing markets and, therefore, the suggested solutions have been public intervention through specific activities by governments (see Pigou, 1920 and Dasgupta and Heal, 1979). Since energy consumption is intrinsically contributing not only to production of goods and services, but also to pollution, it is believed that the consumers of energy must pay not only the energy market price, but also the marginal costs that are related to energy consumption. From this point of view, energy policy can effect energy demand and hence improve allocative efficiency. Energy saving is viewed as one important option for preventing emission of greenhouse gases. Furthermore, when energy saving is reducing the spatial and temporal density of energy consumption, it supports a rising market share of renewable energy sources (Barzantny et al., 2003). In addition, energy saving plays a role in reducing the vulnerability for import dependency and supply disruptions (Adriaan et al., 2006). Despite these virtues, energy saving and energy efficiency - as typical demand side options - appear to be harder to “sell” compared with other options that focus on the supply side such as Power station, high-voltage networks, and search for new oil reserves.

The application of efficiency improvement in order to achieve reductions in pollution and resource consumption have been on the political agenda since the early 1970s and is now frequently suggested as a measure towards the realization of a sustainable development (see e.g. World Commission on Environment and Development, 1986; United Nations, 1995; Organisation for Economic Co-operation and Development, 1995 and 1998). Recent advocates of efficiency improvements have also introduced new concepts. One example is Eco-efficiency, proposed by the World Business Council for Sustainable Development (1999) that introduced measures to reduce ecological impacts and resource intensity throughout the life cycle of goods and services.

While emphasizing the importance of efficiency improvement the literature has, so far, to a large extent ignored the possibility of any “take-back” or rebound effects. Rebound can here be defined as economic forces (demand side effects) that over time weaken the potential (technical) savings associated with efficiency improvements.[1] One important cause of such effects is that higher efficiency reduces energy costs, which again increases demand. Khazzoom (1980, 1986, 1987, and 1989) and Khazzoom et al. (1990) discuss the significance of such effects. Khazzoom questions the adequacy of energy saving programs since greater efficiency could lead to increased, rather than decreased, energy demand. Khazzoom (1987) also presents criticism of Lovins (1985) for ignoring rebound effects when savings from more efficient mandated appliances were assessed. This again triggered a debate on the importance of rebound-effects (see for example Lovins 1988; Henly et al. 1988; Khazzoom 1989). The controversy reappeared a few years later in the context of fossil fuel consumption and emissions. A forerunner to this debate was a work by Manne and Richels (1990), who analyzed the economic costs arising from CO_2 emission limits. This study showed that the autonomous energy efficiency index (AEEI) had a dramatic impact on the economic cost of reducing CO_2 emissions. Brookes (1990) considers efficiency improvements to be an inappropriate way of combating the greenhouse effect. In this thesis paper [I] examines the rebound effect using Swedish consumption data. More specifically it is investigated how exogenous technological

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[1] See Berkhout et al. (2000) for a definition of the rebound effect. A survey of the rebound effect can be found in Greening et al. (2000).

progress, in terms of an increase in energy efficiency, affects consumption choice by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x).

Energy taxes become another reason for such concern regarding efficiency. Many economists have argued that both consumption and production of energy have contributed disproportionately to the generation of various pollution compared with other economic activities. Therefore taxing energy could be a sensible and righteous way to discourage environmentally demanding activities (see for example Goulder 1995 a and b and Parry 1997). On the other hand, energy taxes are relatively efficient instruments for obtaining government revenue in comparison with other taxes (Lee and Walter 1986). The main reason for the fiscal efficiency is that energy supply and demand are relatively inelastic in comparison with other commodities. Under these circumstances a tax on energy can potentially improve efficiency in both the environmental and fiscal dimension. Paper [II] is related to this strand of literature by examining consumer reaction to the introduction, or the change, of energy taxes for different commodities. The paper's objective is to test if changes in the consumer price that results from the introduction, or change, in environmental taxes give a different signal to the consumer, compared to a change in the consumer price that results only from a producer price change. Understanding consumer response to environmental taxes for different commodities is believed to be critical to the environmental policy makers.

Data used in paper [I] and [II]

The data used in paper [I] are time-series data of Swedish consumption of non-durable goods for the period 1980-1997, and emission data related to consumption of each good. In paper [II], the time series are updated to cover the period 1980-2002, and also appended with data on energy taxation. The consumption data used are part of the Swedish National Account (SNA), and the emission data are part of the Swedish Environmental Accounts (SEA).

The consumption data we use in paper [I] and [II] are aggregated into four main commodity groups: food, transports, heating, and other non-durable goods. Expenditures on transportation are in turn divided into expenditure on petrol, car maintenance, and on public and other forms of transport. In the same way, expenditure on heating is divided into three different goods: electricity, oil, and district heating. Finally, other non-durable goods are divided into recreation goods, clothes, medical treatment, domestic appliances and other goods/services.

1.2 The relationship between income, consumption and emissions.

Through consumption, we maintain life and extract pleasure from the physical world. Consumption guarantees subsistence, but it affects the surrounding nature. There exists an intricate and sensitive balance between human activity and the environment. Resources are scarce; we must contemplate what is a good way of using them. We are forced to use them since without consumption there can be no life. Thus, we must accept that in order to maintain society people will consume parts of nature. Sometimes the consumption and usage can be detrimental to the state of nature.

Johan Krutilla predicted in 1967 that people will demand more services of nature in the future (Krutilla, P.1967):

> “Given the phenomenal rise of car camping, if this activity will spawn a disproportionate number of future back-packers, canoe cruisers, cross-country skiers, etc., the greater will be the induced demand for wild, primitive, and wilderness-related opportunities for indulging such interest. Admittedly, we know little about the demand for outdoor experiences which will depend on unique phenomena of nature - its formation, stability, and probable course of development. These are important questions for research, results of which will have significant policy implications.”

Paper [III] addresses the issue raised by Krutilla, by examining the demand for outdoor recreation in Sweden. If outdoor experience is, and always will remain, a luxury good, then the answer is trivial: demand will rise with income. However, little is known about demand for outdoor recreation. It is an empirical question whether outdoor experience is considered by consumers to be luxurious, and if it will stay so over time. Further, we do not know how changes and alterations of our surroundings will affect such demand.

Quality improvements of products, price reductions, introduction of substitutes and complements will affect such demand. Therefore, a study of such demand over time is worthwhile. Weitzman (1992), calls for estimates of demand structures, the debate about future limits to growth is ultimately an empirical one. The outcome depends upon deep structural parameters and assumptions about human behavior. In paper [III], we attempt to sketch a pattern of that demand that may have ramifications on policy. If Krutilla's argument is still valid, the demand for nature services will increase and possibly justify proactive policy formation towards rehabilitation and protection of precious environments and nature attributes that provide valuable services.

Related to Krutilla's hypothesis is the notion of an environmental Kuznets curve. This curve shows an inverted U-shaped relation between pollution and per capita income, indicating that pollution increases in the early stages of economic development in a country up to a turning point, after which pollution starts to decrease with the increase in per capita income. The EKC idea has triggered a good deal of research, theoretical as well as empirical. The theoretical literature has focused mostly on assumptions regarding the relation between technology/preferences and emissions (Lopez, 1994, Selden and Song, 1995, McConell, 1997, Chichilnisky 1998, de Groot 1999). In general, empirical models are of a reduced form type using cross-country data (Grossman and Krueger, 1995, Stern and Common, 2001).

The recent literature in this area emphasizes the importance of the income distribution for the aggregate relation between pollution and income (see for example Stern, 1998, Torras & Boyce, 1998 and Heerink et al. 2001, Huang, 2005). The conclusion from these studies is that using mean income may lead to biased results due to skewed income distributions: Instead, the use of the median income is proposed (see Stern, 1998). According to Bimonte (2002), an increase in equity, measured by the Gini coefficient, shifts the EKC curve leftwards, implying a turning point at a lower income level. Heerink et al. (2001), on the other hand, get the opposite result for several environmental indicators analysed on a cross section of different countries. Thus, according to their results, there may be a trade off between income equality and environmental quality. More importantly, they conclude that this effect may be due to a strictly concave pollution-income relation at the individual level. Paper [IV] investigates the relationship between pollution and income at the household level and relates this to aggregate emissions under different assumptions concerning the income distribution. The results indicate that pollution-income relationship for Swedish households is non-linear, implying that the income distribution matters. Thus in an analysis of the relation between economic growth and income for a country one has to consider how growth is distributed among the people in order to be able to say something about how aggregate emissions will change.

Data used in paper [III] and [IV]

The data used in paper [III] are cross-section data from four different Swedish Family Expenditure Surveys (FES), 1913, 1984, 1988, and 1996. The first household expenditure survey in Sweden was done in 1913. It covered approximately 900 households in eight towns. The 1984 survey included 4354 households, the 1988 survey 3764 households, and 1104 households was included in the 1996 survey.

In paper [IV], we use the same cross-section data except for the 1913 survey. In this paper too, we make use of the emission data from the Swedish Environmental Accounts and link them to each type of non-durable good aggregate. For the choice of consumption of non-durable goods we aggregate household expenditure into eight goods (food, beverages, heating, petrol, other transportation, recreation, clothes and other non-durable goods).

2. Summary of the papers

Paper [I]: Increased Energy Efficiency and the Rebound Effect: Effects on Consumption and Emissions.

The main objective of this paper is to examine how exogenous technological progress, in terms of an increase in energy efficiency, affects consumption choices made by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NOx). The aim of the paper is closely related to the discussion of what is termed the “rebound effect”. To neutralize the rebound effect, we estimate the necessary change in CO_2 tax, i.e. the CO_2 tax that keeps CO_2 emissions at their initial level. In addition, we estimate how this will affect emissions of sulphur dioxide and nitrogen oxides. The results indicate that an increase in energy efficiency of 20 percent will increase emissions of CO_2 by approximately 5 percent. To reduce the CO_2 emissions to their initial level, the CO_2 tax must be raised by 130 percent. This tax increase will reduce the emissions of sulphur dioxide to below their initial level, but will leave the emissions of nitrogen oxides at a higher level than initially. Thus, if marginal damages from sulphur dioxide and nitrogen dioxide are non-constant, additional policy instruments are needed.

Paper [II]: Energy Taxes as a Signaling Device: An Empirical Analysis of Consumer Preferences.

This paper presents an econometric study dealing with household demand in Sweden. The main objective is to empirically examine the differences in consumer reaction to the introduction of, or the change in, environmental taxes. The main focus is on environmental taxes as a signaling device. The hypothesis is that the introduction of an environmental tax provides new information about the properties, or the characteristics, of the directly taxed goods. This in turn may affect consumer preferences for these goods, hence altering the consumption choice. The results of the study show that changes in environmental taxes have a significant signaling effect on the demand for residential heating in the sense that the consumers are more sensitive to a tax change than a producer price change. The result from the econometric analysis also shows that all goods have negative own-price elasticities, and positive income elasticities. Concerning the signaling effect of environmental taxes the results are somewhat ambiguous. The tax elasticity for energy goods used for heating seems to be significantly higher than the traditional price elasticity, whereas the opposite seems to be the case for energy goods used for transportation. It may be the case that there are large differences between different types of households, depending on family size, income level, place of residence, etc., which is not captured using macro data.

Paper [III]: Demand for Environmental Quality: An Empirical Analysis of Consumer Behavior in Sweden.

In this paper we estimate the income elasticity of demand for recreational services and other traditional groups of goods in Sweden and we test for potential changes in such estimates over the twentieth century. Because consumption of recreational services is not directly observed in the market, the paper employs an indirect methodology by using the demand for some outdoor goods as proxies for recreational services demand. Consistent with most prior research, our results confirm the expectation that recreational services, as a public good, represent a luxury good in Sweden. According to this result, the expenditure on environmental services increases with income. This is true when everything else is the same. When preferences, prices, nature attributes, and nature experience production structure change, it is difficult to predict the demand for environmental services in the future. Our results also show that the income elasticities for traditional goods are stable over time, which indicates that the consumer preferences for expenditure on these specific commodities are not changing over time.

Paper [IV]: The Income-Pollution Relationship and the Role of Income Distribution: Evidence From Swedish Household Data.

The main purpose with this study is to examine the relationship between pollution and income at the household level. The study is motivated by the recent literature emphasizing the importance of the income distribution for the aggregate relation between pollution and income. The main finding of previous studies is that if the individual pollution-income relationship is non-linear, then aggregate pollution, for say a whole country, will depend not only on average income, but also on how income is distributed. To achieve our objective we formulate a model determining different types of households' choice of consumption for goods. Furthermore, we link the demand model to emission functions for the various goods. The theoretical analysis shows that unless we impose very restrictive assumptions on preferences and the emission functions, we can not a priori determine the slope or the curvature of the pollution-income relation. The empirical analysis shows that, given the model used, the pollution-income relation has a positive slope in Sweden and is strictly concave for all three pollutants under consideration (CO_2, SO_2, NO_x), at least in the neighborhood of the observed income for an average household. Furthermore the results show that the curvature of the relation differs between different types of households. We also show that altering the prevailing income distribution, given constant average income, will affect aggregate emissions in the sense that an equalization of incomes will give rise to an increase in emissions. One implication is that the development of aggregate pollution, due to growth, not only depends on the income level, but also on how growth is distributed.

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Energy Economics xx (2005) xxx–xxx

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Increased energy efficiency and the rebound effect: Effects on consumption and emissions

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Accepted 5 September 2005

Abstract

The main objective of this paper is to examine how exogenous technological progress, in terms of an increase in energy efficiency, affects consumption choice by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x). The aim of the paper is closely related to the discussion of what is termed the “rebound effect”. To neutralise the rebound effect, we estimate the necessary change in CO_2 tax, i.e. the CO_2 tax that keeps CO_2 emissions at their initial level. In addition, we estimate how this will affect emissions of sulphur dioxide and nitrogen oxides. The results indicate that an increase in energy efficiency of 20% will increase emissions of CO_2 by approximately 5%. To reduce the CO_2 emissions to their initial level, the CO_2 tax must be raised by 130%. This tax increase will reduce the emissions of sulphur dioxide to below their initial level, but will leave the emissions of nitrogen oxides at a higher level than initially. Thus, if marginal damages from sulphur dioxide and nitrogen dioxide are non-constant, additional policy instruments are needed.

JEL classification: D12; H31; Q41

Keywords: Household consumption; Energy demand; Emissions; Rebound effect; Taxation

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1. Introduction

The main objective of this paper is to examine how exogenous technological progress, in terms of an increase in energy efficiency, affects consumption choice by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide

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0140-9883/$ - see front matter © 2005 Published by Elsevier B.V.
doi:10.1016/j.eneco.2005.09.003

(NO_x). The aim of the paper is closely related to the discussion of what is known as the "rebound effect". Briefly, the rebound effect can be described as the direct and indirect effects, such as substitution and income effects, induced by a new energy-saving technology. This rebound effect may then partly, or entirely, offset the initial or direct energy saving resulting from a new technology. As a consequence, the effects on emissions become less clear-cut. A second objective is to estimate the change of the shadow price of CO_2 emissions in a scenario where we have an exogenous change in energy efficiency, and where we maintain CO_2 emissions at their initial level. A third objective is to estimate the effects on SO_2 and NO_x emissions of a policy maintaining CO_2 emissions at their initial level.

The motivation for our paper is threefold. The first can be traced to the existing literature on the rebound effect (RE). The RE is usually discussed in connection with "new energy-saving technology". A new energy-saving technology essentially implies a lower energy bill, which can be viewed as a reduction of the real price of energy services. Thus, if petrol costs less per transport unit, car use may increase, which partially offsets the initial energy-saving potential. Furthermore, lower energy costs increase real income, which leads to an increase in consumption of other goods. This in turn offsets the emission reductions from the initial energy saving. A third effect may be denoted general equilibrium effects, since changes in aggregate consumption patterns may lead to structural change and changes in relative prices. Taken together, these effects can be denoted the rebound effect.[1] Related to this is the long-standing discussion of how growth and technological progress affect the natural environment. On one side the argument has been, and remains, that economic growth inevitably leads to more emissions and hence a degradation of the natural environment (Meadows et al., 1972, 1992). On the other side, it has been suggested that the traditional view of the relationship between growth and the environment is too static with respect to technology and preferences, and that the combination of economic growth and changes in preferences may lead to environmental improvements as a country becomes wealthier. The latter argument can be traced to a report by the World Bank (World Development Report 1992) showing that low income countries have relatively low emissions and middle income countries high emissions, but that high income countries have low emissions. Thus, the relationship between income and emissions is in the shape of an inverted U-curve. The conclusion would then be that emissions will decrease as a country becomes wealthier. This U-shaped curve is usually called the Environmental Kuznets Curve (EKC).

A second motivation can be deduced from the Swedish commitment to reduce emissions of greenhouse gases, such as CO_2. It should be evident that the policy necessary to fulfil such an objective may differ substantially depending on technological progress, among other things. Thus it is of interest to estimate the shadow price, or the necessary tax change, of CO_2 under a growth (or technological progress) scenario.

A third motivation follows from the increasing energy-saving efforts in Sweden, and elsewhere in Europe, to reduce emissions of greenhouse gases. Subsidies for such efforts may then, according to the discussion above, have a rebound effect that counteracts the direct emission reduction potential through higher energy efficiency. By taking substitution and income effects into account we may shed empirical light on this issue.

Our definition of efficiency improvements includes both new technology that replaces the old capital stock, and new technology that makes the present capital stock more efficient. An example of the latter would be a new motor oil that improves the efficiency of an engine.

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[1] See Berkhout et al. (2000) for a definition of the rebound effect. A survey of the rebound effect can be found in Greening et al. (2000).

To achieve our objectives, we formulate and estimate an econometric model for non-durable consumer demand in Sweden that utilises macro data. The system of demand equations is derived assuming cost-minimising households. The model employed here is essentially a three-stage budgeting model 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, we assume that the household allocates its total expenditure for non-durable goods on different non-durable commodity aggregates or groups. Given the allocation for each non-durable commodity group, households in the third stage allocate their group expenditures on the various goods within the group. The resulting model is then used to simulate various changes in energy efficiency.

The rest of the paper is structured as follows. In Section 2 we discuss in greater detail how consumption patterns and emissions are linked, as well as provide a description of the data used in the analysis. The modelling framework as well as aggregation issues and the econometric model are outlined in Section 3. Results from the econometric model are presented in Section 4, and the result of the simulations is given in Section 5. The paper ends with a number of concluding remarks in Section 6.

2. Consumption and emissions

The data used in this study are time series data on Swedish consumption of non-durable goods, and emission data linked to each type of good.[2] The consumption data we use here are aggregated into four main groups: food, transport, heating, and other non-durable goods (see Fig. 1). Expenditures on transportation are in turn divided into car expenditures (petrol and maintenance) and expenditure on public and other forms of transport (air, train and bus). In the same way, expenditure on heating is divided into three different goods: electricity, fuels (oil and solid fuels), and district heating. Finally, other non-durable goods are divided into recreation goods, clothes and shoes, medical treatment, domestic appliances and other goods/services.

The goods considered give rise to various emissions. In this study we focus on emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Emissions from each good are defined as:

$$E_{ikt} = \theta_{ikt}\tilde{x}_{it}$$

where $\tilde{x}_{it}$ is the real consumption of good i in period t, θ_{ikt} is the emission of substance k per unit of real consumption of good i in period t.[3] Index i defines goods, $k = CO_2, SO_2, NO_x$.

Emissions from the various subgroups of goods can now be written as:

$$E_{rkt} = \sum_{i \in r} E_{ikt} = \sum_{i \in r} \theta_{ikt}\tilde{x}_{(r)(i)t},$$

where r denotes groups of goods, i.e. $r = 1, \ldots, n$. Total emissions from private consumption are then:

$$E_{kt} = \sum_{r} E_{rkt}, \quad k = CO_2, SO_2, NO_x$$

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[2] The complete data set can be found on the website http://www.econ.umu.se/~runar.brannlund/data_ee_2005.xls.

[3] The emission coefficient θ_i measures the direct emissions from the households' consumption of heating and transport. For all other goods, the emission coefficients measure the indirect emissions from the households' consumption, i.e. the indirect emissions capture the emissions from the production of the goods that the household consumes.

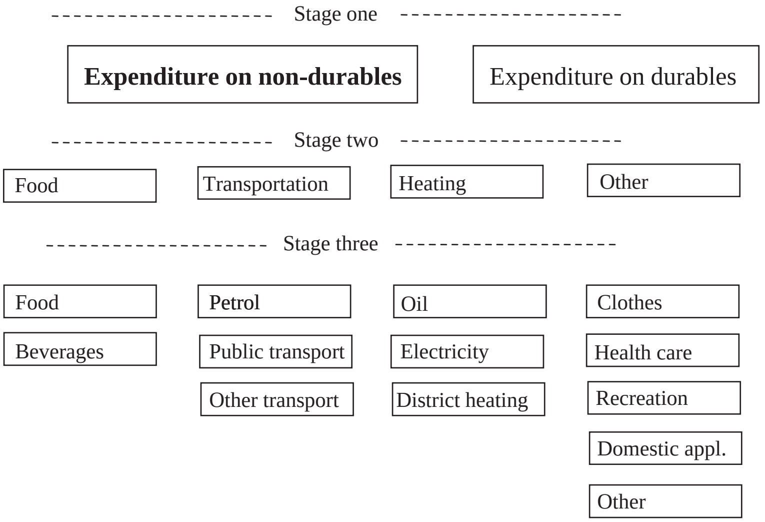

Fig. 1. Three stage budgeting model.

The change in emissions due to a price change of good j is then:

$$\frac{\partial E_{kt}}{\partial p_{jt}} = \sum_i \frac{\partial \tilde{x}_{it}}{\partial p_{jt}} \frac{\partial E_{kt}}{\partial \tilde{x}_{it}} = \sum_i \frac{\partial \tilde{x}_{it}}{\partial p_{jt}} \theta_{ikt}, \quad k = \mathrm{CO_2}, \mathrm{SO_2}, \mathrm{NO}_x$$

After some manipulations, we can express the emission change in elasticity form as:

$$\frac{\partial E_{kt}}{\partial p_{jt}} \frac{p_{jt}}{E_{kt}} = \sum_i \theta_{ikt} \varepsilon_{ij} \frac{\tilde{x}_i}{E_{kt}}, \qquad k = \mathrm{CO_2}, \mathrm{SO_2}, \mathrm{NO}_x,$$

where ε_{ij} is the price elasticity of good j with respect to price i. Similarly, we obtain the emission change due to a change in total expenditures:

$$\frac{\partial E_{kt}}{\partial y_t} = \sum_i \frac{\partial \tilde{x}_{it}}{\partial y_t} \frac{\partial E_{kt}}{\partial \tilde{x}_{it}} = \sum_i \frac{\partial \tilde{x}_{it}}{\partial y_t} \theta_{ikt},$$

or

$$\frac{\partial E_{kt}}{\partial y_i} = \frac{y_t}{E_{kt}} = \sum_i \theta_{ikt} \varepsilon_{yi} \frac{\tilde{x}_i}{E_{kt}}.$$

where y_t is the total expenditure in period t and ε_{yi} is the expenditure elasticity of good i.

From Table 1 we see that car transport, with an expenditure share of 12%, contributes the largest proportion of both $\mathrm{CO_2}$ emissions (61%) and NO_x emissions (67%). Compared to the emissions of $\mathrm{CO_2}$ and NO_x, the $\mathrm{SO_2}$ share for transport is much smaller at 22%. One reason for the relatively low emissions of sulphur dioxide from car transport is the $\mathrm{SO_2}$ tax on petrol. In fact, the table reveals that electricity has the largest share of sulphur dioxide emissions, amounting to about 24%.

During the sample period (1980–1997) there was a substantial substitution from oil to electricity for domestic heating. For example, the expenditure share for both electricity and oil

Table 1
Expenditure shares and emission shares in 1997

	Percentage share of total expenditure	Percentage share of CO_2 emissions	Percentage share of SO_2 emissions	Percentage share of NO_x emissions
Car transport	11.7	60.9	21.9	67.4
Public transport	1.5	1.9	1.5	4.2
Other transport	1.6	1.1	0.7	1.3
Electricity	5.0	7.2	24.5	2.9
Oil	1.2	11.1	13.8	2.6
District heating	1.8	3.2	10.9	1.3
Food	19.0	6.4	10.0	11.1
Beverage	6.9	0.6	1.2	0.7
Recreation	6.9	1.6	3.8	2.9
Clothes	7.5	0.8	1.4	0.9
Medical treatment	3.9	0.4	0.7	0.4
Domestic appliances	7.2	1.1	2.2	1.1
Other goods/services	25.8	3.6	7.6	3.1
	100.0	100.0	100.0	100.0

The emissions from transport and heating are direct, whereas the emissions from all other goods are indirect.

was about 40% of total expenditures on heating in 1980.[4] The corresponding figures for 1997 were 62% for electricity and 14% for oil. Although the expenditure share for oil declined sharply over the sample period, its fraction of sulphur dioxide and CO_2 emissions remained relatively large.

From the table we also see that food consumption, with 19% of total expenditure, generates relatively large emissions of sulphur dioxide and NO_x. In relation to its share of expenditure, recreation also constitutes a relatively large share of the emissions of sulphur dioxide and NO_x.

3. The econometric model

In our model we assume a three-stage budgeting process, as described in Fig. 1. In the first stage total expenditures are allocated between durables and non-durables. The second stage comprises the allocation of non-durable expenditure between four groups of goods, in this case food, transportation, heating, and “other goods”. Finally, in the third stage, the consumer allocates the group expenditure on individual goods within the group.

In the specification of the demand system, we apply Deaton and Muellbauer’s (1980) Almost Ideal Demand model (AID model).[5] Denoting budget shares by w, total expenditure on non-durables by x, and group prices by $p_{(r)}$, we can write the demand for commodity group r in budget share form as

$$w_{(r)t} = \alpha_{(r)} + \sum_{s=i}^{4} \gamma_{(r)(s)} \ln p_{(s)t} + \beta_{(r)}(\ln x_t - \ln P_t), \quad r = 1,\ldots,4 \tag{1}$$

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[4] Compared to total expenditures this amounts to 3%.

[5] An advantage of this class of demand system is that it is less sensitive to multicolinearity in prices than for example the Translog model. In addition, the AID model can be extended to include quadratic terms in the logarithm of expenditures and still allow for exact aggregation. In Section 4, we present test statistics that suggest that the linear specification is sufficient for our data.

where t denotes time. The price index, $\ln P_t$, is here defined as Stone's price index, i.e. $\ln P_t = \sum_r w_{(r)t} \ln p_{(r)t}$. Stone's price index is also used to calculate the group price from the prices within the group, $\ln P_{(r)t} = \sum_i w_{(r)it} \ln p_{(r)it}$, $i = 1, \ldots, m(r)$.

The demand functions for the goods within the subgroups have the same functional form as the demand equations for the main groups. The demand function for goods within the rth group can accordingly be written as

$$w_{(r)it} = \alpha_{(r)i} + \sum_{j=1}^{m(r)} \gamma_{(r)ij} \ln p_{(r)jt} + \beta_{(r)i} \left(\ln x_{(r)t} - \ln p_{(r)t} \right), \quad i = 1,..,m(r), r = 1,\ldots,4 \tag{2}$$

where $w_{(r)it}$ is the within group budget share, $\ln p_{(r)j}$ is the price index of the jth good, $x_{(r)t}$ is total expenditure allocated to the rth group, and $p_{(r)t}$ is Stone's price index for the rth group.

Given this structure of weak separability, the econometric model consists of five separate systems of budget share equations. In the estimation adding up, homogeneity and symmetry restrictions are imposed for each demand system. With respect to the notation used for the main groups, these restrictions can be written as:

Adding up: $\sum \alpha_r = 1, \sum \beta_r = 0$

Homogeneity: $\sum_{s=1}^{4} \gamma_{rs} = 0$

Symmetry: $\gamma_{rs} = \gamma_{rs}, \quad \forall r, s$

Given estimates of the parameters at each "level", we can calculate price and expenditure elasticities, totally and conditional on the expenditures for each group. Using the main group notation and following Edgerton et al. (1996), the expenditure and uncompensated price elasticities are:

$$E_r = 1 + \frac{\beta_r}{w_r} \tag{3}$$

$$e_{rs} = \frac{\gamma_{rs} - \beta_r w_s}{w_r} - \delta_{rs} \tag{4}$$

where E_r denotes the expenditure elasticity and e_{rs} the uncompensated price elasticity; δ_{rs} is equal to one when $r = s$ and zero elsewhere.

Let us denote the within group expenditure elasticity for the ith good within the rth group of goods as $E_{(r)i}$, the group expenditure elasticity for the rth group of goods as $E_{(r)}$, and the total expenditure elasticity for the ith good within the rth group of goods as E_i, with an equivalent definition for the budget shares, w. In this case, we can calculate the total expenditure elasticity as

$$E_i = E_{(r)} E_{(r)i}. \tag{5}$$

In the same way, we can denote the within group price elasticity between the ith and jth goods within the rth group of goods as $e_{(r)ij}$, the group price elasticity as $e_{(r)(s)}$ and the total price elasticities as e_{ij}. The within group price elasticity assumes that group expenditure is unchanged in spite of the price change, while the total price elasticity allows for the relevant changes in group expenditure, and is given by

$$e_{ij} = \delta_{rs} e_{(r)ij} + E_{(r)i} w_{(s)j} \left(\delta_{rs} + e_{(r)(s)} \right) \tag{6}$$

If we look at Eq. (6) for two goods within the same group, we can see that the total price elasticity consists of two components. The first part is a direct effect, which represents the subgroup elasticity, while the second part is an indirect effect, which is a product of three factors. The first measures the relative change in the group price index when the price of the jth good changes (this is equal to $w_{(r)j}$); the second factor measures the effect a change in the price index has on group expenditure ($1+e_{(r)(s)}$), while the third factor measures the effect this change in within group expenditure has on the consumption of the ith good ($E_{(r)i}$).

We can also observe that if the own between group price elasticity $e_{(r)(r)}=-1$, then the group expenditure is unaffected by the price change and $e_{ij}=e_{(r)ij}$. On the other hand, if $e_{(r)(r)}=0$, then the price change produces a proportional effect on group expenditure.

Finally, we can note that alternative specifications of the demand system are also possible. One alternative would be to include the service value of the durable goods as an additional variable in the demand system, see for example Jorgenson and Slesnick (1987) and Slesnick (1992). This approach requires that we can observe the value (or level) of the capital stock. This information is not included in the national accounts nor, with the exception of cars, is it available in other Swedish data sources. However, a large fraction of the capital stock that is assumed to become more efficient is not owned by households. This is for example the case with planes, buses and trains within the transport group, and for district heating plants, hydroelectric power stations and nuclear power stations in the heating group.

Although the three-stage budgeting approach applied in this study may overestimate the effects of the energy efficiency increase, as we do not account for the adjustment process in the capital stock, the inclusion of a capital variable in the demand system does not necessarily imply better estimates. Furthermore, if it were possible to find good estimates of the value of the capital stock, we would also need to simulate the change in the value of the capital stock as a result of the increased energy efficiency.

4. Econometric results

The estimation results using Swedish quarterly consumption data for the period 1980:1–1997:4 are shown in Tables A1–A5 in Appendix A. Although the econometric model is based on a static model that is linear in expenditure, we have tested more flexible models within the AID family, such as the autoregressive model by Alessie and Kapteyn (1991) and the expenditure quadratic model (QAIDS) by Banks et al. (1997). None of these specifications proved to be superior to the model presented in Section 3.

For example is the p-value from a likelihood ratio (LR) test of a QAIDS model against a linear model 0.27 at the second stage[6] of the demand system. For the subgroups at the third stage, LR tests also suggest a linear expenditure specification for the food group [p-value 0.06] and the heating group [p-value 0.14], whereas the test statistics for the transport group suggest a non-linear specification. However, the elasticities for car and public transport, which account for the largest shares of greenhouse gas emissions, are close to each other in

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[6] I.e. the first estimated stage, where the equations for food, transportation and heating are included in the estimation of the demand system.

Table 2
Estimated own price and expenditure elasticities

	Own price elasticity	Expenditure elasticity	Total own price elasticity	Total expenditure elasticity
Main groups				
Food	−0.34	0.15		
Heating	−0.13	0.59		
Transportation	−0.09	0.99		
Other	−0.86	1.49		
Food				
Food(sub)	−0.84	0.77	−0.46	0.12
Beverages	−1.16	1.61	−0.88	0.25
Transports				
Car transport	−0.92	1.06	−0.15	1.06
Public transport	−0.09	0.52	−0.04	0.52
Other transport	−0.51	0.95	−0.42	0.95
Heating				
Electricity	−0.71	0.83	−0.24	0.49
District heating	−0.31	1.39	−0.05	0.82
Oil	−0.93	1.17	−0.79	0.69
Other				
Clothes	−0.52	1.29	−0.49	1.90
Health care	−0.21	0.31	−0.21	0.45
Recreation	−0.56	1.43	−0.54	2.13
Domestic appliances	−0.51	1.34	−0.49	2.00
Other goods	−0.66	0.81	−0.61	1.21

The total own price and expenditure elasticities are calculated according to Eqs. (5) and (6).

the linear and non-linear models.[7] We have therefore chosen to apply a linear specification for the total system.

To account for autocorrelation, a Newey-West estimator has been applied to calculate the covariance matrix. Based on Box-Ljung tests the number of moving average terms is set to 4 in these calculations. The results indicate that most of the estimated parameters are significantly different from zero. However, the homogeneity and symmetry restrictions can generally be rejected. The only exceptions are the subgroups for transportation and "other goods", where homogeneity cannot be rejected for the subgroup "other goods" and symmetry cannot be rejected for the transport subgroup.

In terms of R-squared, the fit of the equations are relatively good, with an R-square higher than 0.90 for all equations, except for food (0.80), district heating (0.76) and car transport (0.59). Given the parameter estimates, expenditure and price elasticities have been calculated according to Eqs. (3)–(6). The resulting elasticities are presented in Table 2.

The elasticities are evaluated at mean values for the final year of the sample. As the table reveals, all own price elasticities have a negative sign. In most cases the own price elasticities lie

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[7] In the QAIDS model the own *price* elasticity for car and public transport is estimated at −0.86 and −0.07 respectively, which can be compared to the own price elasticities from the linear model in Table 2 that amount to −0.92 and −0.09. The *expenditure* elasticities from the QAIDS model for car and public transport are 0.98 (1.06) and 0.60 (0.52), where the figures in parentheses refer to the estimates from the linear model.

between 0 and -1, which implies that a higher price of a good (with the other prices held constant) leads to an increase of the budget share for the same good, in spite of lower consumption of that good. Moreover, all goods have positive expenditure elasticities, implying that they are considered as normal goods.

The first column of Table 2 shows that the demand for "heating" and "transportation" is relatively insensitive to changes in the own price. For example, if the price of "transport" increases by 10%, "transport" demand will decrease by 0.9%. A corresponding increase in the price for "heating" reduces the demand for "heating" by 1.3%. Among the four different main groups, "other goods" have both the highest own price elasticity, -0.86, and the highest expenditure elasticity, 1.49. As one might expect, the table reveals a relatively low expenditure elasticity for food. The results also suggest that transport demand will increase at about the same rate as total expenditures, as the expenditure elasticity for transportation is close to unity.

Although the within group own price elasticity for car transport is relatively high (-0.92), the total own price elasticity for car transport becomes much lower (-0.15) as a result of the low price elasticity for the transportation group. The within group expenditure elasticities and the total expenditure elasticities for the goods within the transportation group are, on the other hand, almost identical since the expenditure elasticity for transportation is close to one.

Within "heating" we find that oil has the highest total own price (-0.79), while district heating has the lowest (-0.05). The highest total expenditure elasticities are found for clothes, recreation and domestic appliances. These results are what we might expect, i.e. that appliances and recreation are more of a luxury good than for example food.

The elasticities found in this study are in line with elasticities in other studies on Swedish data. Wall (1991) estimates for example the own price elasticity for petrol to be in the interval -0.10 to -0.15. Based on time series data from the national accounts, Hansson-Brusewitz (1997) estimates the own price elasticities for car transportation to be -0.15, public transport -0.39, electricity -0.32, and heating (district heating plus oil) -0.10. Brännlund (1997), who also uses time series data from the national accounts, estimates the own price elasticity for petrol to be -0.13, public transport -0.25, other transport -0.52, electricity -0.10, district heating -0.01 and oil -0.19.

5. Simulations

The objective of the simulations is to illustrate the effects of how exogenous technological progress, in terms of increased energy efficiency, affects consumption and emissions. A new energy-saving technology essentially implies a reduction in the energy cost per unit, which can be seen as a reduction of the price of energy services. This is also the approach taken in the simulations, where increased energy efficiency is modelled as a price reduction. As mentioned in the Introduction, this will have several effects. One is the price effect, which means that car use may increase if engines become more efficient and the cost of travel decreases, which partly offsets the initial energy-saving potential. Another effect is the income effect: a reduced cost for energy services increases real income, which in turn implies increased demand for the "own" good and other goods. With the simulated change in energy efficiency, we also calculate the necessary change in CO_2 tax to hold CO_2 emissions at their initial level, and show how this affects emissions of sulphur dioxide and nitrogen oxides.

In the simulations we assume a 20% increase in energy efficiency for the goods within the transport and heating groups. Since the cost of petrol amounts to 50% of the costs for car transport, the price for car transport is reduced by 10%. As we do not know the production function for public transport and other transport, we assume that 20% of the price of public transport consists of energy goods; the corresponding figure for other transport is 30%.

A 20% increase in energy efficiency is basically an ad hoc assumption for illustration purposes only and is not based on any explicit policy goal. However, according to official statistics, the energy efficiency of the Swedish economy has increased by approximately 20% since 1980, indicating that the figure used has some relevance.

5.1. Simulation of increased energy efficiency

In the description of the simulation model, we first consider the simulation of increased energy efficiency whereupon we describe the simulation of the change in CO_2 taxation. Defining the percentage increase in energy efficiency for good i by λ_i, the new price level for good i can be written as:

$$p_i^1 = p_i^0(1-\lambda_i), \tag{7}$$

which means that the after-tax Stone price index for commodity group $r=1, \ldots, n$ equals:

$$\ln p_r^1 = \sum_{i \in r} w_{(r)(i)} \ln p_i^1, \tag{8}$$

where, as previously, $w_{(r)(i)}$ is good i's initial share of total expenditures on goods in group r. The new, after-tax, overall Stone price index is then:

$$\ln P^1 = \sum_r w_{(r)} \ln p_r^1 \tag{9}$$

where $w_{(r)}$ is group r's initial share of total consumption expenditures. It should be noted that we do not allow for possible general equilibrium effects, i.e. we assume that efficiency effects and taxes are shifted completely onto consumer prices. At least for energy goods, such as petrol, this may not be an unreasonable assumption since these goods are traded on international competitive markets.[8]

Substituting expressions (8) and (9) into the demand system representing the first-stage budgeting process gives us the new allocation across the different commodity groups. That is:

$$w_{(r)}^1 = \hat{\alpha}_{(r)} + \sum_s \hat{\gamma}_{(r)(s)} \ln p_s^1 + \hat{\beta}_{(r)}\left(\ln x^0 - \ln P^1\right) + \hat{\varepsilon}_{(r)}^0, \tag{10}$$

where a ^ denotes an estimate. The superscript 0 indicates the point of reference, which means that total expenditures are fixed. The last term in Eq. (10), $\hat{\varepsilon}_{(r)}^0$, represents unexplained time-specific effects not accounted for in the estimations, which are assumed to remain constant over the simulations.

Given the new group shares, according to Eq. (10), we get by definition the new expenditure on each group as:

$$x_{(r)}^1 = w_{(r)}^1 x \tag{11}$$

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[8] This, however, is only valid if energy efficiency improves solely in Sweden. If energy efficiency changes globally we will certainly have an additional effect.

Substituting Eq. (11) into the demand system representing the second stage of the budgeting process, we get:

$$w^1_{(r)(i)} = \hat{\alpha}_{(r)(i)} + \sum_j \hat{\gamma}_{(r)(j)} \ln p^i_j + \hat{\beta}_{(r)(i)} \left(\ln x^1_{(r)} - \ln p_{(r)^1} \right) + \hat{\varepsilon}^0_{(r)}. \tag{12}$$

From (12) we can now define the change in real expenditure on good i as:

$$\Delta \tilde{x}_i = w^1_{(r)(i)} \frac{x^1_{(r)}}{p^1_{(i)}} - w^0_{(r)(i)} \frac{x^0_{(r)}}{p^0_{(i)}}$$

The change in emissions can now be defined as:

$$\Delta E_k = \sum_i \theta_{ik} \Delta \tilde{x}_i, \quad k = \mathrm{CO}_2, \mathrm{SO}_2, \mathrm{NO}_x$$

The results from the simulated increase in energy efficiency are presented in Table 3, where the first column shows the results from increased energy efficiency for transport. The second column shows the effects of increased energy efficiency in heating, while the third column describes the effects when both transport and heating become more efficient. The remaining three columns show the percentage change in consumption and emissions of sulphur dioxide and NO_x from increased energy efficiency and increased CO_2 taxation to hold CO_2 emissions at their initial level.

5.2. Simulation of the tax change

The simulation of the tax change resembles to a large degree the simulation for increased energy efficiency. The percentage price change on good i due to a change in the tax is calculated according to the following formula:

$$\frac{\Delta p_i}{p^1_i} = \frac{\left(t^1_i + \tau^1_i + t^1_i \tau^1_i\right) - \left(t^0_i + \tau^0_i + t^0_i \tau^0_i\right)}{1 + t^0_i + \tau^0_i \tau^0_i}, \tag{13}$$

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. The excise duty, in turn, consists of an energy tax (SEK/kWh) and a CO_2 tax that is levied on the CO_2 content in fuels. It should be noted that τ shows the excise duty share of the producer price (price excluding taxes) and that it includes all energy-related indirect taxes. The price level for good i after the tax change and increased energy efficiency is then equal to:

$$p^2_i = \left(1 + \frac{\Delta p_i}{p^1_i}\right) p^1_i. \tag{14}$$

The simulation then follows the same procedure as before, where we start by calculating the new Stone price index for commodity group $r = 1, \ldots, n$ according to Eq. (8). The CO_2 tax is then changed until $\Delta E_{CO_2} = 0$.

Table 3
Percentage change in demand and emissions due to an increase in energy efficiency of 20% for transport and heating

Percentage change	Transport	Heating	Transport and heating	Transport Δ $CO_2=0$	Heating Δ $CO_2=0$	Transport and heating $\Delta CO_2=0$
ΔCar transport	0.92	4.18	5.53	0.21	1.68	1.91
ΔPublic transport	−0.42	2.00	1.85	−0.38	1.36	1.21
ΔOther transport	−1.76	3.74	2.26	−1.32	3.74	2.78
ΔElectricity	2.09	0.84	3.43	1.03	−0.81	0.69
ΔOil	2.94	1.18	4.85	−3.48	−10.51	−14.42
ΔDistrict heating	3.41	1.37	5.64	4.40	3.66	8.88
ΔFood	−1.09	1.58	0.48	−0.76	2.30	1.62
ΔBeverage	−2.24	3.28	1.00	−1.57	4.78	3.36
ΔRecreation	3.98	1.18	5.19	2.14	−2.63	−1.27
ΔClothes	3.60	1.07	4.69	1.94	−2.38	−1.15
ΔMedical treatment	0.82	0.25	1.06	0.45	−0.58	−0.28
ΔDomestic appliances	3.73	1.11	4.86	2.01	−2.46	−1.19
ΔOther goods/services	2.23	0.67	2.90	1.20	−1.49	−0.72
ΔCO_2						
Transport group	0.83	4.10	5.36	0.17	1.71	1.91
Heating group	2.72	1.10	4.49	−0.79	−5.14	−5.86
Provisions group	−1.19	1.73	0.53	−0.79	2.35	1.66
Diverse group	2.91	0.87	3.79	1.57	−1.93	−0.93
Total effect	1.26	3.05	4.72	0	0	0
ΔSO_2						
Transport group	0.76	4.03	5.21	0.13	1.72	1.89
Heating group	2.62	1.06	4.32	0.51	−2.54	−1.73
Provisions group	−1.21	1.76	0.54	−0.79	2.36	1.67
Diverse group	2.93	0.87	3.81	1.58	−1.94	−0.94
Total effect	1.79	1.82	4.03	0.44	−0.87	−0.35
ΔNO_x						
Transport group	0.79	4.05	5.26	0.15	1.70	1.89
Heating group	2.67	1.07	4.40	−0.09	−3.74	−3.63
Provisions group	−1.16	1.68	0.51	−0.78	2.33	1.65
Diverse group	3.10	0.92	4.04	1.67	−2.05	−0.99
Total effect	0.88	3.30	4.53	0.15	1.09	1.24
ΔCO_2 tax				36.25	76.30	134.20

5.3. Simulation results

In this section we present the results of the simulations. The first column presents the results from an increased energy efficiency in the transport sector of 20%, which given our assumptions lowers the price of car transport by 10%, public transport by 4% and other transport by 6%. As a consequence of increased energy efficiency in the transport sector, the expenditure share for transport will decline. However, since the weighted prices for transport have declined (by 9%), real expenditures on transport increase by 0.5%. The increased real expenditures on transport and changed relative prices within the transport group result in a lower budget share for car transport and increased budget shares for public and other forms of transport.

Due to the lower cost of petrol per mile, the demand for car transport will increase by 0.9% in "real units" (see Table 3). At the same time, there is a reduction in the real demand for public and other transport by 0.4 and 1.8% respectively. The increased energy efficiency in the transport sector leads to higher consumption of heating and other goods, while the consumption of foodstuffs decreases. The reduced consumption of food and beverages is a result of a negative cross-price effect.

Within the heating group the largest demand change is found for district heating, which increases by 3%. The largest demand change in the "other goods" group is for recreation, which increases by 4%. To sum up, the simulation indicates that the improved energy efficiency in the transport sector will increase the emissions of CO_2 by 1.3%, SO_2 by 1.8% and NO_x by approximately 0.9%. If there were no rebound effect, CO_2 emissions would decrease by 6.2%, and SO_2 and NO_x would decrease by 2.3% and 7.0% respectively. Thus the *rebound effect* increases carbon dioxide emissions by 7.5% and sulphur dioxide and nitrogen oxide by 4.1% and 7.9% respectively (see also Table 4).

The second column in Table 3 summarises the simulation results of a 20% increase in energy efficiency for heating. As the table suggests, this scenario will increase the demand for every good in the demand system. The largest increases are for car transport and other transport, which increase by 4.2% and 3.7% respectively. As a result of the increased demand for transport services, the emissions of CO_2 and especially NO_x rise more in this scenario than the previous one. Although the sources of changes in SO_2 emissions differ considerably between the first and second scenarios, the total change in SO_2 is about the same for both. However, the rebound effect for sulphur dioxide differs substantially between the first and second scenarios, amounting to approximately 12% in the second scenario. The rebound effect for carbon dioxide is about the same level in this scenario as in the first, amounting to 7.4%. Compared to the previous scenario, we find a smaller rebound effect of 4.7% for NO_x in this scenario.

In the third scenario, Column 3, we consider a 20% increase in energy efficiency for both transportation and heating. Here we find the highest demand changes for district heating (5.6%), car transport (5.5%) and recreation (5.2%) as a result of lower costs for energy goods and increased real expenditures. The increased energy efficiency will in this case increase the emissions of CO_2 and NO_x by 4.5%, while SO_2 emissions will increase by approximately 4%. For all emission categories, the largest change is found for the transport group. In this scenario, the rebound effects for CO_2 amount to approximately 15%. The corresponding figures for SO_2 and NO_x are 16% and 13% respectively.

Table 4
The estimated rebound effect in percent

Percentage change	Transport	Heating	Transport and heating
ΔCO_2	7.5	7.4	15.3
ΔSO_2	4.1	11.6	16.1
ΔNO_x	7.9	4.7	12.9

The rebound effect is calculated as the difference between a scenario where the increased energy efficiency of 20% reduces the emissions from the sector without considering the substitution and income effects and the corresponding scenario in Table 2, where these effects are accounted for.

The final three columns in Table 3 consider the CO_2-neutral case, i.e. CO_2 emissions are held at their initial level by changes to the CO_2 tax. In other words, we increase the CO_2 tax for each scenario in Columns 1 to 3 until we obtain a zero change in the CO_2 emissions. For the transport scenario, we have to increase the CO_2 tax by 36% to achieve the same level of CO_2 emissions as before the increase in energy efficiency. The increased CO_2 tax also reduces SO_2 and NO_x emissions. However, the net effect is still positive for SO_2 and NO_x. As the table reveals, the largest demand change is for oil. As a consequence of the decreased demand for oil, the emission of CO_2 is reduced by 0.8% for the heating group, counteracting the increased emission of CO_2 from the transport and "other goods" groups.

For the heating scenario, we must increase the CO_2 tax by about 75% to achieve zero change in CO_2 emissions. As in the transport scenario, we find the largest demand change for oil. However, we also find a demand reduction for the goods in the "other goods" group, among other things as a result of lower real expenditures due to the tax increase. Among the goods in the "other goods" group, we find the largest demand change for recreation (-2.6%). In this scenario, there is a reduction in CO_2, SO_2 and NO_x emissions from both the heating and the "other goods" group. In this scenario we also find a reduction in the total emissions of SO_2 while the emissions of NO_x still increase.

The general pattern from the previous scenario is also repeated in the final scenario (Column 6), where we consider efficiency improvements for both transport and heating with no change in CO_2 emissions. In this scenario we must increase the CO_2 tax by about 135%. As in the previous scenario, demand decreases for oil (-14%) and the goods in the "other goods" group. The demand for all other goods in the demand system increases. As can be seen for the goods in the heating group, this scenario indicates a substitution from oil to district heating.

Although the goods in the "other goods" group have relatively low emissions of CO_2 per unit, the last two simulations indicate that these goods will nevertheless be subject to a relatively large demand reduction. As in the previous scenario (Scenario 5), the increased CO_2 tax reduces the emissions of SO_2 to a level below their initial level. As for all the other scenarios, the change in NO_x emissions is still positive in this last scenario. Thus additional policy instruments would be needed to hold NO_x unchanged or to reduce it.

Among the goods that are not directly affected by the increase in energy efficiency, we generally find the greatest impact on recreational demand. In the first three scenarios we find the largest demand change when the simulation involves improved energy use in the transport sector—for example, recreational demand increases by 4% and 5% in Scenarios 1 and 3. However, in the fourth scenario, too, where the increased energy efficiency in the transport sector is counteracted by a higher carbon dioxide tax, there is a positive effect on recreational demand.

In the final scenario, where we have increased energy efficiency in both the transport and heating sectors, in combination with a higher CO_2 tax, recreational demand is reduced by fully 1%. Thus in the scenario that seems most likely to appear in real world, with improved technology in both the transportation and heating sectors and increased CO_2 taxes, recreational demand will be negatively affected.

6. Conclusion and discussion

The main objective of this study was to examine how an exogenous change in energy efficiency affects consumption choice by Swedish households and thereby emissions of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO_x). Initially an improvement in energy efficiency implies lower consumption of energy goods, and thus lower emissions. However, this also means that the real relative prices between goods are altered, and that real income increases, the latter due to the initial reduction in energy costs. Thus it may very well be the case that the initial energy saving is counteracted by these changes in real relative prices and income. In the literature these latter effects are denoted “rebound effects”. The magnitude of this rebound effect is, however, an empirical issue, which will depend on consumers’ preferences for the various goods.

In this particular empirical application, we have shown that the “rebound effect” can be considerable. That is, the initial emission reduction due to an increase in energy efficiency is more than counteracted by changes in consumption. The main conclusion, then, is that an exogenous increase in energy efficiency may not lead to lower energy consumption, and hence lower emissions. On the contrary, it is very likely that this “growth effect” will result in higher emissions. Furthermore, the results show that the CO_2 tax change necessary to counteract and hold CO_2 emissions constant is quite large, 135%. In addition, we show that an increase in energy efficiency will also lead to changes in other emissions, such as sulphur dioxide and nitrogen oxides. A policy of holding CO_2 emissions at their initial level will also affect the emissions of sulphur dioxide and nitrogen dioxide, but not to the same extent as the change in CO_2 emissions. Thus, if marginal damages from sulphur dioxide and nitrogen oxides are non-constant, additional policy instruments are needed.

Related to the issue of the Environmental Kuznets Curve (EKC), the empirical findings in this study may be discouraging, since technological progress in terms of increased energy efficiency tends to increase emissions. However, in the model used here there is no preference-driven “policy response” as a result of technological progress. That is, the increase in real income, due to the exogenous increase in energy efficiency, may increase the demand for public goods, inherited in for example “recreational goods”. This increase in demand, however, does not spill over into policy changes in our simulations. Thus, if there really exists an EKC for CO_2 emissions in Sweden[9], the CO_2 tax necessary to keep CO_2 emissions at their initial level may be interpreted as the willingness to pay for emission reductions.

Although the simulation model can handle the substitution and income effects that increased energy efficiency generates, the model is not able to handle the general equilibrium effects that may arise as a result of technological progress. Whether these effects are large or not is difficult to say, but future research in this direction may be of interest.

Acknowledgments

Financial support from Formas and Riksbankens Jubileumfond is gratefully acknowledged.

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[9] Lundgren and Kriström (2005) show that Swedish CO_2 emissions may be lower in the future, in spite of economic growth and technological progress.

Appendix A

Table A1
Demand system parameter estimates for 1980–1997 in the main group

	Constant	Food price	Heating price	Transport price	Expenditure coefficient	R-squared	Durbin-Watson
Food	1.8 (45.3)	0.11 (14.5)	−0.04 (−8.7)	0.007 (1.3)	−0.22 (−38.6)	0.98	2.18
Heating	0.32 (4.4)		0.66 (11.6)	−0.02 (−4.4)	−0.03 (−3.2)	0.94	1.72
Transportation	0.14 (2.8)			0.13 (15.3)	−0.0008 (−0.13)	0.95	1.94

t-values within parenthesis are robust to autocorrelation.

Table A2
Demand system parameter estimates for 1980–1997 in the food subgroup

	Constant	Price of food	Expenditure coefficient	R-squared	Durbin-Watson
Food	1.7 (5.8)	0.02 (1.8)	−0.16 (−3.3)	0.80	0.57

t-values within parenthesis are robust to autocorrelation.

Table A3
Demand system parameter estimates for 1980–1997 in the transport subgroup

	Constant	Price of car	Price of public transport	Expenditure coefficient	R-squared	Durbin-Watson
Car transportation	0.5 (8.9)	0.1 (6.6)	−0.07 (−8.4)	0.05 (4.8)	0.59	1.09
Public transportation	0.34 (10.3)		0.08 (18.02)	−0.05 (−7.6)	0.91	1.37

t-values within parenthesis are robust to autocorrelation.

Table A4
Demand system parameter estimates for 1980–1997 in the heating subgroup

	Constant	Electricity price	District heating price	Expenditure coefficient	R-squared	Durbin-Watson
Electricity	1.1 (7.9)	0.11 (4.7)	−0.1 (−8.7)	−0.11 (−3.8)	0.94	1.95
District heating	−0.11 (0.63)		0.16 (9.7)	0.08 (2.06)	0.76	1.01

t-values within parenthesis are robust to autocorrelation.

Table A5
Demand system parameter estimates for 1980–1997 in the “other” subgroup

	Constant	Price of clothes	Price of other goods	Price of health care	Price of recreation	Expenditure coefficient	R-squared	Durbin-Watson
Clothes	−0.09 (−0.9)	0.07 (5.3)	−0.13 (−7.3)	−0.04 (−10.4)	0.02 (2.3)	0.04 (2.9)	0.89	1.23
Other goods	1.1 (12.9)		0.12 (17.9)	0.08 (22.3)	−0.04 (−4.9)	−0.09 (−7.6)	0.95	0.89
Health care	0.4 (9.7)			0.06 (20.7)	−0.006 (−1.8)	−0.05 (−8.3)	0.94	1.25
Recreation	−0.25 (−11.3)				0.06 (5.5)	0.05 (17.01)	0.93	1.34

t-values within parenthesis are robust to autocorrelation.

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Energy taxes as a signaling device: An empirical analysis of consumer preferences

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Abstract

This paper presents an econometric study dealing with household demand in Sweden. The main objective is to empirically examine the differences in consumer reaction to the introduction of, or the change, in environmental taxes. Main focus is on environmental taxes as a signaling device. The hypothesis is that the introduction of an environmental tax provides new information about the properties of the directly taxed goods. This in turn may affect consumer preferences for these goods, hence altering the consumption choice. The result from the econometric analysis shows that all goods have negative own-price elasticities, and positive income elasticities. Concerning the signalling effect of environmental taxes the results are somewhat ambiguous. The tax elasticity for energy goods used for heating seems to be significantly higher than the traditional price elasticity, whereas the opposite seems to be the case for energy goods used for transportation.

JEL Classification: D12; H31; Q41

Keywords: Household demand; Energy tax; Tax elasticities

1. Introduction

The main objective of this paper is to empirically examine consumer reactions as a response to the introduction of, or the change in, environmental taxes for different groups of commodities. Understanding consumer response to environmental taxes for different commodities is believed to be critical to the environmental policy makers.

One of the premises implied in this study is that the changes in consumer prices, as a result of changes in environmental taxes, may send a different signal to the consumer compared with other changes in consumer prices, such as changes in producer price. In addition, this assumed difference in the signalling effect of the changes in environmental taxes, compared to changes in the producer price, may also differ between different commodities (Berkhout et al., 2004).[1]

Over the last decade and, particularly, after the framework Convention on Climate Change of 1992, many OECD countries have considered the introduction of "Green Tax Reforms" aimed at reducing the emission of green house gases. The reduction is usually used to measure the effectiveness of environmental taxes (OECD, 2000). OECD (2003) emphasizes the need for more research that examines the magnitude of the behavioural response of consumers to environmental taxes once they have been introduced. Such behavioural response is considered to be a necessary precondition for the correct implementation of different instruments of any environmental policy. For a better understanding of this behavioural response, it is essential to empirically examine consumer reactions to the introduction of, or change in, environmental taxes on different categories of commodities.

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[1] The signalling effect may not be due to the tax change itself, but rather the tax change comes in a combination with information and campaigns, which alters consumer preferences. For an analytical analysis of the signalling effect in tax policy, see for example, Barigozzi and Villeneuve (2004).

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doi:10.1016/j.enpol.2005.09.011

Behavioural response to environmental taxes can be estimated ex ante (predicted value) or ex post (actual values). The latter approach concentrates on the absolute reduction in consumption caused by the introduction or the increase of an environmental tax in a specific country at a specific time (Agnolucci, 2004). The ex ante approach uses econometric methods to estimate price elasticities, which, with precaution, are used to predict behavioural responses to environmental taxes (Garcia-Cerruti, 2000; Halvorsen and Larsen, 2001).

In this paper, we formulate and estimate an econometric model for non-durable consumer demand in Sweden that utilises macro data. The system of demand equations is derived assuming cost-minimising households. The employed model is essentially a three-stage budgeting model 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 different non-durable commodity aggregates, or groups. Given the allocation on each non-durable commodity group, households in the third stage allocate their group expenditures on the various goods within the group. Our model is based on Deaton and Muellbauer's (1980) almost ideal model (AIDS).

Specific in our modelling approach is the hypothesis of taxes as a signalling device. To account for this the consumer price is divided into a producer price part and a tax part. Given this partition, it enables us to estimate separate effects; a producer price effect and a tax effect. We also want to conduct tests of structural stability of the demand system for the entire sample period. It is important to check the stability of the model, since if it is unstable, it will be difficult to interpret the regression results.

The rest of this paper is structured as follows. In Section 2 we illustrate the design and purpose of the energy and environmental taxes introduced in Sweden. Section 3 describes the demand system, the data, as well as the estimation and test approach. Section 4 discusses the results. Finally, in Section 5 we draw some conclusions.

2. Energy and environmental taxation in Sweden

Environmental effects caused by energy generation and consumption are significant because of the widespread use of fossil fuels in the economic system. The magnitude of these effects is of concern, particularly in the case of climate change, but also due to other external costs related to fossil fuel use.

Sweden has used taxes on energy since 1929, when a tax on gasoline was introduced. Electricity has been taxed since 1951, followed by a broadening of energy taxes in 1957. The motivation underlying these taxes was purely fiscal. Propelled by the global energy crisis in the 1970s; energy taxes were increasingly motivated by a desire to discourage consumption of fossil fuels. Thus, increased tax on oil products were coupled with a significant expansion of electricity supply in order to promote a different profile of energy consumption.

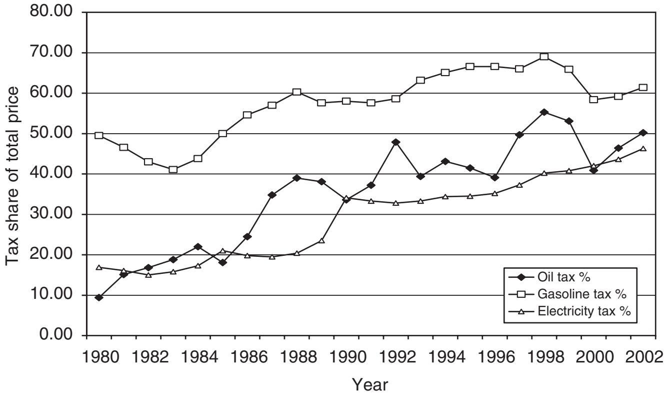

Fig. 1. Energy tax as a share of total price in Sweden, 1980–2002.

In the eighties, environmental concerns entered the discussion, manifested by the introduction of a tax differentiation of leaded gasoline in 1986. This was followed by the Environmental Tax Commission that recommended a rich array of environmental taxes in their proposal. New primarily environmental taxes, introduced in the 1991 tax reform, include a carbon dioxide tax on fossil fuel, and a sulphur tax on coal and oil. In addition, the VAT has been extended to all fuels, and a nitrogen dioxide tax is charged on emissions from large combustion plants (Brännlund and Kriström, 1997). Another green tax reform was discussed with the appointment of the Swedish "Green Tax Commission" (SOU 1997, p.11). The Green Tax Commission's main objective was to analyse the potential of fiscally neutral green tax reforms. The prospects in mind were that there may exist a "double dividend" (Brännlund and Nordström, 2004).[2]

This idea of a green tax swap was decided upon during spring 2000. It was decided that a switch from taxes on labour to environmental taxation amounting to 30 billion SEK will be carried out during the following 10 years. The main taxes considered are the CO_2 tax and the energy tax on electricity.

The development of the general energy tax, as a share of consumer price, is displayed Fig. 1. Here we can see that the tax share on oil for heating has increased from approximately 10% of the consumer price in 1980, to approximately 50% in 2002. The tax on electricity shows a similar pattern.

3. The model

In this section we formulate the demand system for non-energy and energy goods. We assume that consumers

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[2] The "double dividend" will not be discussed in this work. For a review of this issue, see for example, Bovenberg (1999) and Schöb (2003).

follow a three-stage budgeting process.[3] In the first stage, the household decides on its leisure consumption, savings and investments (durable consumer goods). In the second stage, the household determines, given its total budget, how much to spend on food, heating, transports, and other goods. In the third stage, the household allocates resources within each of these groups. For, example, given a specific amount of money to be spent on transports, the household determine how much that should be allocated to expenditure on gasoline, car maintenance, and public and other transport. In the same manner the household determines in the third stage how to use its budget for heating. In this case the household can choose between electricity for heating, oil for heating and district heating. Our main objective is to model and estimate household choices in the second and third stage, with particular reference to energy taxes.

Demand function estimates are also very useful as they provide us with income and price elasticities. Consumers' response to income and changes is required for the design of many different policies; For example, policy design for indirect taxation and subsidies requires knowledge of the response for taxable commodities and services (Deaton and Muellbauer, 1980). Such knowledge would normally be obtained by the analysis of time series data on demand of commodities, prices, and income.

We use the Almost Ideal Demand System (AIDS), first derived by Deaton and Muellbauer (1980). The advantages of this system are well known. It gives an arbitrary first order approximation to any demand system, satisfies the axioms of choice exactly, and is simple to estimate.

The AIDS assumes that consumer preferences fall within the price-independent generalized logarithmic (PIGLOG) class so that exact aggregation over consumers is possible. In the AIDS model the budget share on a specific commodity, or group of commodities, in relation to full expenditure, can be written as

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln p_j + \beta_i \ln(Y/P), \tag{1}$$

where w_i is the budget share for good i, p_j is the price for good j, Y is total expenditure on non-durable goods, P is the consumer price index, and the parameters to be estimated are α, γ, and β. The consumer price index, P, is defined as Stone's price index, which is expressed as

$$\ln\ P = \sum_j w_j \ln\ p_j. \tag{2}$$

In order to analyse the difference in the signalling effect of the changes in environmental taxes compared to changes in the producer price, we have to separate the consumer price into a producer price part and energy tax part:

$$p_j = \bar{p}_j \tau_j, \tag{3}$$

where p_j is the consumer price index for energy good j, $\bar{p}_j$ the producer price index for energy good j, and τ_j is the energy tax index, which represents the environmental tax for specific good. Using Eq. (3), we can calculate the energy tax index by dividing the observed consumer price index on observed producer price index, which can be represented by the following equation:

$$\tau_j = \frac{p_j}{\bar{p}_j}. \tag{4}$$

Allowing for a difference in signalling effects, Eq. (1) can now be written as

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(\bar{p}_i) + \sum_j \tilde{\gamma}_{ij} \ln\ \tau_i + \beta_i \ln(Y/P). \tag{5}$$

The budget share Eq. (5) includes two parameters representing the consumer price, the first one, γ_{ij}, is the coefficient for the producer price index and the other, $\tilde{\gamma}_{ij}$, is the coefficient for energy taxes index. In this case we can capture the effect of energy taxes on the consumer behaviour and see if there is any difference between the parameters of energy taxes and the parameters of producer price.

To obtain consistent estimates we have to assume that under multi-stage budgeting the direct utility function is weakly separable.[4] This approach implies that goods can be divided into a number of separate groups, where a change of the price of a good in one group affects the demand for all goods in another group in the same manner.

If we have a three-stage budgeting process, the first stage comprises of allocation between saving durables and non-durables goods. In the second stage, the household allocates its total expenditure between n groups of non-durable goods. In the third stage, the household allocates its expenditure between m goods within each of the n groups. Given this structure, the Linear Ideal Demand System (LAIDS) model can be written in stochastic form as

$$\begin{aligned} w_{(r)t} = \alpha_{(r)} + \sum_{s=1}^{n} \gamma_{(r)(s)} \ln \bar{p}_{(s)t} + \sum_{s=1} \tilde{\gamma}_{ij} \ln\ \tau_{(r)(s)} \\ + \beta_{(r)}(\ln x_t - \ln P_t) + \varepsilon_{(r)t}, \end{aligned} \tag{6}$$

$$\begin{aligned} w_{(r)it} = \alpha_{(r)i} + \sum_{s=1}^{n} \gamma_{(r)ij} \ln \bar{p}_{(r)it} + \sum_{s=1} \tilde{\gamma}_{ij} \ln\ \tau_{(r)jt} \\ + \beta_{(r)i}(\ln x_{(r)t} - \ln p_{(r)t}) + \varepsilon_{(r)it}, \end{aligned} \tag{7}$$

where $r = 1, \ldots, n$ denotes group, $i = 1, \ldots, m(r)$ denotes commodities within group r, and $t = 1, \ldots, T$ denotes time period. Eq. (6) thus describes the allocation between groups, where $w_{(r)t}$ denotes the budget share for good r in period t, $\bar{p}_{(r)t}$ is a group producer price index, x_t is total expenditure on non-durables, $\tau_{(r)t}$ is the group energy taxation index, and P_t finally is the consumer price index

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[3] In order to overcome the problem caused by the immense of goods and services available to the consumer, we have this convenient assumption.

[4] This assumption implies that goods can be divided into a number of separate groups, where a change of price in a good in one group affects the demand for all goods in another group in the same manner.

for non-durables. Eq. (7) describes allocation within the rth group, where $w_{(r)it}$ is the within group budget share, $\ln \bar{p}_{(r)j}$ is the producer price index of the jth good, $x_{(r)t}$ is the total expenditure allocated to the rth group, $\tau_{(r)jt}$ is the energy taxation index of goods j within group r, and $p_{(r)t}$ is the stone price index for the rth group.

Given estimates of the parameters at each "level", we can calculate price and expenditure elasticities, totally and conditional on the expenditures for each group (Edgerton et al., 1996).[5] Using the main group notation the expenditure and uncompensated price elasticities are:

$$E_r = 1 + \frac{\beta_r}{w_r}, \quad r = 1, \ldots, n, \tag{8}$$

$$e_{rs} = \left(\frac{\gamma_{rs} - \beta_r w_s}{w_r} - \delta_{rs} \right), \quad r = 1, \ldots, n, s = 1, \ldots, n, \tag{9}$$

$$\tilde{e}_{rs} = \left(\frac{\tilde{\gamma}_{rs} - \beta_r w_s}{w_r} - \delta_{rs} \right), \quad r = 1, \ldots, n, s = 1, \ldots, n, \tag{10}$$

where E_r denotes the expenditure elasticity for group r, e_{rs} the uncompensated producer price elasticity, and $\tilde{e}_{rs}$ the uncompensated energy taxation elasticity, δ_{rs} equals one when $r = s$, and zero otherwise.

Let us denote the expenditure elasticity for the ith good within the rth group of goods as $E_{(r)i}$. The group expenditure elasticity for the rth group of goods as $E_{(r)}$, and the total expenditure elasticity for the ith good within the rth group of goods, E_i, is then defined as

$$E_i = E_{(r)} E_{(r)i}. \tag{11}$$

In the same way, we can denote the within group price elasticity between the ith and jth goods within the rth group of goods as $e_{(r)ij}$, the group price elasticity as $e_{(r)(s)}$ and the total price elasticities as e_{ij}. We can notice that the within group price elasticity assumes that group expenditure is unchanged in spite of the price change, whilst the total price elasticity allows for the relevant changes in group expenditure.

Finally, we can denote the equivalent total price elasticity as

$$e_{ij} = \delta_{rs} e_{(r)ij} + E_{(r)i} w_{(s)j} (\delta_{rs} + e_{(r)(s)}). \tag{12}$$

If we look at Eq. (12) for two goods within the same group, we can see that the total price elasticity consists of two components. The first part is a direct effect, which represents the subgroup elasticity, while the second part is an indirect effect, which is a product of three factors. The first measure the relative change in the group price index when the price of the jth good change (this is equal to $e_{(r)j}$'the budget share'), the second factor measures the effect a change in the price index has on the group expenditure $(1 + e_{(r)(s)})$, while the third factor measures the effect this change in within group expenditure has on the consumption of the ith good $(E_{(r)I})$.

We can also notice that if the own between group price elasticity $e_{(r)(r)} = -1$, then the group expenditure is unaffected by the price change and $e_{ij} = e_{(r)ij}$. On the other hand, if $e_{(r)(r)} = 0$, then the price change produce a proportional effect on the group expenditure.

The model specified above will be estimated using time series data on Swedish consumption of non-durable goods from 1980 to 2002. Energy tax data are then linked to each type of good within the heating and transportation group.

Since the data spans over a relative long period we conduct tests of structural stability of the demand system for the entire sample period. The usual practice in assessing the constancy of regression coefficients over time it is to use prior information concerning the true point of structural change in the nature of regression relationship. The researcher identifies an event that is hypothesized to cause structural change, estimates separate regression, and examines whether the multiple sets of estimated coefficients are significantly different from each other using an F-test. This is the so-called Chow test. An alternative procedure is to estimate the model over the full sample period with one or more dummy variables. One drawback of Chow tests is the maintained assumption that the sample variances are equal in both time periods. An alternative, suggested by Hansen (1992), is the Wald test that does not impose this restriction.

It is important to note that both of these approaches require prior information regarding the event that is alleged to cause the structural change. One approach, which does not require prior information concerning the true point of structural change is to conduct a series of Chow tests for each time period. An attractive property of these 1-step Chow tests is that they allow the data to identify when the true point of structural change occurs. A related approach is that of Brown et al. (1975) (CUSUMSQ test). In this case, an analysis of the cumulative sum of squared residuals from the regression determines, if at all, structural (break) or shift occurs. These tests have been employed on time series data to analyse the demand for money (see Heller and Moshin, 1979), and aggregate output fluctuations (seeMcConnell and Perez-Quiros, 2000). In our context, we will use CUSUM (which is based on the cumulative sum of recursive residuals) and CUSUMSQ tests and the null hypothesis of these tests is that the demand system coefficients are constant over the time period.

4. Description of the data

The data set employed consist of aggregate time series over Swedish consumption of non-durable goods, and energy taxes linked to each type of good within the heating and transportation group covering the years 1980–2002. Our demand system is composed of expenditure on the following four main consumption groups: Foodstuff, transports, heating, and other goods. Expenditures on

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[5] The model is estimated without any homogeneity, and symmetry restrictions.

each of these groups are divided into individual goods as follows:

1. *Foodstuff*: expenditure on *food* and *beverages*.
2. *Transport*: expenditure on petrol, car maintenance, and public and other transport.
3. *Heating*: expenditure on electricity, district heating, and oil.
4. *Other goods*: expenditure on clothes, health care, recreation, domestic appliances and other.

The estimation of household demand for the main groups (Eq. (6)) requires the following prices: general price index (P_t), producer price index for each group ($\bar{p}_{(s)t}$), and an energy tax index ($\tau_{(r)(s)}$) for heating and transportation. The general price index is calculated using Eq. (2). The energy tax index for heating is defined as

$$\ln(\tau_{he}) = w_{el}\ln(\tau_{el}) + w_{dis}\ln(\tau_{dis}) + w_{oil}\ln(\tau_{oil}),$$

where w_{el}, w_{dis}, and w_{oil} are weights representing the budget share for electricity, district heating, and oil. The energy tax index for transportation is defined in a similar way, where w_{pe}, and w_{pub} are the budget share for petrol and public and other transport. Information on all the necessary weights is available from our data. Finally, we can use Eq. (3) to calculate the producer price index for the heating and transportation groups since we have consumer price indexes from our data and energy tax indexes as described above.

Figs. 2–4 contain summary statistics for the consumption data for the four main groups, and for the individual types of energy goods.

As can be seen in Fig. 2 consumption of "transports" and "heating", measured as expenditure shares, have been fairly stable over the period, although there is a weak positive trend in the heating share. The "food" share, however, has decreased strongly, whereas "other goods" has increased. Since income has increased over this time period, the pattern in Fig. 2 indicates that "food" is a necessary good, whereas "other goods" is a luxury.[6] In Fig. 3 we see that about 85% of total household expenditure on heating during the sample period is used on electricity and oil. Furthermore it can be seen that there has been a substantial substitution from the use of oil towards electricity during the same period.

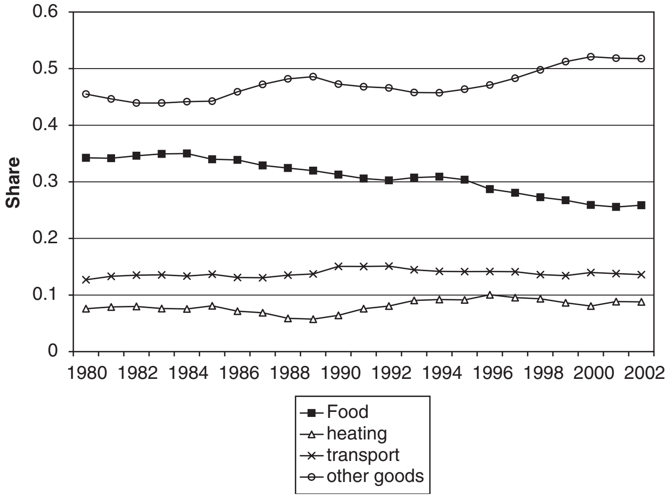

Fig. 2. Expenditure shares, main groups.

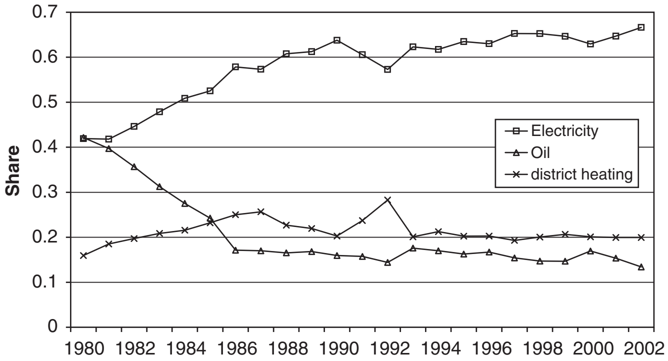

Fig. 3. Expenditure shares, within heating group.

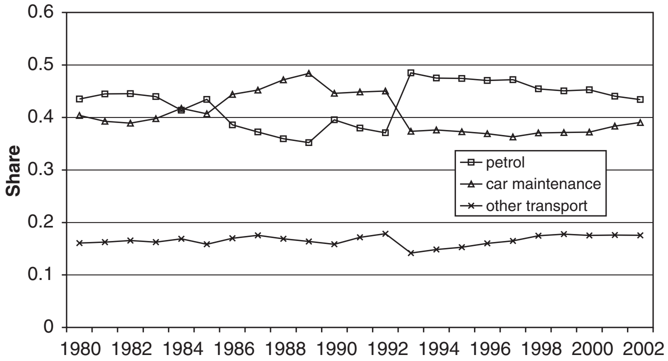

Fig. 4. Expenditure shares, within transportation group.

5. Estimation and empirical results

Following the specification in Eqs. (6) and (7), the demand system for the main groups and for the goods within the main groups is estimated by OLS. Tables B1–B5 in the Appendix, gives the estimates of the parameters of the model. The results indicate that most of the estimated parameters are significantly different from zero, and that the degree of explanation is good.

Based on the results from Tables B1–B5, we try to address two issues before calculating the own-price and expenditure elasticities. The first is to test if the parameters that represent the producer price and energy taxation are equal or not. The result from this test is presented in Table 1. According to the results, the null hypothesis of equality between the producer price and energy tax is

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[6] This conjecture is of course conditioned on unchanged relative prices.

Table 1
F-test of parameter equality

Goods	*F*-test	The null hypothesis: $\gamma_{ij} = \bar{\gamma}_{ij}$
Heating	13.5*	Reject
Transport	0.49	Do not reject
Petrol	7.4*	Reject
Other transportation	52.5*	Reject
Electricity	31.8*	Reject
District heating	52.8*	Reject
Oil	0.65	Do not reject

Note: * significant at the 5% level.

rejected for every energy good except for the transport group and oil.[7]

The second issue is related to parameter stability in the demand system. If the model is unstable it will be difficult to interpret the regression results. Since a parametric econometric model is completely described by its parameters, model stability is equivalent to parameter stability (see Chan and Lee, 1997). We rely on the CUSUM and CUSUMSQ tests of Brown et al. (1975). The tests are applied to the residuals of each main group in Eq. (6). The CUSUM test is based on the cumulative sum of recursive residuals. It is updated recursively and is plotted against the time. If the plot of CUSUM statistic stays within 5% significance level (portrayed by two straight lines whose equations are given in Brown et al., 1975), then coefficient estimates are said to be stable. A similar procedure is used to carry out the CUSUMSQ, which is based on the squared recursive residuals. In general, if the CUSUM or CUSUMSQ move outside the critical lines of 5% significance level, the null hypothesis will be rejected, meaning that the model is unstable.

As can be seen from Appendix B, the plot of CUSUM statistic stays within the critical lines indicating stability in demand model. On the other hand, according to the CUSUMSQ plot the line indicating the other goods group moves outside of the 5% significance level. However, since this group contains a diverse composition of goods, it is not wise to rely too heavily on this particular result and therefore reject stability. Accordingly, there is evidence supporting a stability hypothesis of the demand system.

Now we can use the estimated parameters to calculate the elasticities. These elasticities depend on the values of prices, energy taxes and total expenditure at which they are evaluated. Here we evaluate the elasticities at the sample mean for the period 1980–2002. Given the estimated parameters, the expenditure and price elasticities can be calculated according to (8)–(12). The resulting elasticities are presented in Table 2.

From Table 2 we can notice that all expenditure and own-price elasticities have the expected signs. The expenditure elasticities indicate that food, heating and transportation are necessities, whereas other goods are luxuries. All own-price elasticities have a negative sign, meaning that a price increase will reduce demand for that good.

Table 2 should be read in the following way. If the price of electricity increases by 10%, the demand for electricity decreases by 6.1%. But if the energy tax for electricity increases by 10%, the demand for electricity is reduced by 18%. In other words, the energy tax for electricity has larger impact on consumer demand than the producer price of electricity.

From this point of view, we can notice that Swedish consumers are more sensitive to energy taxes than producer price for most energy goods except petrol and public and other transport. It seems that a change in energy taxes for these goods have a smaller impact than a change in producer price for these goods. It should be noted that most of the own price elasticities are between 0 and -1, which implies that a higher price of one good increase its budget share in spite of lower consumption of that good.

Also from Table 2, the total expenditure elasticities indicate that all goods in the within food, heating and transportation are necessities, i.e. these have total expenditure elasticities less than one except for district heating. Within the "other goods" group, clothes, recreation, and domestic appliances are found to be luxuries, since they have total expenditure elasticities that are larger than one. These results are what we might expect, i.e. that appliances and recreation are more of a luxury good than for example food.

Furthermore, the results in Table 2, show that the tax elasticities seem to be—in absolute value—higher than -1 for electricity, oil, and district heating. For these goods, higher energy taxes will lead to a relatively large reduction in consumption, but also a decrease in the budget share. From this point of view, we can say that the energy taxes may be efficient if the objective is to reduce emissions, but inefficient if the objective with the tax is strictly fiscal. On the other hand, the tax elasticities for petrol and public and other transport is less than -1, meaning that if the tax increases on these goods, energy taxes will be more efficient from a fiscal point of view, at least in the short run.

6. Conclusion and discussion

One of the key issues in public policy in general, and perhaps in environmental policy in particular, is how consumers respond to changes in policy. In this paper the issue is how consumers respond to changes in taxation, in particular environmental taxation. The basic question posed is if the response to a price change depends on the source of the price change. The idea is to test if changes in the consumer price that results from the introduction, or change, in environmental taxes give a different signal to the consumer, compared with changes in the consumer price that results only from a producer price change.

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[7] To calculate the *F*-test, we first estimate the unrestricted model (Eq. (6) for the main groups, or Eq. (7) for the goods within the main groups). In the estimation of the restricted model we include an equality constraint on the own-price parameter and the own-tax parameter, i.e. there is one restriction in each equation.

Table 2
Estimated own price and expenditure elasticities

	Own-price	Expenditure	Total own-price	Total expenditure
Main groups				
Foodstuff	−0.11	0.26		
Heating	−0.07	0.61		
Heating tax	−0.36*			
Transport	−0.17	0.53		
Transport tax	−0.20			
Other goods	−0.84	1.50		
Foodstuff				
Food	−0.78	0.79	−0.31	0.21
Beverages	−0.98	1.43	−0.57	0.38
Heating				
Electricity	−0.61	0.75	−0.14	0.46
Electricity tax	−1.80*		−1.40	
District heating	−0.43	1.92	−0.08	1.18
District heating tax	−1.83*		−1.59	
Oil	−0.99	1.04	−0.86	0.64
Oil tax	−1.58*		−1.49	
Transports				
Petrol	−0.71	0.72	−0.45	0.32
Petrol tax	−0.46		−0.21	
Car maintenance	−0.99	1.53	−0.49	0.82
Public and other transport	−0.55	0.49	−0.47	0.26
Public and other transport tax	−0.76		−0.69	
Other				
Clothes	−1.29	0.72	−1.27	1.12
Other goods	−0.81	1.03	−0.73	1.60
Health care	−0.23	0.64	−0.23	0.90
Recreation	−0.87	1.33	−0.84	2.06
Domestic appl.	−1.58	1.05	−1.56	1.60

Note: *the signalling effect is significant.

To achieve the objectives a system of demand functions for Swedish households is estimated. To test for the signalling effect of environmental taxes the consumer price for energy goods is partitioned into a producer price part and a tax part. The results of the study show that changes in environmental taxes has a significant signalling effect on the demand for residential heating in the sense that the consumers are more sensitive to a tax change than a producer price change. For transports, however, the results show no significant difference. Concerning individual commodities within the main groups the results shows that the tax elasticity is higher (in absolute value) for all types of energy within heating (electricity, oil, district heating). Within transports, however, the results indicate the opposite, i.e. petrol consumption seems to be less sensitive to a tax change than to a change in the producer price. These results are then indicating that environmental policy, in the form of energy taxes, will be more effective in reducing pollution due to consumption of heating, but less effective in reducing pollution from transports.

In this paper we use macro level time-series data for Swedish household expenditure. This may be one explanation to the somewhat ambiguous results concerning the signalling effect, i.e. we have not been able to control for long-run trends in petrol consumption affected by for example improvements in fuel efficiency. Furthermore, the aggregate nature of the data may be another explanation. It may be the case that there are large differences between different types of households, depending on family size, income level, place of residence, etc., which is not captured using macro data. Thus, using panel data to determine the difference in signalling effect at the specific level of household may be a better way to investigate this matter. Furthermore, one could also examine the effect of the "consistency" of environmental policy by estimating the above model for the first major introduction of the environmental tax, compared with the subsequent increases of the same tax. It may be the case that the signalling effect is "non-linear" in the sense that the signalling effect is stronger when the tax is introduced than for subsequent changes of the tax. However, this will be subject for future research.

Acknowledgements

I would like to thank Runar Brännlund, Kurt Brännäs and Jonas Nordström for helpful comments and suggestions. Research grants from FORMAS and Riksbankens Jubileumfond are gratefully acknowledged.

Appendix A

Consider the share equation for Ideal Demand system model using our previous notation:

$$w_i = \alpha_i + \sum_j \gamma_{ij} \ln(\bar{p}_j) + \sum_j \tilde{\gamma}_{ij} \ln \tau_i + \beta_i \ln(Y_t/P_t), \qquad \text{(A.1)}$$

where t denotes time. The price index, $\ln P_t$, is here defined as Stone's price index, i.e.,

$$\ln P_t = \sum_j w_{jt} \ln p_{jt}, \quad \text{and} \quad p_{jt} = \bar{p}_{jt}\tau_{jt}.$$

A general definition of the price elasticities of demand from the LAIDS model (e_{ij}), suppressing t subscripts for time being, is

$$e_{ij} = \frac{\mathrm{d}\ln Q_i}{\mathrm{d}\ln \bar{p}_j} = -\delta_{ij} + \frac{\mathrm{d}\ln w_i}{\mathrm{d}\ln \bar{p}_j} = -\delta_{ij} + \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i}\frac{\mathrm{d}\ln P}{\mathrm{d}\ln \bar{p}_j}, \qquad \text{(A.2)}$$

where these elasticities refer to allocations within the group holding constant total group expenditure (Y) and all other prices, δ_{ij} is Kronecker delat ($\delta_{ij} = 1$ for $i = j$; $\delta_{ij} = 0$ for $i \neq j$).

In the linear Approximate Almost Ideal Demand system model, the common approach (e.g., Chalfant, 1987) is to use a special case when:

$$\frac{\mathrm{d}\ln P}{\mathrm{d}\ln \bar{p}} = w_j. \qquad \text{(A.3)}$$

Substituting (A.3) into (A.2) yields:

$$e_{ij} = -\delta_{ij} + \frac{\gamma_{ij}}{w_i} - \frac{\beta_i}{w_i} w_j. \qquad \text{(A.4)}$$

By the same way, we can drive the price elasticity for energy tax.

In the LAIDS model, expenditure elasticities also ought to account for the role of expenditure shares as variables in Stone's price index. The general expression for the expenditure elasticity in Eq. (A.1) is

$$E_i = \frac{\mathrm{d}\ln Q_i}{\mathrm{d}\ln Y} = 1 + \left(\frac{\mathrm{d}w_i}{\mathrm{d}\ln Y}\right) / w_i. \qquad \text{(A.5)}$$

The usual approach treats shares as fixed parameters in the Stone's price index (P) and obtains:

$$\frac{\mathrm{d}w_i}{\mathrm{d}\ln Y} = \beta_i. \qquad \text{(A.6)}$$

Substituting (A.6) in (A.5) yields the expenditure elasticity as following:

$$E_i = 1 + \frac{\beta_i}{w_i}. \qquad \text{(A.7)}$$

Appendix B

Demand system parameter Estimates for the period 1980–2002 for different group are Tables B1–B5.

Table B1
Demand system parameter estimates for the period 1980–2002 in the main group

	Constant	Price of food	Price of heating	Heating tax	Price of transport	Transport tax	Price of other goods	Expenditure coefficient
Food	1.6 (16.4)	0.17 (7.9)	−0.004 (−0.29)	−0.01 (−1.2)	0.007 (0.31)	0.006 (0.3)	−0.18 (−6.1)	−0.18 (−12.7)
Heating	0.23 (1.5)	−0.03 (−0.85)	0.07 (3.9)	0.05 (2.6)	−0.03 (−1.2)	0.002 (0.06)	0.02 (0.6)	−0.03 (−1.6)
Transport	0.5 (4.9)	0.01 (0.51)	−0.03 (−1.8)	−0.2 (−1.3)	0.01 (4.4)	0.09 (4.0)	−0.07 (−2.3)	−0.06 (−4.2)
Other goods	−1.4 (−9.1)	−0.14 (−4.2)	−0.05 (−2.5)	−0.02 (−0.92)	−0.06 (−1.8)	−0.09 (−2.5)	0.22 (4.9)	0.28 (12.1)

Table B2
Demand system parameter estimates for the period 1980−2002 in the food subgroup

	Constant	Price of food	Price of beverages	Expenditure coefficient
Food	1.5 (10.4)	0.05 (4.6)	−0.05 (−5.1)	−0.13 (−5.2)
Beverages	−0.54 (−3.7)	−0.5 (−4.6)	0.05 (5.2)	−0.13 (−5.2)

Table B3
Demand system parameter estimates for the period 1980–2002 in the heating subgroup

	Constant	Price of Electricity	Electricity tax	Price of district heating	District heating tax	Price of oil	Oil taxation	Expenditure coefficient
Electricity	2.7 (7.5)	0.14 (2.4)	−0.64 (−4.5)	−0.07 (−1.5)	0.19 (2.2)	0.8 (1.7)	0.17 (1.3)	−0.16 (−3.1)
District Heating	−2.5 (−10.9)	−0.11 (−2.6)	0.2 (3.2)	0.14 (4.6)	−0.13 (−2.3)	0.08 (2.5)	0.38 (4.4)	0.18 (5.4)
Oil	1.1 (3.2)	−0.16 (−2.5)	−0.03 (−0.2)	−0.14 (−3.1)	−0.12 (−1.5)	0.002 (0.04)	−0.07 (−0.54)	0.006 (0.16)

Table B4
Demand system parameter estimates for the period 1980–2002 in the transport subgroup

	Constant	Price of petrol	Petrol tax	Price of car maintenance	Price of public and other transport	Public and other transport tax	Expenditure coefficient
Petrol	0.9 (3.9)	0.06 (1.4)	0.18 (2.3)	0.01 (0.29)	−0.02 (−0.40)	−0.11 (−2.2)	−0.16 (−3.9)
Car maintenance	−0.69 (−2.9)	−0.11 (−2.6)	−0.18 (−2.4)	0.08 (1.8)	−0.02 (−0.37)	0.004 (0.09)	0.21 (4.5)
Public and other transport	0.88 (8.1)	0.04 (2.2)	0.0001 (0.004)	−0.09 (3.7)	0.06 (2.7)	0.12 (5.2)	−0.08 (−4.1)

Table B5
Demand system parameter estimates for the period 1980–2002 in the Other goods subgroup

	Constant	Price of clothes	Price of other goods	Price of health care	Price of recreation	Price of Domestic appliances	Expenditure coefficient
Clothes	1.1 (4.80)	−0.05 (−1.5)	−0.18 (−4.2)	−0.03 (−1.7)	0.17 (4.1)	−0.01 (−0.2)	−0.04 (−2.9)
Other goods	−0.14 (−0.68)	0.007 (0.2)	0.09 (2.4)	0.06 (2.9)	−0.18 (−4.4)	0.1 (1.4)	0.02 (1.07)
Health care	0.22 (2.7)	−0.009 (−0.64)	0.007 (0.5)	0.05 (7.1)	−0.01 (−0.79)	−0.03 (−1.4)	−0.02 (−4.8)
Recreation	−0.59 (−3.0)	0.02 (0.44)	0.06 (1.7)	−0.04 (−2.4)	0.03 (0.67)	0.02 (0.36)	0.05 (3.6)
Domestic appliances	0.43 (3.1)	0.04 (1.9)	0.009 (0.37)	−0.03 (−2.5)	−0.007 (−0.31)	−0.7 (−1.6)	0.007 (0.75)

Note: *t*-values are presented in the parenthesis.

Appendix C

CUSUM and CUSUMSQ test for different groups are given in Figs. C1–C4.

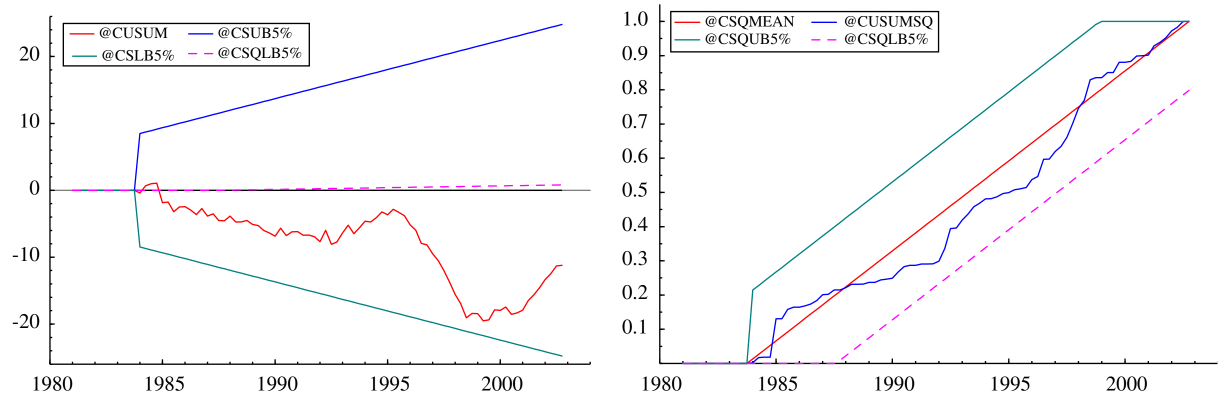

Fig. C1. CUSUM and CUSUMSQ test for food group. The straight lines represent critical bounds at 5% significance level.

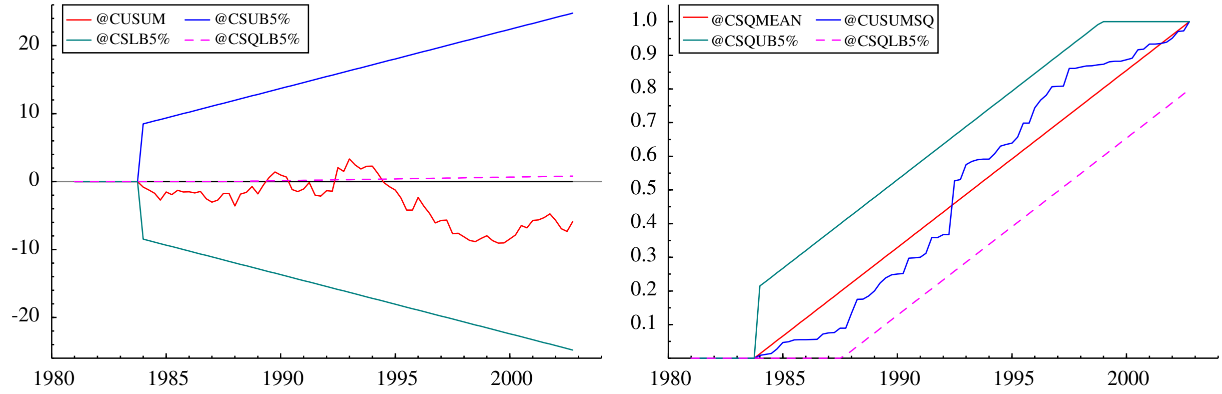

Fig. C2. CUSUM and CUSUMSQ test for heating group. The straight lines represent critical bounds at 5% significance level.

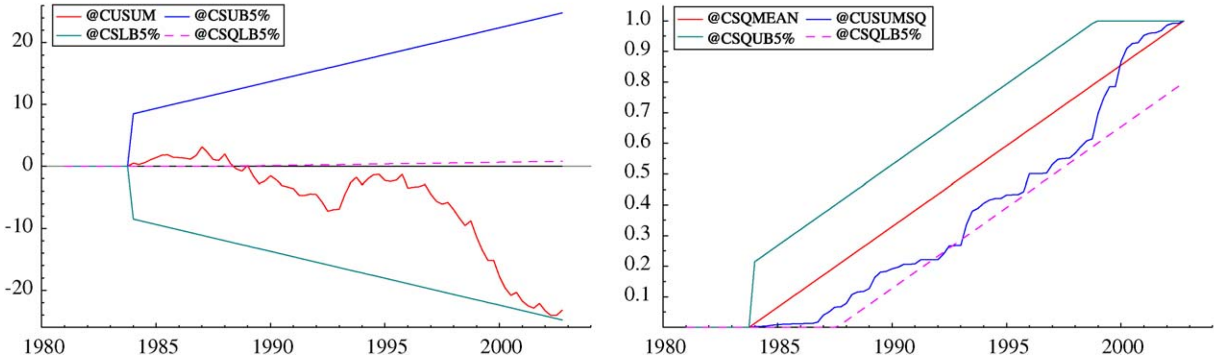

Fig. C3. CUSUM and CUSUMSQ test for transport group. The straight lines represent critical bounds at 5% significance level.

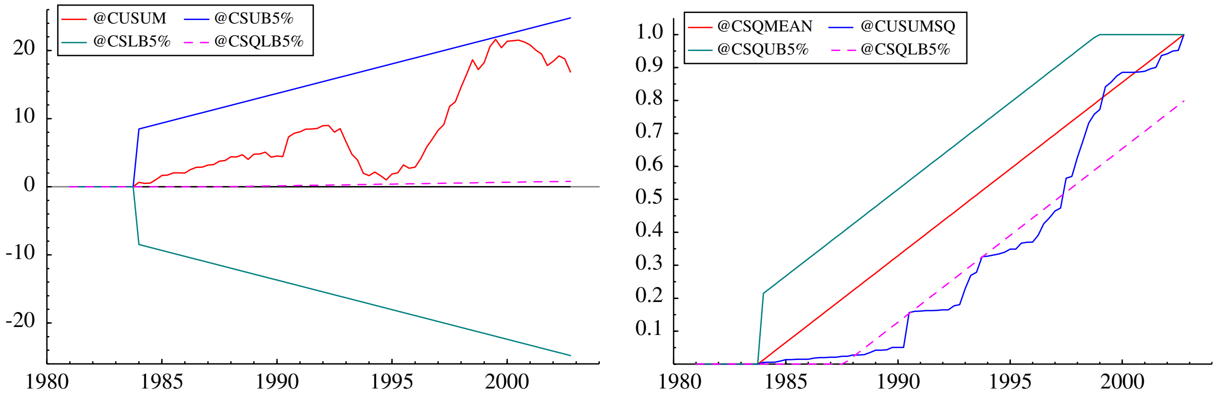

Fig. C4. CUSUM and CUSUMSQ test for other goods. The straight lines represent critical bounds at 5% significance level.

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Demand for Environmental Quality: An Empirical Analysis of Consumer Behavior in Sweden[†]

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Abstract

In this paper we estimate the income elasticity of demand for recreational services and other traditional groups of goods in Sweden and test for potential changes in such estimates over the twentieth century. Due to the difficulty of directly observing the demand for recreational services, we employ an indirect methodology by using the demand for some outdoor goods as a proxy for the demand for recreational services. In line with most prior research, our results confirm the expectation that recreational services, as a public good, is a luxury good in Sweden. Our results also show that the income elasticities for traditional goods are stable over time, indicating that consumer preferences for expenditure on these specific commodities do not change over time.

Keywords: Household demand; environmental services; income elasticities;
Engel curves.

JEL Classification: D12; H41; Q26.

[†] The author acknowledges financial support from the Bank of Sweden Tercentenary Foundation (Riksbankens Jubileumsfond, Kulturdonationen). The author also wishes to thank Runar Brännlund, Jonas Nordström, Peter Berck, and Karl-Gustaf Löfgren for valuable comments.

1. Introduction

One of the main goals in studying individual consumption behavior is to analyze the relationships between commodity expenditure and income or total expenditure (i.e. the well-known Engel curves). There are several reasons why these relationships are of interest. Firstly, it may be useful to see how demand for various goods develops under different growth scenarios. A second reason is to determine whether consumer preferences regarding various commodities have changed over time.

The main objective of this paper is to compare how demand for recreational services and other major private goods in Sweden reacts to changes in income and, in particular, how these reactions have changed over time. Specifically, we investigate how the income elasticity in Sweden has changed over time with respect to some specific goods that are closely related (complementary) to environmental services.[1] Because consumption of recreational services is not directly observed in the market, the study uses the demand for complementary market products as a proxy for the demand for environmental services. Further, the objective of this paper is closely related to the notion of an environmental Kuznets curve (EKC), which describes a specific relation between environmental quality and growth.

Several studies have examined the income elasticity for different commodities using data from different countries in different time frames. For example, Segal (2001) reports that the budget share for food has fallen dramatically in the United States over the twentieth century, from 50% for poor households and 30% for affluent households in 1901 to 10-15% in 1999. Segal's (2001) finding reaffirms Engel's law of food from 1895.[2] On the other hand, Segal (2001) found that the budget share for transportation increased from about 2% to more than 20%. Such results indicate a remarkable instability of the budget share for food and transportation expenditure in the U.S. over the century.

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[1] For convenience, we use the label "environmental services" for all goods and services provided by the environmental and the ecological system, including environmental quality, see for example, Mäler (1974).

[2] Formulated by German-born statistician, Ernst Engel (1821-1896), Engel's Law states that as incomes increase, the proportion of income spent on food falls.

Larsen (2001) used Norwegian survey data on purchasing behavior for equipment and lodging over the period 1986-1995. He found that the income elasticity was fairly stable over time, and that both equipment and lodging were luxury goods over the whole period. Further, Miles et al. (2002) used several models, both parametric and non-parametric, to estimate Engel curves using survey data from Uruguay. They found that the results differ substantially depending on model specification and estimation method. However, their results support the hypothesis that the environment is a luxury good in Uruguay. Kriström and Riera (1996) using estimates of the willingness to pay for environmental goods for different European countries (Finland, France, Norway, Holland, Spain and Sweden), found that the hypothesis that environmental goods are necessary goods cannot be rejected in most cases (income elasticity is less than one).

The estimation of income elasticities over several years has strict requirements for data. The data sets must be comparable, span a substantial period, be of high quality, exhaustively cover expenditure opportunities, and preferably be random samples. The Swedish Family Expenditure Survey (FES) have some attractive features for the question at hand: respondents are randomly selected, data contain information of actual market behavior where budget constraints are observed and obeyed, the classifications of goods are retained over time and the choice set is saturated and exhausts purchase possibilities. Time trends are detectable since data span a considerable time period and are comparable over time. This paper uses FES data for 1913, 1984, 1988, and 1996.

The rest of the paper is organized as follows: In the next two sections, we elaborate further on the existing literature, as well as on the theoretical framework for our empirical investigation. Our econometric model is presented in section 4. Section 5 describes the data used in the study. The results from the model are presented in section 6. Finally, a short summary and some concluding remarks are given in section 7.

2. Previous Studies

Much discussion exists in the economic literature of the possible effects of income and economic growth on the environment, including speculation on the possible existence of an “environmental Kuznets curve”. This curve shows an inverted U-shaped relation between pollution and per capita income, indicating that in the early stages of a country’s economic development pollution increases up to a turning point and then begins to decrease as per capita income increases further. The EKC idea has triggered a good deal of research, theoretical as well as empirical. The theoretical literature has focused mostly on assumptions regarding the relationship between technology/preferences and emissions (Lopez, 1994, Selden and Song, 1995, McConell, 1997, Chichilnisky 1998, de Groot 1999). In general, empirical models are of a reduced form type using cross country data (Grossman and Krueger, 1995, Stern and Common, 2001). An obvious drawback with most of the empirical models is that they can only describe the relation, not explain it. To understand the mechanisms at work, we need further knowledge about technological progress and how consumer preferences are formed.

Clearly related to this issue is the question of how consumer demand for recreational services and environmental goods reacts to income changes. If the income elasticity is greater than one, this would be consistent with the EKC hypothesis. However, income elasticity is also important from a distributional perspective, since it will tell us which groups in society will reap the benefits of projects that improve environmental services. Therefore, such estimates of demand and income elasticity of recreational services and environmental goods may provide significant information to any cost-benefit analysis or ex-post project evaluation; see Kanninen and Kriström (1992), Kriström and Riera (1996), and Hökby and Söderqvist (2001).

The basic problem in the estimation of income elasticity for environmental goods is that we cannot directly observe individual demand for recreational services due to its public good and/or non-market priced nature. Therefore, we cannot directly estimate the income elasticity for such goods. To overcome this problem, two different approaches are suggested in the literature. The first approach is to use "stated preference" data,[3] and the second is to employ an indirect estimation technique derived from the fact that households have to purchase complementary goods.

The first approach is a direct approach based on contingent valuation surveys (Kriström and Riera, 1996, Hökby and Söderqvist, 2001). Under this approach, willingness to pay data is regressed on income and other individual characteristics. In Kriström and Riera

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[3] This approach mainly relies on individuals' hypothetical behavior on markets set up for environmental service in some survey setting. The contingent valuation method (CVM) is widely used in this approach (Mitchell and Carson, 1989 and Batemen and Willis, 1999).

(1996) willingness to pay data for various environmental goods in a number of European countries are regressed on income. Contrary to the conventional wisdom, Kriström and Riera found that willingness to pay for environmental improvements decreases with income, which indicates that the income elasticity is lower than one. Using the same methodology, Hökby and Söderqvist (2001) found similar results. A problem with this approach is that the magnitude of the willingness to pay elasticity with respect to income may not give complete information concerning the demand elasticity with respect to income.[4] To address this problem, Hökby and Söderqvist also merge data from several willingness to pay studies for the same environmental good, reduced marine eutrophication in the Baltic Sea, and again found that the income elasticity for reduced eutrophication is less than one.

The second approach is an indirect estimation approach based on the fact that individuals, in order to generate utility from the environment, need private goods that are bought and sold in the market and, therefore, can be observed. For example, to enjoy the excitement of a salmon river it is necessary to have some fishing gear, or at least some outdoor gear. Thus, if demand for fishing gear and other goods that are closely related to the "consumption" of environmental amenities increase more than proportionally with the increase in income, the interpretation may be that the environment is a luxury good (Mäler, 1974).

There are a number of previous studies that have used the indirect approach, such as Costa (1997), Pereyra and Rossi (1998), Miles et al. (2002), and Larsen (2001). Costa (1997), using U.S. data, reported elasticities greater than one for recreation goods. However, she found that these elasticities decreased significantly over the last hundred years. Pereyra and Rossi (1998) applied a parametric method using data from Uruguay and found corroborative evidence that environmental goods constitute a luxury good. Miles et al. (2002) used parametric estimates to confirm the hypothesis that the outdoor recreational services constitute a luxury good in Uruguay. Larsen (2001) used Norwegian survey data on purchasing behavior for equipment and lodging over the period 1986-1995 to estimate Engel curves. He found that the income elasticity was

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[4] The income elasticity of willingness to pay and the ordinary income elasticity of demand are related. However, knowledge of one is insufficient to determine the magnitude or even the sign of the other. The income elasticity of willingness to pay is influenced by additional factors that are generally unobservable. For more details, see Flores and Carson (1997).

fairly stable over time, and that both equipment and lodging were luxury goods over the whole period.

In this study, we follow the second approach, using household survey data for Sweden. Using this data, we estimate Engel curves for private goods that are used in the production of environmental services. As well as estimating the income elasticity for proxy goods used for recreational services (outdoor recreation), we also estimate the income elasticity of demand for other traditional market goods in Sweden over the same period in order to compare relative changes in consumer preferences.

To achieve our objectives, we formulate and estimate an econometric model for purely private goods and for private goods that are complementary to public goods. The model employed is based on the assumption of a two-stage budgeting process. It is assumed that in the first stage, the household allocates its total expenditure for purely private goods and goods complementary to recreation on different commodity aggregates, or groups. There are five groups: one group of goods complementary to outdoor recreation, and four purely private groups: food, transportation, energy goods, and other goods. Given the allocation to each commodity group, households in the second stage allocate their group expenditures on the various goods within the group. Our econometric model is based on Deaton & Muellbauer's (1980) almost ideal model (AIDS). The inclusion of data from a budget survey for 1913 enables us to compare the results over a longer time span.

3. Theory

The theory behind our approach can be outlined as follows. Assume that individuals have preferences over a vector of private goods $\mathbf{x} = [x_1, \ldots, x_K]$ and a vector of environmental commodities (experiences), $\mathbf{e} = [e_1, \ldots, e_P]$, that can be translated into a utility function that is weakly separable in $\mathbf{x}$ and $\mathbf{e}$:

$$U(\mathbf{x}, \mathbf{e}) = U(\mathbf{x}, u^e(\mathbf{e})) \tag{1}$$

Following Freeman (2003), we assume that environmental commodities, **e,** are produced using environmental attributes,[5] $\mathbf{A} = (A_1,..., A_k)$, and market goods, **z** = $(z_1,..., z_m)$, according to:

$$e_r = e(\mathbf{z}, \mathbf{A}) \qquad r = 1,...,l \tag{2}$$

The production function (2) has the properties that *e* is increasing in **A** and **z**, and that all inputs are essential in the production of *e*. In other words, both environmental attributes and market goods contribute to production of outdoor recreational experiences. By substituting (2) into (1), we obtain the following optimization problem:

$$\max_{\mathbf{x},\mathbf{z}} \left\{ U(\mathbf{x}, u^e(\mathbf{e}(\mathbf{z}, \mathbf{A}))\right\} \qquad s.t. \quad \mathbf{p}_x\mathbf{x} + \mathbf{p}_z\mathbf{z} \le y, \tag{3}$$

where $\mathbf{p}_x$ and $\mathbf{p}_z$ are the price vectors corresponding to **x** and **z** respectively, and *y* is the expenditure on private and complementary goods.

The first order conditions to this problem implicitly define the demand functions for the “instrumental” goods, **z**, as a function of prices, income, attributes, preferences, and production technology, i.e.:

$$z_i = z(\bar{p}_x, \mathbf{p}_z, \mathbf{A}, y) \qquad i = 1,...,m \tag{4}$$

where $\bar{p}_x$ is the price index for private goods, and *y* is expenditure on goods that are complementary to environmental goods.[6]

According to equation (4), changes over time in expenditure on z_i may result from changes in prices, income, or environmental attributes. However, we do not attempt to account here for changes in environmental attributes, and therefore consider them to be constant over time. Thus equation (4) constitutes the basis for our analysis, and will serve as a starting point in the specification of the econometric model in the following section.

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[5] Freeman gives examples of environmental attributes, such as number of fish per volume of water and water quality. Here, we may add air quality, sounds, wild-life, ski tracks and number of sunny days.

[6] The reason for using $\bar{p}_x$ instead of a vector of private good prices is the assumption of weak separability between private and public goods.

4. The Modeling Framework

In this section we formulate a demand system for public and private goods. In the first stage, the household determines, given its total budget, how much to spend on food, energy goods, transportation, and other goods as private groups, and outdoor recreation services as a public group. In the second stage, the household allocates resources within each of these groups. For example, given a specific amount of money to be spent on transportation, the household determines how much of that should be allocated to gasoline, car maintenance, and public transport. In the same manner, the household determines in the second stage how to use its budget for outdoor recreation. In this case, the household can choose between "equipment for sporting, fishing and camping", and "other recreational goods". Our main objective is to model and estimate household choices in the first and second stage.

The Linear Almost Ideal Demand system (LAIDS) is one of the most popular demand models for estimation of Engel curves. In the empirical estimation of Engel curves, non-linearity has been found to be important for some goods. For instance, Banks et al. (1997) found that the Engel curves for some specific goods in the UK are non-linear in the logarithm of expenditure. To overcome the problem of non-linearity, Banks et al. (1997) developed the Quadratic Almost Ideal Demand system (QUAIDS).

In this paper we take the quadratic AIDS (QUAIDS) model as our basic specification. Given the structure of two-stage budgeting, we can express demand for the complementary goods, *z*, and pure private aggregates, *x*, in budget share form for household *h* as: [7]

$$w^h_{(z)t} = \alpha^h_{(z)} + \gamma^h_{(zz)} \ln \bar{p}_{(z)t} + \gamma^h_{(zx)} \ln \bar{p}_{(x)t} + \beta^h_{(z)}\left(\ln R^h_t - \ln \bar{P}_t\right) + \lambda^h_{(z)}\left(\ln R^h_t - \ln \bar{P}_t\right)^2 + \varepsilon^h_{(z)t} \quad (5)$$

$$w^h_{(x)t} = \alpha^h_{(x)} + \gamma^h_{(xz)} \ln \bar{p}_{(z)t} + \gamma^h_{(xx)} \ln \bar{p}_{(x)t} + \beta^h_{(x)}\left(\ln R^h_t - \ln \bar{P}_t\right) + \lambda^h_{(x)}\left(\ln R^h_t - \ln \bar{P}_t\right)^2 + \varepsilon^h_{(x)t} \quad (6)$$

Equation (5) describes the budget share for the public commodity group for household *h* = 1, ..., *H*, where $w_{(z)t}$ denotes the budget share for group *z* in period *t*, $\bar{p}_{(z)t}$ and $\bar{p}_{(x)t}$ are group price indices for public and private goods, respectively R_t is total expenditure

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[7] In the estimation, we have three main private groups (foodstuff, energy goods, and transportation). Thus *x* in equation (6) can be viewed as a vector of private goods, and the group price index for private goods as a vector of group price indices.

on public and private goods, $\overline{P}_t$ is the overall consumer price index, and $\varepsilon_{(z)t}$ is the error term. In the same manner, equation (6) gives the budget share for private commodities, where $w_{(x)t}$ denotes the budget share for private goods *x* in period *t*, $\overline{p}_{(x)t}$ is a group price index for private goods and $\varepsilon_{(x)t}$ is the error term. The parameters to be estimated are α, γ, β, and λ.

The demand functions for household *h* in goods within the sub-groups have the same functional form as the demand equations for the main groups. The demand function for goods within the z^{th}, and the x^{th}, groups can thus be written as

$$w^h_{(z)it} = \alpha^h_{(z)i} + \sum_{j=1}^{m} \gamma^h_{(z)ij} \ln p_{(z)jt} + \beta^h_{(z)i}\left(\ln R^h_{(z)t} - \ln \overline{p}_{(z)t}\right) + \lambda^h_{(z)i}\left(\ln R^h_{(z)t} - \ln \overline{p}_{(z)t}\right)^2 + \varepsilon^h_{(z)it}, \quad (7)$$

where $i = 1, \ldots, m$ denotes the number of goods within *z* and $h = 1, \ldots, H$ denotes households' and

$$w^h_{(x)it} = \alpha^h_{(x)i} + \sum_{j=1}^{n} \gamma^h_{(x)ij} \ln p_{(x)jt} + \beta^h_{(x)i}\left(\ln R^h_{(x)t} - \ln \overline{p}_{(x)t}\right) + \lambda^h_{(x)i}\left(\ln R^h_{(x)t} - \ln \overline{p}_{(x)t}\right)^2 + \varepsilon^h_{(x)it}, \quad (8)$$

where $i = 1, \ldots, n$ denotes the number of goods within *x*.

Equations (7) and (8) give the allocation within the public and private groups, where $w_{(z)it}$ and $w_{(x)it}$ are the budget shares for the individual goods within each group, $p_{(z)j}$ and $p_{(x)j}$ are the commodity prices within respective group, $R_{(z)t}$ is the total expenditure on goods complementary to public goods, and $R_{(x)t}$ is the total expenditure on the pure private goods.

In any time period *t*, we assume that the prices of goods are equal across all households. This means that since we will estimate the model for each cross-section separately, the prices can be included directly into the intercept term for any time period. Thus, for each cross-section we can write the budget shares to be estimated as: [8]

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[8] This means that we can exclude the price in the estimation of each cross-section.

$$w^h{}_{(z)t} = \alpha^h_{(z)t} + \beta^h_{(z)t}\left(\ln R^h_t\right) + \lambda^h_{(z)t}\left(\ln R^h_t\right)^2 + \varepsilon^h_{(z)t} \qquad (9)$$

$$w^h{}_{(x)t} = \alpha^h_{(x)t} + \beta^h_{(x)t}\left(\ln R^h_t\right) + \lambda^h_{(x)t}\left(\ln R^h_t\right)^2 + \varepsilon^h_{(x)t} \qquad (10)$$

$$w^h{}_{(z)it} = \alpha^h_{(z)it} + \beta^h_{(z)it}\left(\ln R^h_{(z)t}\right) + \lambda^h_{(z)it}\left(\ln R^h_{(z)t}\right)^2 + \varepsilon^h_{(z)it}\,, \qquad i=1,\ldots,m \qquad (11)$$

$$w^h{}_{(x)it} = \alpha^h_{(x)it} + \beta^h_{(x)it}\left(\ln R^h_{(x)t}\right) + \lambda^h_{(x)it}\left(\ln R^h_{(x)t}\right)^2 + \varepsilon^h_{(x)it}\,, \qquad i=1,\ldots,n$$

(12)

where $t = 1,\ldots, T$ is the number of cross-sections, and where $\alpha^h_{(z)t}$, $\alpha^h_{(x)t}$, $\alpha^h_{(z)it}$, and $\alpha^h_{(x)it}$ now include the (constant) price.

According to this system, equations (9) and (10) describe how household h allocate its total expenditure between public and private groups respectively, while equation (11) and (12) describe the allocation of household expenditure to goods within the public and private groups.

5. Data and Econometric Consideration

This study uses cross-sectional data from four Swedish Family Expenditure Surveys (FES) 1913, 1984, 1988, and 1996. The first household expenditure survey in Sweden was performed in 1913, covering approximately 900 households in eight towns. The 1984 survey included 4354 households, the 1988 survey 3764 households, and the 1996 survey 1104 households. The surveys contain expenditure data on a rather disaggregated level. Here, however, we will focus on four main aggregates:[9]

Outdoor recreation: Expenditure on "*sporting, fishing, and camping equipment*", and "*other recreation goods*".

Transport: Expenditure on *"petrol", "car maintenance",* and *"public and other transport".*

Energy goods: Expenditure on *"electricity",* and *"other energy goods".*

Foodstuffs: Expenditure on *"food"* and *"beverages".*

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[9] The 1913 survey uses only an aggregate general title for recreational goods, which includes outdoor and indoor recreation and gives no data within the groups except for foodstuffs.

Table 1 presents the budget shares for the four main groups and their sub-groups. As shown, household expenditure for outdoor recreation, transportation, and energy goods have been fairly stable over time, although there is a weak negative trend in the energy goods share. However, the share of foodstuffs has decreased significantly, while approximately 45% of household expenditure went to foodstuff in 1913, this share declined to less than 30% in 1984, and to less than 20% in 1996.

Table 1 also shows that there was no dramatic change in household expenditure for most of the goods within the main groups, except for spending on sporting, fishing and camping equipment, which decreased substantially. Approximately 60% of household expenditure on recreation went to equipment in 1984, but by 1996 this share had decreased to 35%.

Household characteristics may affect consumer behavior with respect to these four groups of goods. There are basically two different ways to consider different household characteristics in the model estimation (Pollak and Wales, 1992). The first technique is to consider the sample as a whole and use different dummy variables to capture different household characteristics. The second is to divide the sample into homogenous sub-samples depending on household characteristics. In this paper, we follow the first approach. The variables relating to household characteristics were: (a) a continuous variable that represents the number of adults, and (b) three dummy variables for the cases when the household has one child, two children, or more than two children less than 18 years of age.[10] We also create regional dummy variables (seven for the eight census regions in the 1913 survey, and five for the six census regions in the 1984, 1988, and 1996 surveys). In the estimation, we use total expenditure rather than income because expenditure better reflects permanent income.

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[10] We also estimated the model by using dummy variables for the number of adults, but this did not change the results.

Table 1. Descriptive statistics of budget shares of various commodity goods.

	1913		1984		1988		1996	
	Budget share %	s.e	Budget share %	s.e	Budget share %	s.e	Budget share %	s.e
MAIN GROUPS								
Foodstuff	0.47	(0.07)	0.30	(0.09)	0.27	(0.09)	0.18	(0.07)
Energy goods	0.05	(0.01)	0.14	(0.11)	0.14	(0.10)	0.13	(0.12)
Transport	0.02	(0.01)	0.08	(0.06)	0.07	(0.06)	0.08	(0.07)
Outdoor recreation	0.01	(0.009)	0.005	(0.01)	0.005	(0.02)	0.008	(0.02)
Sum	0.55		0.525		0.485		0.498	
FOODSTUFFS								
Food	0.97	(0.03)	0.90	(0.09)	0.89	(0.10)	0.86	(0.10)
Beverages	0.03	(0.03)	0.10	(0.09)	0.11	(0.10)	0.14	(0.10)
Sum	1.00		1.00		1.00		1.00	
ENERGY GOODS								
Electricity			0.39	(0.40)	0.37	(0.32)	0.34	(0.21)
Other energy goods			0.61	(0.40)	0.63	(0.31)	0.66	(0.28)
Sum			1.00		1.00		1.00	
TRANSPORT								
Petrol			0.51	(0.33)	0.51	(0.12)	0.60	(0.33)
Car maintenance			0.40	(0.31)	0.41	(0.33)	0.28	(0.31)
Public and other transport			0.09	(0.12)	0.08	(0.19)	0.12	(0.21)
			1.00		1.00		1.00	
OUTDOOR RECREATION								
Equipment for sporting, fishing, and camping			0.61	(0.45)	0.52	(0.42)	0.37	(0.44)
Other recreational goods			0.39	(0.42)	0.48	(0.44)	0.63	(0.46)
Sum			1.00		100		1.00	
Number of observation	908		4354		3764		1104	

Note: Standard errors within parentheses.

In this study, we estimate the quadratic almost ideal demand system in expenditure form. To capture the effect of household size and composition on the consumer preferences, we follow Blundell et al. (1993) in allowing the parameters in the model ($\alpha^h_{it}, \beta^h_{it},$ and λ^h_{it}) to vary over time and over different types of household characteristics (e.g. household size and composition, as well as place of residence):

$$\alpha^h_{(r)t} = \alpha_{(r)0} + \sum_{k=1}^{q} \alpha_{(r)k} D_{hkt} \qquad r = z, x \qquad (13)$$

$$\beta^h_{(r)t} = \beta_{(r)0} + \sum_{k=1}^{q} \beta_{(r)k} D_{hkt} \qquad r = z, x \qquad (14)$$

$$\lambda^h_{(r)t} = \lambda_{(r)0} + \sum_{k=1}^{q} \lambda_{(r)k} D_{hkt} \qquad r = z, x \tag{15}$$

$$\alpha^h_{(z)it} = \alpha_{(z)i0} + \sum_{k=1}^{q} \alpha_{(z)ik} D_{hkt} \qquad i = 1 ..., m \ , h = 1, ..., H \tag{16}$$

$$\alpha^h_{(x)it} = \alpha_{(x)i0} + \sum_{k=1}^{q} \alpha_{(x)ik} D_{hkt} \qquad i = 1 ..., n \ , h = 1, ..., H \tag{17}$$

$$\beta^h_{(z)it} = \beta_{(z)i0} + \sum_{k=1}^{q} \beta_{(z)ik} D_{hkt} \qquad i = 1 ..., m \ , h = 1, ..., H \tag{18}$$

$$\beta^h_{(x)it} = \beta_{(x)i0} + \sum_{k=1}^{q} \beta_{(x)ik} D_{hkt} \qquad i = 1 ..., n \ , h = 1, ..., H \tag{19}$$

$$\lambda^h_{(z)it} = \lambda_{(z)i0} + \sum_{k=1}^{q} \lambda_{(z)ik} D_{hkt} \qquad i = 1 ..., m \ , h = 1, ..., H \tag{20}$$

$$\lambda^h_{(x)it} = \lambda_{(x)i0} + \sum_{k=1}^{q} \lambda_{(x)ik} D_{hkt} \qquad i = 1 ..., n \ , h = 1, ..., H \tag{21}$$

D_{hkt} represents dummy variables for demographic characteristics, including number of children and a dummy variable for different regions. The number of dummy variables, q, is equal to 11 in the 1913 survey, and 9 in the1984, 1986, and 1996 surveys.

Given the estimates of the parameters in the demand model, we can now calculate the income elasticities as[11]

$$\xi^h_i = 1 + \frac{\hat{\beta}^h_{it}}{\hat{w}^h_{it}} + \frac{2\hat{\lambda}^h_{it} lnR^h_t}{\hat{w}^h_{it}} \tag{22}$$

Where ξ^h_i denotes household h's income elasticity for good i. A good with an income elasticity larger than one is a luxury, while a good with an income elasticity lower than one is a necessity. However, equation (16) implies that each good can be either a necessity or a luxury for different households, depending upon the distribution of total expenditure and the household specific parameters.

Finally, the most challenging problem is how to deal with observed zero expenditure, since the parameter estimation tends to be biased in a regression model where a large

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[11] The income elasticity for a specific good denotes the percentage change in the consumption of the good as a result of the percentage change in total consumption. See Chalfant (1987) for a derivation of income elasticitiy in an AIDS model.

proportion of the dependent variable is zero (Deaton 1986, Greene 2000).[12] There are at least two possible reasons for an observation of zero. One is that the household is not interested in the good. Another is that even if a household does have a preference for a good, expenditures may be infrequent and lie outside the observation period. To be sure that our data is consistent with the estimation results, we estimate the demand equation by an alternative estimator (Tobit estimator) which assumes that any observation for which the dependent variable takes a zero value is truncated.[13] However, this does not change the results concerning income elasticity to any great extent.[14]

6. Results

This section presents the results of applying the parametric approach to estimate the income elasticity for outdoor recreation, energy goods, transportation, and foodstuffs for Swedish households in four different years during the twentieth century. We start the analysis by testing the functional form for the expenditure equations in order to decide whether the non-linear expenditure term should be included in the model or not. Table 2 shows the results of this test.

According to the F-tests in table 2, we cannot reject linearity for any of the main groups in any of the surveys except for the energy goods group in 1984 and 1988. Among the sub-groups, linearity cannot be rejected for any of the goods within the foodstuffs group in all surveys, for public and other transport in the 1984, 1988, and 1996 surveys, or for any goods within the recreation group in the 1996 survey.

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[12] The proportion of zero expenditure on outdoor recreation in our surveys is approximately 35%.

[13] The standard Tobit model was originally formulated by Tobin (1958).

[14] The results from the Tobit estimator was compared with OLS estimator which we used in this estimation.

Table 2. Test for Linearity (F-test).

	1913	1984	1988	1996
		MAIN GROUPS		
Foodstuff	0.64	1.01	0.91	0.50
Energy goods	0.86	2.45*	5.82*	0.89
Transport	0.24	0.73	1.79	0.29
Outdoor recreation	0.41	0.21	0.12	0.15
		FOODSTUFFS		
Food	1.85	0.70	0.51	1.43
Beverages	1.85	0.69	0.51	1.43
		ENERGY GOODS		
Electricity		8.19*	12.55*	1.93
Other energy goods		8.19*	12.56*	1.93
		TRANSPORT		
Petrol		31.54*	22.36*	13.60*
Car maintenance		31.89*	23.22*	11.80*
Public and other transport		0.46	0.74	1.86
		OUTDOOR RECREATION		
Equipment for sporting, fishing, and camping		3.68*	2.43*	1.71
Other recreational goods		3.68*	2.43*	1.72

* Linearity rejected at the 5% level.

Following the specifications in equations (9), (10), (11), and (12), the demand equations for the goods in the main groups and within the main groups are estimated by ordinary least squares (OLS) and the functional form is determined according to the linearity tests above.[15] For example, in the main group, the linear form should be used in the estimation of every group except energy goods for the 1913 and 1988 surveys.

Table 3 presents estimates with standard errors of the income elasticities of the various goods. These elasticities are computed from the coefficient estimates, the estimated budget shares, and the mean total expenditures for all households in every survey, following equation (22). Standard errors are computed with the delta method (see Greene, 2000).

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[15] Estimates with standard errors of the parameters of the demand equations are available from the author upon request.

Table 3. Estimated income elasticities, standard errors within parentheses.

	1913		1984		1988		1996	
	Income elasticity	Total income elasticity	Income elasticity	Total income elasticity	Income elasticity	Total income elasticity	Income elasticity	Total income elasticity
MAIN GROUPS								
Foodstuff	0.59		0.53		0.48		0.46	
	(0.01)		(0.01)		(0.01)		(0.03)	
Energy goods	0.55		0.31		0.22		0.26	
	(0.04)		(0.04)		(0.02)		(0.04)	
Transport	1.22		0.99		0.97		1.27	
	(0.09)		(0.03)		(0.03)		(0.06)	
Outdoor recreation	1.78		1.87		1.94		2.05	
	(0.08)		(0.15)		(0.16)		(0.27)	
FOODSTUFFS								
Food	0.98	0.58	0.92	0.48	0.91	0.43	0.92	0.42
	(0.002)		(0.004)		(0.01)		(0.01)	
Beverages	1.04	0.61	1.68	0.89	1.71	0.82	1.44	0.80
	(0.06)		(0.03)		(0.04)		(0.05)	
ENERGY GOODS								
Electricity			0.70	0.21	0.32	0.07	0.48	0.12
			(0.02)		(0.02)		(0.05)	
Other energy goods			0.83	0.25	1.35	0.30	1.20	0.31
			(0.09)		(0.07)		(0.02)	
TRANSPORTS								
Petrol			0.95	0.94	0.73	0.71	0.70	0.88
			(0.01)		(0.01)		(0.02)	
Car maintenance			1.32	1.30	1.57	1.52	1.87	2.37
			(0.06)		(0.06)		(0.17)	
Public and other transport			0.86	0.85	0.97	0.94	0.29	0.37
			(0.04)		(0.04)		(0.07)	
OUTDOOR RECREATION								
Equipment for sporting, fishing, and camping			1.23	2.30	1.10	2.13	1.26	2.58
			(0.01)		(0.02)		(0.01)	
Other recreational goods			0.62	1.15	0.79	1.53	0.90	1.84
			(0.03)		(0.05)		(0.02)	

Note: total income elasticity for any good within the main group of goods is calculated by multiplying the income elasticity for the main group by the income elasticity within the main group.

Elasticities can be examined in two different ways, focusing either on the differences between different goods, or on differences over time.

Considering differences over time, we can conclude that outdoor recreation seems to be a luxury good in 1913, and has retained that classification until 1996. This result is consistent with previous research such as that of Costa (1997), Pereyra and Rossi (1998), Miles et al. (2002), and Larsen (2001). However, it contradicts to some extent the finding of Kriström and Riera (1996), who showed some empirical evidence that environmental amenities are not luxury.

Our results support the classification of environmental goods as luxury goods, as income elasticities are estimated above one for all the time periods. This, in combination with the fact that income in Sweden has increased over the last 100 years, implies that demand for environmental goods has been non-decreasing for that time period. Thus, if we have an increase in future income, we may expect a more than proportional increase in demand for recreation goods. This is consistent with the assumed shape of the environmental Kuznets curve (EKC).

Table 3 also shows that the income elasticity for the main groups seems to remain constant over time. The income elasticity fluctuates around two for outdoor recreation and around one for transportation. On the other hand, the income elasticities for food and energy goods decreased slightly between 1913 and 1996.[16] This implies that we cannot reject the hypothesis that the budget for these goods is stable over time, indicating that consumer preferences for expenditures on these specific commodities have not changed significantly over time.[17]

Concerning the differences between different goods, the results in Table 3 show that the income elasticities for transportation fluctuate around one over the various cross-sections. For energy goods and foodstuffs, the elasticity is smaller than one, indicating that these goods are considered as necessities.

From Table 3, we also notice that the total income elasticities within the main groups indicate that equipment for sporting, swimming, and camping, car maintenance and other recreational goods are luxuries, (i.e. they have income elasticities higher than one), while food, petrol, public and other transport, electricity, and other energy goods are necessities, since they have income elasticities that are less than one. Two tailed t-tests show that the income elasticities for all goods are significantly different from one

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[16] Remember that the expenditure elasticities are estimated for independent cross-sections, where households face the same prices. Between cross-sections, there will be price changes and quality changes, however this is not considered here.

[17] Since the difference in the income elasticities for these goods is quite small, we cannot reject stability.

except for the transport group in the 1984 and 1988 surveys and beverages in the 1913 survey (the results from this test are presented in Table A1 in Appendix A).

Income elasticities evaluated at the mean for different categories of household are presented in Tables A2-A5 in Appendix A. From these results, we see that there are no large differences in income elasticities between households in different regions or of different family size, indicating that household location and family size do not have a big impact on consumer preferences for expenditure on these specific commodities.

In summary, we find that outdoor recreation is a luxury good and that its luxury status seems to be robust over time. Foodstuffs and energy goods, however, serve as necessities. We may also conclude that the demand for transportation has increased more than the demand for foodstuffs and energy goods, but less than the demand for outdoor recreation.

7. Concluding Remarks

In this paper, we estimated the income elasticity of demand for recreational services and other traditional groups of goods in Sweden, and tested for potential changes in such estimates over the twentieth century. The data were drawn from Swedish household surveys for the years 1913, 1984, 1988, and 1996. Because of the difficulty of directly observing the demand for recreational services, we employed an indirect methodology by using the demand for some outdoor goods as a proxy for the recreational services demand. In line with most prior research, our results confirm the expectation that recreational services, as a public good, is a luxury good in Sweden.

In relation to the shape of an environmental Kuznets curve (EKC), our results support the suggested shape of the EKC, at least to some extent. We found that outdoor recreational service is a luxury good and that demand was non-decreasing during the whole period. Our contribution supplements that of other studies of the phenomenon (Grossman and Krueger, 1995, Hilton and Levinson, 1998, Selden and Song, 1995).

The results also show that recreational services have maintained this luxury good attribute in Sweden over the twentieth century, indicating no significant change in consumer preferences over time. The income elasticity for transportation goods fluctuated around one during the period of interest, while both energy goods and food maintained their attributes as necessities during this period, with a steady decline in their income elasticities over time.

According to our results, expenditure on environmental services increases with income. This is true when all other factors remain constant. However, when changes occur in preferences, prices, environmental attributes, and the production structure for outdoor recreational experiences, it becomes difficult to predict the demand for environmental services in the future. This is a question of interest for future research. Quality changes are well-known causes of data misinterpretations, e.g., the difficulties in disentangling the relation between changes in quality and price. Further, the demand function is also a function of relative prices. If outdoor recreation becomes cheaper to produce, then, all other things being equal, we would expect more households to consume it. If prices, preferences, and mean income change at the same time, interpretation becomes difficult. As it is, this study relegates price effects to a constant term.

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Appendix A

Table A1: Test for an income elasticity different from 1 (t-test).

	1913	1984	1988	1996
MAIN GROUPS				
Foodstuff	-41.00*	-47.00*	-52.00*	-14.66*
Energy goods	-11.25*	-17.25*	39.00*	-16.75*
Transport	2.44*	-0.33	-1.00	4.50*
Outdoor recreation	9.75*	5.80*	5.87*	3.88*
FOODSTUFFS				
Food	-10.00*	-20.00*	-9.00*	-8.00*
Beverages	0.66	22.66*	17.75*	8.80*
ENERGY GOODS				
Electricity		-15.00*	-42.50*	-10.40*
Other energy goods		-1.88*	5.00	10.00*
TRANSPORT				
Petrol		-5.00*	-27.00*	-15.00*
Car maintenance		5.33*	9.50*	5.12*
Public and other transp.		-3.50*	-0.75*	-10.14*
OUTDOOR RECREATION				
Equipment for sporting, fishing, and camping		23.00*	5.00*	26.00*
Other recreation goods		-12.66*	-4.20*	-5.00*

Note: * denotes significance at the 5% percent level. A negative t-value indicates that the income elasticity is less than one, and a positive value that the income elasticity is larger than one.

Table A2: Estimated income elasticities in 1913.

	Food-stuffs	Standard Error	Energy Goods	Standard Error	Transport	Standard Error	Outdoor Recreation	Standard Error
				Number of children				
C1	0.64	(0.01)	0.55	(0.03)	1.12	(0.08)	1.69	(0.09)
C2	0.66	(0.01)	0.55	(0.03)	1.07	(0.08)	1.65	(0.09)
C3	0.61	(0.01)	0.55	(0.03)	1.17	(0.08)	1.83	(0.09)
				Region				
R1	0.66	(0.01)	0.55	(0.03)	1.07	(0.08)	1.64	(0.09)
R2	0.67	(0.01)	0.54	(0.03)	1.06	(0.08)	1.64	(0.09)
R3	0.66	(0.01)	0.56	(0.03)	1.06	(0.08)	1.57	(0.09)
R4	0.66	(0.01)	0.56	(0.03)	1.07	(0.08)	1.62	(0.08)
R5	0.66	(0.01)	0.56	(0.03)	1.07	(0.08)	1.64	(0.09)
R6	0.67	(0.01)	0.56	(0.03)	1.04	(0.08)	1.63	(0.09)
R7	0.67	(0.01)	0.55	(0.03)	1.06	(0.12)	1.66	(0.09)

Notes: C1= 1 child below 18, C2= 2 children below 18, C3= more than 2 children below 18, R1=Uppsala, R2= Eskilstuna, R3= Jönköping, R4=Malmö, R5= Hälsingborg, R6= Gothenburg, R7=Västerås. Standard errors within parentheses.

Table A3 : Estimated income elasticities in 1984.

	Food-stuffs	Standard Error	Energy Goods	Standard Error	Transport	Standard Error	Outdoor Recreation	Standard Error
				Number of children				
C1	0.64	(0.01)	0.32	(0.03)	0.92	(0.03)	1.89	(0.13)
C2	0.61	(0.01)	0.35	(0.03)	0.93	(0.03)	1.85	(0.14)
C3	0.61	(0.01)	0.33	(0.03)	0.94	(0.03)	1.87	(0.13)
				Region				
R1	0.65	(0.01)	0.35	(0.03)	0.92	(0.03)	1.89	(0.13)
R2	0.65	(0.01)	0.35	(0.03)	0.92	(0.03)	1.88	(0.13)
R3	0.65	(0.01)	0.36	(0.03)	0.92	(0.03)	1.90	(0.13)
R4	0.65	(0.01)	0.34	(0.03)	0.92	(0.03)	1.89	(0.13)
R5	0.65	(0.01)	0.36	(0.03)	0.93	(0.03)	1.90	(0.13)
R6	0.65	(0.01)	0.35	(0.03)	0.93	(0.03)	1.90	(0.13)

Notes: C1= 1 child below 18, C2= 2 children below 18, C3= more than 2 children below 18, R1 = Stockholm, R2= Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas, R6= northern areas. Standard errors within parentheses.

Table A4 : Estimated income elasticities in 1988.

	Food-stuffs	Standard Error	Energy Goods	Standard Error	Transport	Standard Error	Outdoor Recreation	Standard Error
Number of children								
C1	0.62	(0.01)	0.16	(0.03)	0.91	(0.03)	1.86	(0.13)
C2	0.61	(0.01)	0.13	(0.03)	0.90	(0.03)	1.86	(0.14)
C3	0.58	(0.01)	0.16	(0.03)	0.91	(0.03)	1.85	(0.14)
Region								
R1	0.60	(0.01)	0.19	(0.03)	0.89	(0.03)	1.83	(0.13)
R2	0.59	(0.01)	0.19	(0.03)	0.89	(0.03)	1.83	(0.13)
R3	0.61	(0.01)	0.18	(0.03)	0.89	(0.03)	1.83	(0.13)
R4	0.59	(0.01)	0.18	(0.03)	0.89	(0.02)	1.83	(0.13)
R5	0.61	(0.01)	0.19	(0.03)	0.90	(0.03)	1.84	(0.13)
R6	0.60	(0.01)	0.18	(0.03)	0.90	(0.03)	1.83	(0.13)

Notes: C1= 1 child below 18, C2= 2 children below 18, C3= more than 2 children below 18, R1 = Stockholm, R2= Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas, R6= northern areas. Standard errors within parentheses.

Table A5 : Estimated income elasticities in 1996.

	Food-stuffs	Standard Error	Energy Goods	Standard Error	Transport	Standard Error	Outdoor Recreation	Standard Error
Number of children								
C1	0.74	(0.03)	0.32	(0.03)	1.11	(0.06)	1.93	(0.24)
C2	0.72	(0.03)	0.32	(0.04)	1.13	(0.06)	1.98	(0.25)
C3	0.67	(0.03)	0.33	(0.04)	1.13	(0.06)	1.97	(0.26)
Region								
R1	0.70	(0.03)	0.33	(0.04)	1.10	(0.06)	1.93	(0.24)
R2	0.67	(0.02)	0.33	(0.04)	1.11	(0.06)	1.94	(0.24)
R3	0.67	(0.04)	0.32	(0.03)	1.11	(0.06)	1.94	(0.24)
R4	0.70	(0.04)	0.32	(0.03)	1.11	(0.06)	1.92	(024)
R5	0.72	(0.03)	0.32	(0.03)	1.10	(0.06)	1.93	(0.24)
R6	0.71	(0.03)	0.32	(0.03)	1.11	(0.06)	1.95	(0.24)

Notes: C1= 1 child below 18, C2= 2 children below 18, C3= more than 2 children below 18, R1 = Stockholm, R2= Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas, R6= northern areas. Standard errors within parentheses

The income-pollution relationship and the role of income distribution

Evidence from Swedish household data[†]

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Abstract

The main purpose of this study is to analyze the relationship between pollution and income at household level. The study is motivated by the recent literature emphasizing the importance of income distribution for the aggregate relation between pollution and income. The main findings from previous studies are that if the individual pollution-income relationship is non-linear, then aggregate pollution for, say, a whole country, will depend not only on average income, but also on how income is distributed. To achieve our objective we formulate a model for determining the choice of consumption of goods in different types of household. Furthermore we link the demand model to emission functions for the various goods. The theoretical analysis shows that without imposing very restrictive assumptions on preferences and the emission functions, it is not possible to determine *a priori* the slope or the curvature of the pollution-income relation. The empirical analysis shows that, given the model used, the pollution-income relation has a positive slope in Sweden and is strictly concave for all three pollutants under study (CO_2, SO_2, NO_x), at least in the neighborhood of the observed income for an average household. Further, the results show that the curvature of the relation differs between different types of households. We also show that altering the prevailing income distribution, holding average income constant, will affect aggregate emissions in the sense that an equalization of incomes will give rise to an increase in emissions. One implication is then that the development of aggregate pollution due to growth depends not only on the income level, but also on how growth is distributed.

JEL classification: D12, Q53, Q56

[†] The authors acknowledge valuable comments and suggestions from Peter Berck, Karl-Gustaf Löfgren and Jonas Nordström. The usual disclaimer applies. Financial support from The Bank of Sweden Tercentenary Foundation (Riksbankens Jubileumsfond, Kulturdonationen) is also gratefully acknowledged.

1. Introduction

The main purpose of this paper is to investigate the relationship between pollution and income at household level. The analysis is motivated by the recent literature emphasizing the importance of income distribution for the aggregate relation between pollution and income (see for example Stern, 1998, Torras & Boyce, 1998, Heerink et al. 2001, and Huang, 2005). For example, Heerink et al. (2001) showed that if the relationship between pollution and income is non-linear at the individual level, the aggregate pollution-income relationship will depend on income distribution. Thus, if the individual relationship is non-linear, omitting income distribution from the aggregate analysis will produce biased results. However, no studies to date have used a structural approach to investigate the way in which individual (or household) pollution changes with economic growth. The empirical analyses available are mostly reduced form aggregate types of studies that are unable to encompass tests of how income changes affect individual pollution via changes in the real consumption basket. Here we will address the issue on the household level by estimating a demand model for Swedish households which is directly linked to emissions of sulfur, nitrogen oxides, and carbon dioxide. We will then use the result to illustrate how changes in income distribution affect aggregate emissions of CO_2, SO_2 and NO_x in Sweden.

The relationship between environmental performance and economic development has been the subject of discussion for a long time. One line of argument is that economic growth inevitably leads to more emissions and ultimately to degradation of the natural environment (Meadows *et al.* 1972, 1992). Another is that economic growth is necessary for improving the environment. This latter argument can be found in, for example, Grossman and Krueger (1991, 1995), who showed that for some emissions there appears to be an inverted U-shaped relationship between emissions and income. Countries with relatively low income appear to have relatively low emissions, middle income countries have relatively high emissions, and high income countries tend to have relatively low emissions. Thus the conclusion would be that as a poor country gets richer, emissions rise. However, when income passes a certain critical level emissions start to fall. This inverted U-shaped relationship between emissions and income has been dubbed the environmental Kuznets curve (EKC).

The discovery of this potential relationship triggered substantial research efforts in this area, theoretical as well as empirical. The theoretical literature has focused mainly on the assumptions required with respect to technology/preferences and emissions (Lopez, 1994;

Selden and Song, 1995; McConell, 1997; Andreoni & Levinson, 1998; Kriström 2000) for an EKC relationship to exist. However, the bulk of the empirical literature differs substantially from the theoretical. In general the empirical models are a reduced form type using cross-country data over relatively short time periods. A typical empirical model specifies emissions as a nonlinear function of income, income distribution, and a number of country specific characteristics such as population density, trade intensity and openness to trade (see Grossman and Krueger, 1991, 1995; Stern, 1998).[1] One conclusion from these studies is that openness seems to be beneficial to the environment.[2] Another conclusion from more recent studies is that using mean income may lead to biased results due to skewed income distributions. Instead the use of the median income is proposed (see Stern, 1998). According to Torras & Boyce (1998) and Bimonte (2002) an increase in equity, measured by the Gini coefficient, shifts the EKC curve leftwards, implying a turning point at a lower income level. Heerink et al. (2001) on the other hand get the opposite result for several environmental indicators analyzed on a cross-section of different countries. Thus, according to their results there may be a trade off between income equality and environmental quality. More importantly they conclude that this effect may be due to a strictly concave pollution-income relation at the individual level.

The rest of this paper is structured as follows. In section 2 we provide a discussion of how the household pollution-income relation may affect the aggregate relation and lay out the basis for our structural model. In section 3 and 4 we discuss in greater detail how consumption patterns and emissions are linked, as well as providing the modeling framework and a description of the data used in the analysis. Results from the econometric model are presented in section 5, along with an empirical analysis of the pollution-income relationship. The paper ends with some concluding remarks in Section 6.

2. Pollution and income

It is obvious that consumption will give rise to emissions of various pollutants. This in turn implies that any change in prices, income, or preferences that affects the consumption bundle will also have an affect on pollution. Essentially, there are two possible effects; an income

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[1] It may be questioned whether models of this kind should be denoted "reduced form" models. The reason is that a right hand shock (policy or other) affecting pollution probably affects income as well.

[2] For a survey of the empirical literature in this area, see Stern (1998), or Panayotou (2000).

effect and a substitution effect. Thus we would in principle be able to express pollution from a specific household as:

$$E_i = g(x_1(\mathbf{p}, y_i), x_2(\mathbf{p}, y_i), \ldots, x_k(\mathbf{p}, y_i)) = f(\mathbf{p}, y_i), \quad i = 1, \ldots, n \tag{1}$$

where E_i is emissions of the pollutant from household i, $x_j(\mathbf{p}, y_i)$ is consumption of good j as a function of prices $\mathbf{p} = [p_1, p_2, \ldots, p_k]$ and income y_i. g is the function that maps consumption to emissions.

Thus, a change in income for a household will result in a change in emissions, E, via a change in the composition of the consumption basket. Aggregating over the n households gives:

$$\overline{E} = \frac{1}{n}\sum_{i=1}^{n} f(\mathbf{p}, y_i) = f(\mathbf{p}, \overline{y}) + \frac{1}{n}\sum_{i=1}^{n}\left[f(\mathbf{p}, y_i) - f(\mathbf{p}, \overline{y})\right], \tag{2}$$

where $\overline{y} = (1/n)\sum_{i=1}^{n} y_i$, i.e. the average income per capita.

The second term on the right hand side of (2) indicates the degree of non-linearity of the household reduced form function f. Thus, if the household pollution-income relationship is non-linear, income distribution, as well as the income level, matters for aggregate pollution. Suppose that f is a strictly convex function. Then the second term in (2) is positive which means that a redistribution of income towards equalization would reduce the value of the second term, and hence also average emissions per capita (see Figure 1a). The opposite holds true if f is strictly concave, an increase in equality would increase aggregate emissions (see Figure 1b).

An illustration is provided in Figure 1. Consider two households, one poor (y_1) and one rich (y_2). Given income distribution y^1 we see that average emissions are $\overline{E}_1$. The effect on pollution of a redistribution from the rich to the poor, resulting in income distribution y^2, thus depends on the curvature, as can be seen from Figures 1a and 1b.

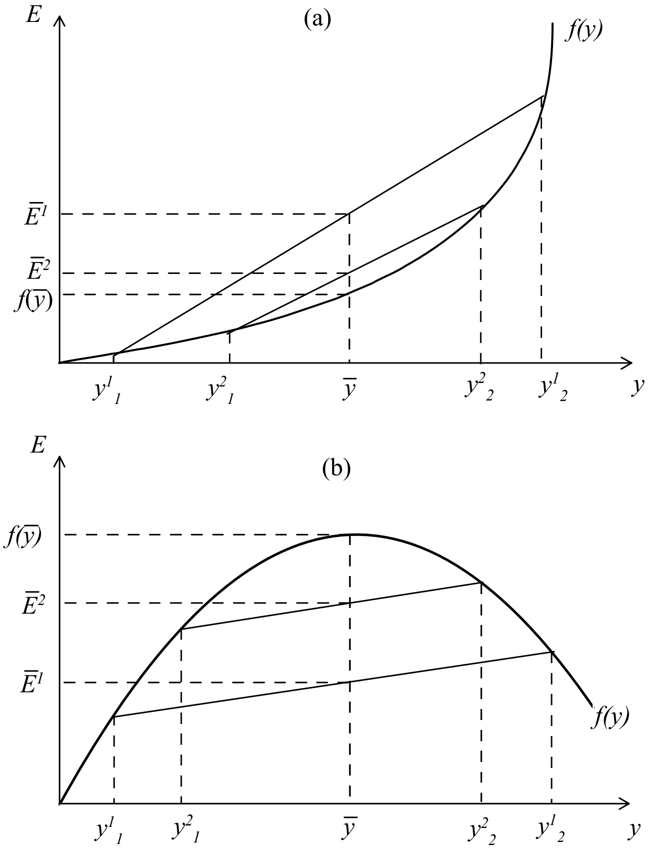

Figure 1. Household and aggregate emissions.

From equations (1) and (2) it is clear that we cannot determine the curvature of the household pollution-income relation *a priori* since the curvature depends not only on the relation between consumption and pollution, but also on how consumption is affected by a change in income. The slope of the pollution-income relation for individual *i* can be written as

$$\frac{\partial f(\mathbf{p}, y_i)}{\partial y_i} = \sum_{j=1}^{k} \frac{\partial g}{\partial x_j} \frac{\partial x_j(\mathbf{p}, y_i)}{\partial y_i} \quad , \quad i = 1, \ldots, n \tag{3}$$

Equation (3) can be written in terms of income elasticities and budget shares (weighted by prices) as:

$$\frac{\partial f(\mathbf{p}, y_i)}{\partial y_i} = \sum_{j=1}^{k} \frac{\partial g}{\partial x_j} \frac{1}{p_j} \varepsilon_{ij} s_{ij}, \quad i = 1, \ldots, n \tag{4}$$

where $\varepsilon_{ij} = \frac{\partial x_{ij}(\mathbf{p}, y_i)}{\partial y_i} \frac{y_i}{x_j}, \; s_{ij} = \frac{p_j x_{ij}}{y_i}$

PROPOSITION 1

Given that $\partial g/\partial x_{ij} \geq 0$ for all j, it follows that a sufficient condition for a positive pollution-income relationship is that all goods are normal goods, i.e. if all goods have a non-negative income elasticity.

Proof:

Follows directly from equation (4), and that $s_{ij} > 0$ and $p_j > 0$.

It should be pointed out however that this is not a necessary condition. Thus, given that $\partial g/\partial x_{ij} \geq 0$ for all j, a necessary condition for a downward-sloping relationship is that at least one good is an inferior good.

The curvature of the pollution-income relation can then be expressed as (suppressing the household index i):

$$\frac{\partial^2 f}{\partial y^2} = \sum_{j=1}^{k} \frac{1}{p_j} \left[\left(\frac{\partial^2 g}{\partial x_j^2} \frac{\partial x_j}{\partial y} s_j + \frac{\partial g}{\partial x_j} \frac{\partial s_j}{\partial y} \right) \varepsilon_j + \frac{\partial g}{\partial x_j} \frac{\partial \varepsilon_j}{\partial y} s_j \right] \tag{5}$$

From (5) we see that the curvature depends on the shape of the pollution function g, as well as the income elasticity for each good, and the budget shares.

PROPOSITION 2

If $(\partial g/\partial x_1)/(1/p_1) = \ldots = (\partial g/\partial x_k)/(1/p_k) = \Phi > 0$, and $\partial \varepsilon_j/\partial y = 0, j = 1, \ldots, k$, then the pollution-income relationship has a positive slope and is linear, i.e.

(a) $\dfrac{\partial f(p,y)}{\partial y} = \Phi \sum_{j=1}^{k} \varepsilon_j s_j > 0$

(b) $\dfrac{\partial^2 f}{\partial y^2} = \Phi \sum_{j=1}^{k} \dfrac{\partial s_j}{\partial y} \varepsilon_j = 0$

Proof:

From the consumers budget constraint we have that:

$\sum_{k=1}^{k} s_j \varepsilon_j = 1$. Since $\Phi > 0$ (a) is true.

Differentiating $\sum_j s_j \varepsilon_j = 1$ with respect to y, and putting $\partial \varepsilon/\partial y = 0$, we get

$$\sum_{j=1}^{k} \frac{\partial s_j}{\partial y} \varepsilon_j = 0 \text{, which proves (b)}$$

If $(\partial g/\partial x_i)/(1/p_i) \neq (\partial g/\partial x_j)/(1/p_j)$ for any $i, j = 1, \ldots, k$, and/or $\partial \varepsilon_j/\partial y \neq 0$, for any $j = 1, \ldots, k$, then the pollution-income relationship can have a positive or negative slope, and be concave or convex even if the pollution function, g, is linear ($\partial^2 g/\partial x_i^2 = 0$, $i = 1, \ldots, k$). Thus, we can conclude that the sufficient conditions for a linear and positive pollution-income relationship are very restrictive and are probably never fulfilled in practice. We can also conclude that the curvature of the pollution-income relationship can take any form, depending not only on preferences, but also on the g-function.

3. Modelling framework

In order to empirically assess the curvature of the household pollution-income relationship we can either estimate a reduced form relation, denoted f in equation (1) for each pollutant, or estimate a structural model for consumer demand and link this to an “emission module”, denoted g in equation (1). In any case, however, we need data on emissions, but in the structural case we also need data on consumption and a pollution function for each good. Here we have chosen the second approach for several reasons. One is that we are not only interested in the relation *per se*, but also in the driving forces behind the relation, i.e. whether a specific pattern is mostly driven by g, or by preferences. Another reason is that a structural approach enables us to trace changes in emissions due to an income change back to changes in the consumption basket. If we use a reduced form approach, neither of these objectives can be met. However, as pointed out, the structural approach is demanding in the sense that we need data on how an individual household allocates its budget, and on what the emissions will be under different allocations.

The data we have in this case comes from the Swedish Family Expenditure Survey (FES) 1984, 1988, and 1996. In the FES, households are asked to record their expenditures on non-durables such as food, clothing and public transportation during a four-week period. For some commodities such as petrol and heating the households report their annual expenditure. Apart from real consumption and income, the data include various household characteristics, such as age, family size, and residential location.

Since the data on consumption includes only expenditure on non-durable goods, we implicitly assume that each household’s utility function is weakly separable in durables and non-durables, which means that the consumption decision can be modelled as a two-stage budgeting process. In the first stage, disposable income is allocated between durables and non-durables. In the second stage, the household decides the allocation within the non-durable group, given the total allocation to this group. Here we will only model the second stage. A shortcoming of this approach is of course that changes in income will also affect consumption of durables, and hence emissions. Thus the results here may be viewed as short-term results.

Next we have to consider an appropriate framework for the demand model at the microeconomic level. It is clear from the discussion above that our framework should be as flexible as possible in order to encompass a wide range of preferences, while at the same time obeying the constrains originating from the budget constraint and utility maximization. One possible candidate is the Almost Ideal Demand System (Deaton & Muellbauer, 1980) which has a flexible functional form. However, the AIDS model is linear in expenditure, which is a very restrictive assumption. In fact it is very common in microdata that demand patterns vary considerably across households with different levels of income, even when controlled for variations in household characteristics. Banks et al. (1997), for example, found that expenditure on some goods is non-linear in total expenditure (or income) while expenditure on others is linear. Similar results were found by Ghalwash (2006). In the previous section, we showed that the shape of the pollution-income relation depends on derivative of the income elasticity with respect to income, which stresses the importance of including non-linear effects in our demand model. To handle non-linear expenditure effects we employ a quadratic extension of the AIDS model, the so called QUAIDS model (Banks et. al. 1997).[3] Then, given the QUAIDS specification we can write the system of demand equations, in budget share form, as:

$$s_{ijt} = \boldsymbol{\alpha}'_{jt}\mathbf{d}_{it} + \sum_{m=1}^{k}\gamma_{jm}\ln p_{jt} + \boldsymbol{\beta}'_{jt}\mathbf{d}_{it}\ln\left[y_{it}/P_t\right] + \boldsymbol{\delta}'_{jt}\mathbf{d}_{it}\ln\left[y_{it}/P_t\right]^2 + \upsilon_{ijt}, \quad j = 1,\ldots,k, \qquad (6)$$

where $s_{ijt} = p_{jt}x_{ijt}/y_{it}$ is the budget share for good j in household i and period t, p_{jt} is the price of good j, and y_{it} is household i's total expenditure on the goods $m = 1,...,k$. Household i's characteristics are represented by the column vector $\mathbf{d}_{it}$, and the corresponding parameter vectors are denoted $\boldsymbol{\alpha}_{jt}$, $\boldsymbol{\beta}_{jt}$, and $\boldsymbol{\delta}_{jt}$.[4] The last term, υ_{ijt}, is an error term reflecting unobserved (for the researcher) variation in taste.

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[3] The specification used here deviates from Banks et al. in the sense that we use the same price index as deflator in the linear and non-linear terms.

[4] It is, of course, straightforward to also include household specific effects on the part containing the price.

Worth noting in equation (6) is that the price of the goods are equal across households in any given time period *t*. This means that, since we will estimate the cross-sections separately, the price will be a constant in the regressions, and hence can be included directly into the intercept term $\boldsymbol{\alpha}$. The system of demand equations to be estimated then becomes a system of Engel curves, i.e.

$$s_{ijt} = \tilde{\boldsymbol{\alpha}}'_{jt}\mathbf{d}_{it} + \boldsymbol{\beta}'_{jt}\mathbf{d}_{it}\ln[y_{it}/P_t] + \boldsymbol{\delta}'_{jt}\mathbf{d}_{it}\ln[y_{it}/P_t]^2 + \upsilon_{ijt},\ j = 1, \ldots k \qquad (7)$$

Differentiating equation (7) with respect to ln$y$, we get

$$\frac{\partial s_{ijt}}{\partial \ln y_{it}} = \boldsymbol{\beta}'_{jt}\mathbf{d}_{it} + 2\boldsymbol{\delta}'_{jt}\mathbf{d}_{it}\ln[y_{it}/P_t],$$

which enables us to write the income, or expenditure, elasticity as:

$$\varepsilon_{ijt} = \frac{1}{s_{ijt}}\left[\boldsymbol{\beta}'_{jt}\mathbf{d}_{it} + 2\boldsymbol{\delta}'_{jt}\mathbf{d}_{it}\ln[y_{it}/P_t]\right] + 1, \qquad j = 1, \ldots, k \qquad (8)$$

The non-linear income effect on the budget share in equation (7) then implies that the income elasticity is a linear function of income. Furthermore we see that the income elasticity and its relation to income can vary between different types of households.

Given estimates of the parameters in our demand model, we can estimate the effect of a change in income on demand for the various goods. Then, given a pollution function related to each good, this in turn enables us to calculate total change in emissions. Here we will focus on three different emissions; carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Furthermore, we assume that emissions of each substance are a linear function of consumption. Emissions from each good are then defined as:[5]

$$E_{jm} = \theta_{jm} \cdot x_j \qquad (9)$$

where x_j is the real consumption of good *j*, and θ_{jm} is the emission of substance *m* per unit of real consumption of good *j*,[6] for $m = CO_2, SO_2, NO_x$

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[5] The household index and time index have been suppressed to spare us from notational clutter.

[6] The emission coefficient θ_i, measure the direct emissions from the household's consumption of heating and transport. For all other goods, the emission coefficients measure the indirect emissions from the household's consumption, i.e. the indirect emissions include the emissions from the production of the goods that the household consume.

A household's total emission can then be written as:

$$E_m = \sum_{j=1}^{k} E_{jm} = \sum_{j=1}^{k} \theta_{jm} \cdot x_j \ , \quad m = \mathrm{CO_2, SO_2, NO_x} \qquad (10)$$

The change in emissions due to a change in income is then:

$$\frac{\partial E_m}{\partial y} = \sum\nolimits_j \frac{\partial x_j}{\partial y} \frac{\partial E_m}{\partial x_j} = \sum\nolimits_i \frac{\partial x_j}{\partial y} \theta_{jm} \ , \qquad m = \mathrm{CO_2, SO_2, NO_x} \qquad (11)$$

4. Data

To estimate the demand model we use pooled cross-sectional data from the Swedish Family Expenditure Survey (FES) of 1984, 1988 and 1996, comprising in all about 10000 observations. FES is a comprehensive microdata survey on household expenditure, income and characteristics. For the choice of consumption of non-durable goods we aggregate household expenditure into eight goods (food, beverages, heating, petrol, other transportation, recreation, clothes and other non-durable goods), and link emission data to each type of good.

It is very important to achieve data compatibility between the three surveys. There were some differences in the classification of goods and in household characteristics. To overcome these problems we aggregated expenditures in homogeneous goods following survey definitions, and used the same methodology for demographics by defining new variables containing the same household characteristics in the three surveys.

Table 1 summarizes the changes in the expenditure share for each good between 1984 and 1996, along with the 1996 share of three different emissions; carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x). As shown, household expenditure for food, beverages and clothes has been fairly stable over time, although there is a weak negative trend in the food share. However, the share for heating and other transportation both decreased slightly between 1984 and 1988, while approximately 17% of the household expenditure went to heating in 1984, this share had declined to 16% in 1988 and to 9% in 1996. Finally, the table also depicts a simultaneous rise in the budget share of both petrol and recreation between 1988 and 1996.

Table 1: Descriptive statistics of budget and emission shares of eight types of good. Percentage of total expenditures and emissions. Emission intensities are in kg/1000 SEK.

	Budget share			Emission share 1996			Emission intensities		
	1984	1988	1996	CO_2	NOx	SO_2	CO_2	NOx	SO_2
Food	35.0	28.0	31.0	8.4	15.1	10.8	19.80	0.02	0.18
Beverages	4.0	4.0	5.0	0.5	0.6	0.7	7.27	0.01	0.04
Heating	17.0	16.0	9.0	29.1	9.2	50.9	178.56	0.23	0.28
Petrol	6.0	5.0	8.0	44.7	51.3	13.2	292.34	0.06	1.48
Other transp.	6.0	5.0	3.0	4.3	8.2	2.5	118.16	0.05	1.09
Recreation	3.0	4.0	10.0	2.4	4.3	4.5	13.90	0.02	0.13
Clothes	9.0	9.0	10.0	1.0	1.2	1.5	6.71	0.01	0.04
Others	20.0	29.0	24.0	9.6	10.1	15.9	8.67	0.01	0.05
Sum	100.0	100.0	100.0	100.0	100.0	100.0			

Note: The emissions from transport and heating are direct, whereas the emissions from all other goods are indirect

Concerning the budget shares and emission shares in the 1996 survey, Table 1 shows that petrol, with an expenditure share of 8%, is the good with the largest contribution of both CO_2 emissions (45%) and NO_x emissions (51%). Compared to the emissions of CO_2 and NO_x, the SO_2 share for petrol is much smaller (only 13%). One reason for the relatively low emissions of sulfur dioxide from petrol is the SO_2 tax on petrol, which has led to a move from petrol with high to low sulfur content. In fact, the table reveals that heating has the largest share of sulfur dioxide emissions, amounting to about 51%.

From Table 1 we also see that food consumption, with 31% of total expenditure, generates relatively large emissions of sulfur dioxide and NO_x. In relation to its share of expenditure, recreation also constitutes a relatively large share of the emissions of sulfur dioxide and NO_x.

Household characteristics may affect consumer behavior with respect to these eight goods, and hence also emissions. There are basically two different ways to consider different household characteristics in the model estimation (Pollak and Wales, 1992). The first technique is to consider the sample as a whole and use different dummy variables to capture different household characteristics. The second is to divide the sample into homogenous sub-samples depending on household characteristics. In this paper, we follow the first approach. The variables relating to household characteristics include three dummy variables for the cases when the household has one child, two children, or more than two children less than 18 years of age, and five regional dummy variables for the six census regions in the surveys[7]. In

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[7] To avoid perfect collinearity we dropped a variable from each set of dummy variables.

the estimation, we use total expenditure rather than income because expenditure better reflects permanent income.

5. Estimation results

In this section we present some of the estimation results from the demand model. Concerning estimation we have, in principle, two approaches to follow. The first is to estimate each equation separately using ordinary least squares. The second is to estimate the equations as a system using seemingly unrelated regressions. We have chosen the latter, mainly motivated by the belief that errors between equations are correlated, hence gaining some efficiency.

We start the analysis by testing the functional form for the expenditure system in order to decide whether the non-linear expenditure term should enter the model or not. Table 2 shows the results of this test.

Table 2: Likelihood-ratio tests for non-linearity.

	1984	1988	1996
Non-Linearity	110*	190*	141*

* Non-linearity cannot be rejected at the 5% level.

The results in Table 2 indicate that we can reject linearity for the whole expenditure system. According to the test results and specification in equation (7), the demand system for the eight goods is estimated by using the SURE technique (Seemingly Unrelated Regression Equations). Tables A1-A3 in the appendix provide estimates of the parameters of the model. Given the parameter estimates, income elasticities can be calculated according to equation (8). Table 3 presents the resulting income elasticities, together with their standard errors. The elasticities in Table 3 are evaluated at the mean budget shares and the mean total expenditure for all household in each survey. The standard errors are computed with the delta method (see Greene, 2000).

Table 3. Estimated income elasticities.

	1984		1988		1996	
	Budget elasticity	(Standard error)	Budget elasticity	(Standard error)	Budget elasticity	(Standard error)
Food	0.79	(0.01)	0.70	(0.01)	0.66	(0.02)
Beverages	0.90	(0.04)	0.63	(0.05)	0.84	(0.07)
Heating	0.59	(0.03)	0.27	(0.03)	0.71	(0.05)
Petrol	0.77	(0.02)	0.68	(0.03)	0.67	(0.05)
Other transport	1.34	(0.04)	1.25	(0.05)	1.77	(0.25)
Recreation	1.49	(0.05)	1.65	(0.04)	1.91	(0.08)
Clothes	1.56	(0.03)	1.34	(0.03)	1.34	(0.06)
Other goods	1.27	(0.01)	1.42	(0.006)	1.02	(0.02)

Note: Standard errors within parentheses.

Table 3 reveals that all goods were normal goods over the various cross-sections, since they had non-negative income elasticity. Further it shows that food, beverages, heating and petrol seems to be necessities, i.e. they have income elasticities lower than one, whereas other transport, recreation, clothes and other goods appear to be luxuries, since they have income elasticities that are higher than one.[8]

Table 3 also reveals relatively low income elasticity for heating in 1984 and 1988, and for food in 1996, whereas recreation seems to have become monotonically more income-elastic over time.

Regarding the change in income elasticity over time, we can conclude that the income elasticities for food and petrol were decreasing between 1984 and 1996. On the other hand, those for heating, beverages, other transport and other goods were decreasing between 1984 and 1988, but increasing between 1988 and 1996, whereas the income elasticity for recreation was increasing monotonically between 1984 and 1996.

Pollution – Income Relationship

To analyze the EKC hypothesis at the household level we must empirically derive the pollution-income relationship stated in equation (1) using the parameter estimates in Tables A1-A3 and the emission data. Given an empirical version of equation (1), it is straightforward to calculate the slope and curvature of the relationship. However, applying Proposition 1 reveals directly that the slope of the pollution-income relationship is positive for an average

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[8] These results support the results of Ghalwash (2006).

household. According to the results in Table 3, all goods are normal goods, i.e. the average income elasticity is positive for all goods, which is a sufficient condition for a positive slope according to Proposition 1. Thus we can conclude that a (small) rise in household income will give rise to an increase in the household's emission of sulfur, nitrogen oxides, and carbon dioxide. Here it should be pointed out that this is valid under the assumptions that the technology is "fixed", i.e. the emission intensities do not change, and that the prices remain unchanged. These may be plausible assumptions for marginal changes, but they are more questionable for large changes in income.

The second issue is related to the curvature of the pollution-income relation. Since the sufficient condition for a linear relationship stated in Proposition 1 is not fulfilled, the results in Table 3 cannot be used directly to reveal the curvature. However, by using the estimation results in table A3 in the appendix in equation (6), we can calculate the curvature at an arbitrary point. Table 4 presents the result of this calculation at the mean for the budget shares and the mean income. For all three pollutants the results suggest that the relation between pollution and income is non-linear and concave. Based on this we can conclude that pollution is increasing with income, but at a decreasing rate, for all three pollutants. This result is valid at least in the neighborhood of the point of evaluation (at the mean of the data). Concerning the issue of an EKC, the results here do not rule out the possibility of an EKC at the household level.

Table 4. Curvature of income-pollution relations, evaluated at the mean.

Pollutant	Curvature, $\partial^2 f/\partial y^2$
CO_2	-7.46
SO_2	-0.003
NO_x	-0.025

One implication of the results in Table 4 is that the aggregate pollution-income relationship will depend on income distribution. Due to the concave relationship, according to Table 4, a redistribution of income from high-income households to low-income households, *ceteris paribus*, will increase emissions of all three pollutants. Thus, the results here do to some extent support the findings of Heerink et al. (2001) and Huang (2005).

Figure 2 presents the pollution-income relationship for an average Swedish household, in order to illustrate the pollution-income relationship for non-marginal changes in income. It shows that the relationship is monotonically positive within the range of the actual income distribution. Moreover it can be seen that the concavity is more pronounced for CO_2 and SO_2, compared to NOx. Figure 2 also illustrates that mean pollution over all households, $(\bar{E})$, is lower than pollution evaluated at the mean income $E(\bar{y})$. This implies, as stated above, that an increase in income equality will increase aggregate emissions of all three pollutants.

The concavity property of the pollution-income relationship follows from the magnitudes of the income elasticities reported in Table 3, in combination with the emission intensities reported in Table 2. From Table 3 we have that the income elasticities for the most emission intensive goods are lower than one, whereas less-emission intensive goods, such as recreation, have income elasticities higher than one. Thus, an increase in income will lead to a more than proportional increase in consumption of the low-intensity goods, and less than proportional increase in the high-intensity good. Taken together this implies that emissions are increasing, but at a decreasing rate. However, due to the restrictions we have imposed, the simulations in Figure 2 should be viewed as illustrations rather than predictions. Perhaps the most serious restriction is that the emission intensities are fixed and independent of income. A more realistic setting is that income growth, due to for example technological progress, also affects the emission intensities, and hence also shifts the curve downwards and changes the curvature. If we interpret the income growth in Figure 2 as a result of technological progress, the resulting pollution-income relation may perhaps be viewed as a "worst case" concerning environmental effects. Another reason as to why a fixed intensity is restrictive is that an income change may give rise to substitution *within* our commodity groups, and hence induce a change in emission intensities. Thus, a fixed emission intensity is valid only if there is no substitution within the groups, or if the emission intensities are similar for all the goods within the commodity group.

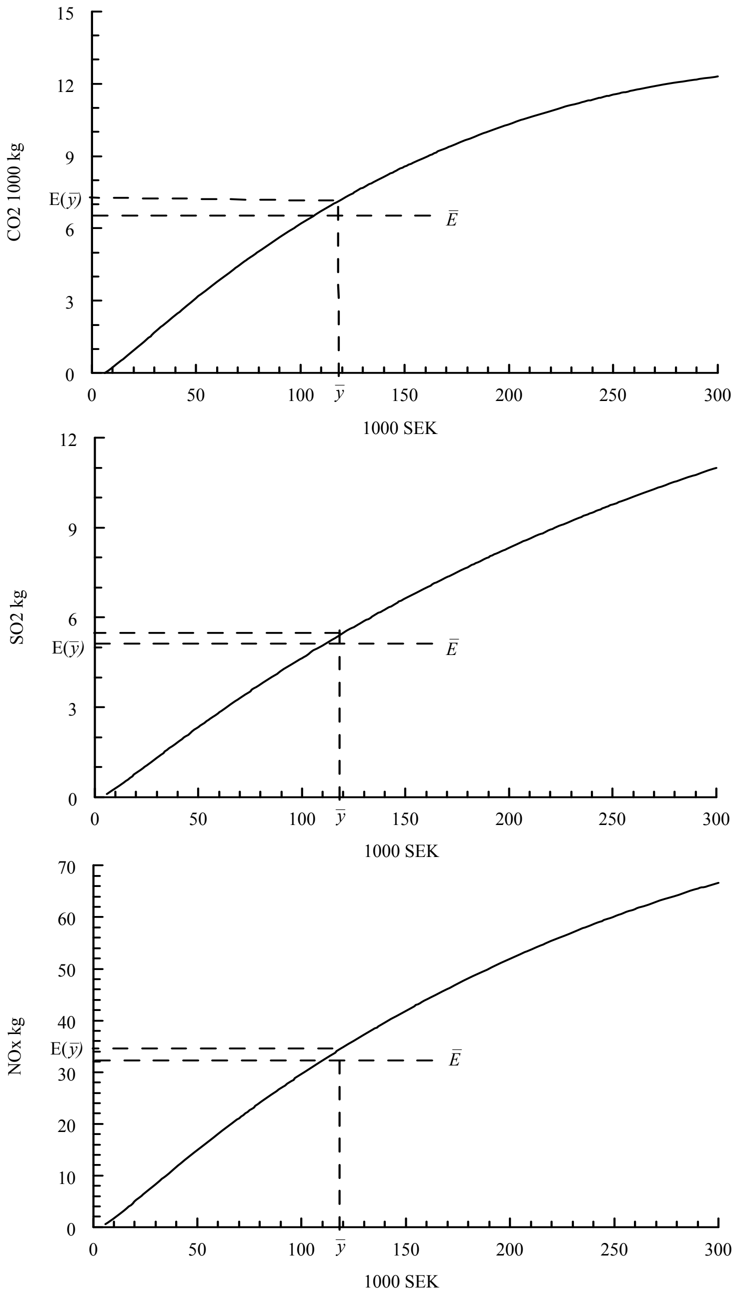

Figure 2. The pollution-income relationship for an average Swedish household.

Figure 3 presents the household income-pollution relationships in different regions. The relationship is evaluated for an average household in four of the regions. Here we see a clear pattern in the sense that the relationships are less concave for a typical household in Stockholm than in the rest of the country.[9] Furthermore, as can be seen in Figure 3, it is more

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[9] An exception though is NOx, for which the relationship is almost linear for the northern rural area.

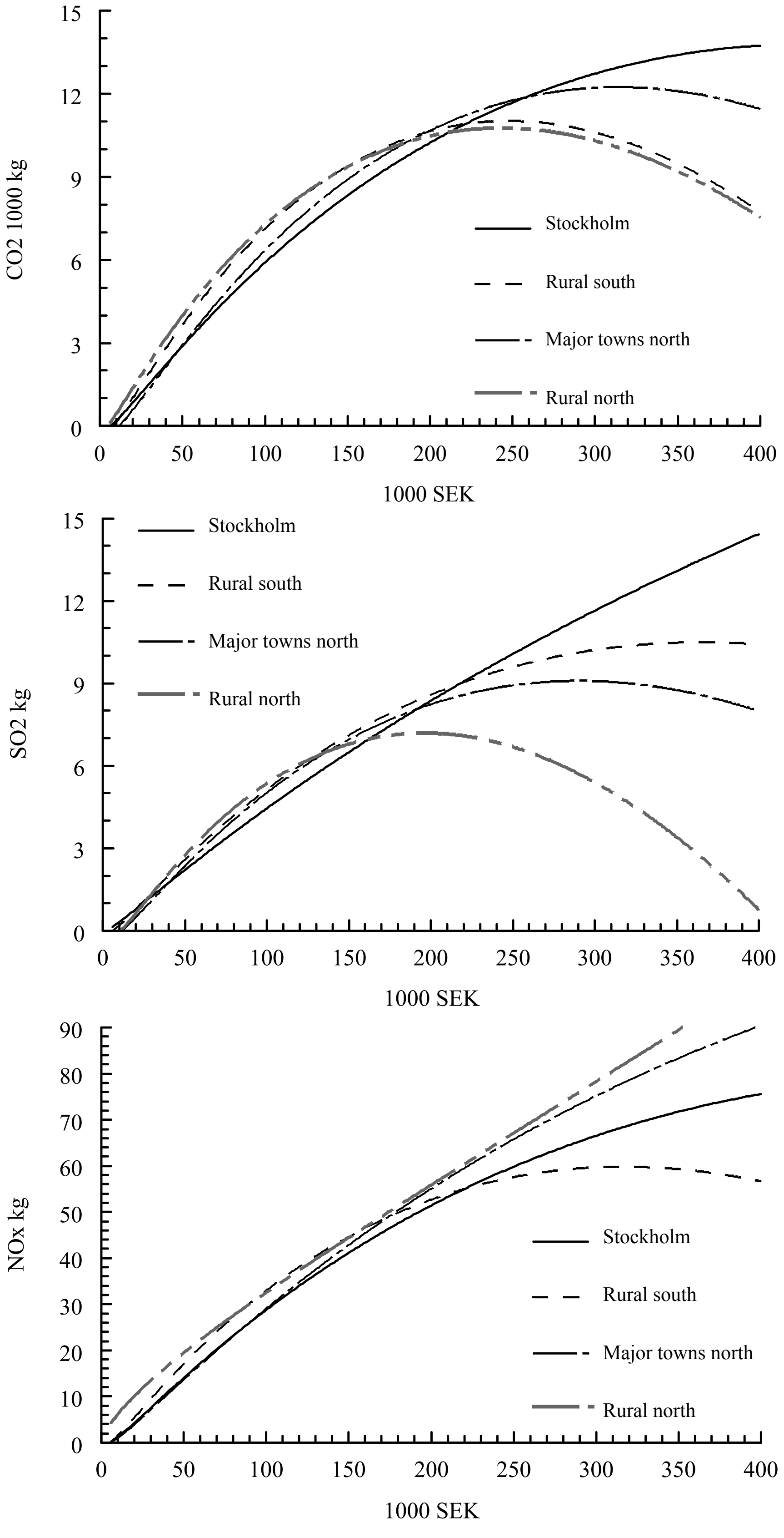

Figure 3. The pollution-income relationship for an average household in Stockholm, the rural south, in northern major towns, and in the rural north.

likely that an EKC type of relationship will exist in northern towns and rural areas for CO_2 and SO_2 compared with NO_x since the pollution curve bends down as income becomes sufficiently high. One implication of this pattern is that what matters is not only income distribution in the usual sense, but also the regional distribution of growth. Thus, if we wish to test the EKC hypothesis on the aggregate level we have to consider both of these factors.

Income distribution and aggregate pollution

One conclusion from the above discussion is that the individual, or household, pollution-income relationship is non-linear, which in turn implies that the aggregate relationship depends not only on aggregate income but also on how income is distributed. To illustrate this we will investigate how a change in the income distribution we observe in our data would affect aggregate emissions, or emissions per capita. To do this we assume that income distribution follows a lognormal distribution, i.e. $\ln y \sim N(m, s)$, where m is the mean and s the standard deviation. Given this distribution we can write the mean (μ) and standard deviation (σ) for y, in terms of m and s as:

$$\mu = e^{\frac{2m+s^2}{2}}, \ \sigma = \sqrt{e^{2m+2s^2} - e^{2m+s^2}}$$

Given our data we can estimate m and s as the mean and standard deviation of $\ln y$. Figure 4 displays the empirical distribution for y in 1996 showing that this empirical distribution has a shape typical of a lognormal distribution. We see also that the distribution in Figure 4 corresponds to a Gini coefficient of 0.33.[10]

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[10] The Gini coefficient is a measure of inequality, and takes a value between 0 and 1, where 0 corresponds to perfect equality (everyone has the same income) and 1 to perfect inequality (where one person has all the income, and everyone else has zero income). The Gini value obtained here differs to some extent from other estimates of the Gini coefficient. The reason is that the Gini coefficient in this case correpsponds to the distribution of consumption expenditures on non-durable goods for this particular sample. According to the United Nations WIDER database (http://www.wider.unu.edu/wiid/wiid.htm) the Gini coefficient for Sweden was 0.27 in 1996, which should be compared to 0.39 for the USA. Given a lognormal distribution the Gini coefficient can be calculated as $G = 2\Phi(s/\sqrt{2}) - 1$, where Φ is the standard cumulative normal distribution (McDonald, 1984)

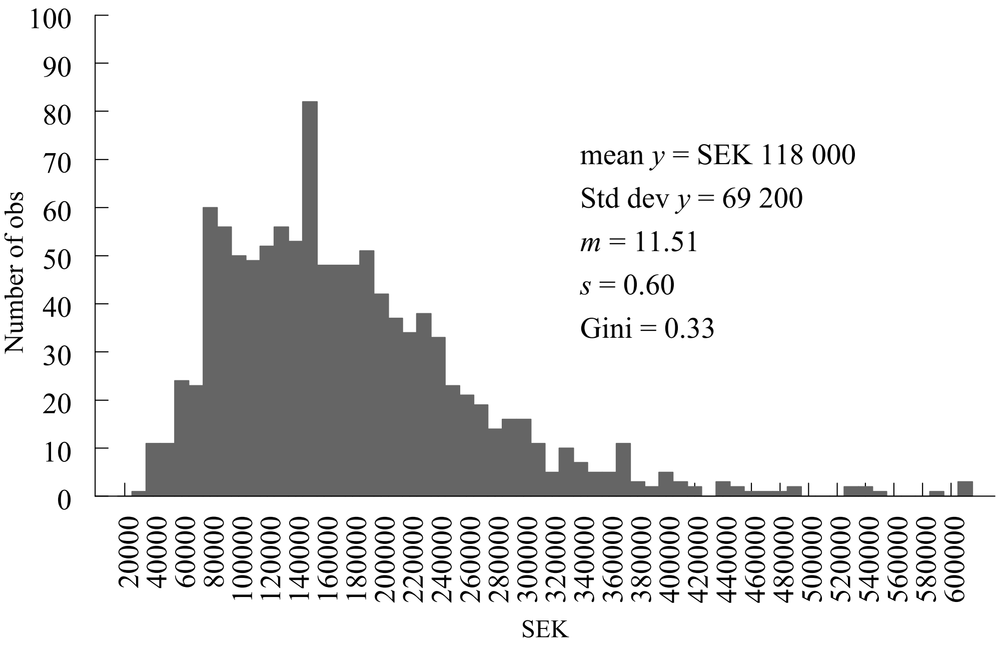

Figure 4. Distribution of expenditures on non-durable goods in the 1996 household survey.

To illustrate the effect on aggregate emissions from a change in income distribution we change the value of s in the lognormal income distribution. However, in order to keep average income unchanged we adjust the value of m.[11]

Table 5 displays the results from three simulations. The scenario with superscript 0 refers to the outcome at the observed s, whereas 1 is a low variance scenario ($s^1 = 0.5 \cdot s^0$), and 2 is a high variance scenario ($s^2 = 1.5 \cdot s^0$). In each scenario we sample 30 000 observations from the scenario-specific income distribution and calculate the emissions of each substance according to equation (10). We repeat this 20 times and calculate the average emissions.

Table 5. Income distribution and effects on aggregate emissions. Simulations assuming a lognormal income distribution.

	Low variance	Reference	High variance
S	0.30	0.60	0.90
σ	52 716	78 087	100 304
$\bar{y}$	119 000	119 000	119 000
Gini	0.23 (-30%)	0.33	0.39 (+18%)
CO_2 (1000 kg/cap)	6.93 (+6.3%)	6.52	6.01 (-7.8%)

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[11] Since $\bar{y} = e^{m+s^2/2}$, we have that $d\bar{y} = e^{m+s^2/2}dm + 0.5e^{m+s^2/2}ds^2 = 0$, which gives us that $dm = -0.5ds^2$

SO_2 (kg/cap)	5.35 (+4.5%)	5.12	4.88 (-4.7%)
NO_x (kg/cap)	33.70 (+4%)	32.40	30.96 (-4.4%)

From Table 5 we see that, as expected, a higher degree of inequality will lead to a decrease in total emissions, and vice versa. We also see that the emission effect is most pronounced for CO_2. These results raise several interesting questions related to the Environmental Kuznets issue including to what extent income equalization during a growth path counteracts a possible reduction in emission growth among the rich part of a population.

6. Concluding remarks

The analysis in this paper is motivated by the recent literature emphasizing the importance of income distribution for the aggregate relation between pollution and income. The main finding from previous studies is that if the micro, or individual pollution-income relationship is non-linear, then the aggregate pollution, for say a whole country, will depend not only on average, or aggregate income, but also on how income is distributed. Our aim was not only to determine which conditions on individual preferences and the link between consumption and pollution would lead to a linear relationship, but also to empirically assess the relationship.

We have shown that the sufficient condition for a positive and linear pollution-income relationship is a rather restrictive combination of certain preferences and a very specific link between consumption and pollution. In fact, it is not very likely that we would observe such a combination in practice. Thus we can conclude that is not possible to say much about the curvature *a priori* rather, it is an empirical issue that depends on the particular links between consumption and pollution, as well as preferences over the various consumption goods.

The results from the empirical analysis show that, at least in a close neighborhood of observed income and pollution, we can reject linearity for all three types of pollutions, CO_2, SO_2, and NO_x. According to our results the pollution-income relationships are all strictly concave. Thus the implication is that income distribution seems to matter in the sense that equalization of income will lead to higher emissions. Furthermore it has been shown that the slope as well as the curvature differ between different types of households, which means that preferences differ across households. A consequence of this is that regional distribution will also have implications for aggregate pollution under a growth scenario. The basic reason for the concavity property can be found in the negative correlation between emission intensities and income elasticities for the various goods. Goods with relative high income elasticities tend to have relatively low emission intensities, and vice versa. This means that an increase in income tends to give rise to a move from high emission-intensive goods to low emission-intensive goods. A typical example is consumption of petrol for cars and consumption of recreation. Petrol has a relatively low income elasticity (below one), but very high emission intensity, whereas recreation has a relatively high income elasticity, but relatively low emission intensity. Hence, consumption of petrol will grow at a lower rate than income, and recreation at a higher rate, which gives rise to a slowdown in emissions since recreation is less emission-intensive.

The analysis we provide here is admittedly based on several restrictive assumptions, and the results should for this reason be handled with care. Perhaps the most restrictive assumption is the fixed emission intensities, at least if the objective is to analyze the effects of large changes in income. An interesting prospect for future research is thus to have a more general equilibrium type of approach in which the emission intensities are functions of income, since income to some extent is related to technical progress which in turn also affects production and abatement technology. For such an approach to be possible we would need time-series data for the emission intensities; work to compile a database with time series is currently underway.

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Appendix 1

Table A1: Parameter estimates from the demand model in 1984, t-ratio within parentheses.

	Food	Beverages	Heating	Petrol	Other transport	Recreation	Clothes
Intercept of the expenditure equation							
Constant	-3.44	0.33	5.26	-1.66	0.29	0.79	1.03
	(-4.77)	(0.86)	(5.65)	(-4.60)	(0.57)	(1.92)	(1.80)
R1	-0.45	-1.26	-1.14	-0.07	0.03	-0.48	0.16
	(-0.60)	(-2.51)	(-1.08)	(-.13)	(0.04)	(-0.91)	(0.27)
R2	-1.83	-1.22	0.03	0.03	-0.35	0.42	1.79
	(-1.71)	(-1.81)	(0.02)	(0.04)	(-0.30)	(0.59)	(2.24)
R3	-1.14	-0.06	-2.70	-0.48	0.42	0.22	-1.18
	(-1.28)	(-0.09)	(-2.05)	(-0.91)	(0.59)	(0.23)	(-1.62)
R4	-1.42	-0.54	0.50	0.16	1.79	-1.18	-0.44
	(-1.25)	(-0.80)	(0.32)	(0.27)	(2.24)	(-1.62)	(-0.34)
R5	-8.99	-2.86	1.43	-5.20	0.76	0.53	8.83
	(-2.63)	(-1.98)	(0.36)	(-3.72)	(0.33)	(0.34)	(3.37)
Ch1	3.01	0.05	-0.50	-0.45	-1.83	-1.14	-1.42
	(1.40)	(0.06)	(-0.23)	(-0.60)	(-1.71)	(-1.28)	(-1.25)
Ch2	0.05	0.51	-2.35	-1.26	-1.22	-0.06	-0.54
	(0.06)	(0.49)	(-.68)	(-2.51)	(-1.81)	(-0.09)	(-0.80)
Ch3	-0.50	-2.35	4.03	-1.14	0.03	-2.70	0.50
	(-0.23)	(-.68)	(0.96)	(-1.08)	(0.02	(-2.05)	(0.32)
Linear expenditure coefficients							
Constant	0.72	-0.05	-0.82	0.43	-0.07	-0.15	-0.22
	(5.74)	(-0.71)	(-5.07)	(7.77)	(-0.73)	(-2.08)	(-2.23)
R1	0.08	0.22	0.22	0.02	-0.0004	0.08	-0.03
	(0.67)	(2.59)	(1.18)	(0.16)	(-0.004)	(0.91)	(-0.26)
R2	0.31	0.22	0.02	-0.0004	0.05	-0.08	-0.35
	(1.66)	(1.85)	(0.09)	(-0.004)	(0.27)	(-0.61)	(-2.28)
R3	0.20	0.01	0.47	0.08	-0.08	-0.04	0.21
	(1.28	(0.10	(2.09)	(0.91)	(-0.61)	(-0.22)	(1.61)
R4	0.25	0.10	-0.07	-0.03	-0.35	0.21	0.08
	(1.29)	(0.85)	(-0.28)	(-0.26)	(-2.28)	(1.61)	(0.35)
R5	1.57	0.49	-0.27	0.91	-0.33	-0.11	-1.50
	(2.61)	(1.96)	(-0.39)	83.66)	(-2.22)	(-0.39)	(-3.26)
Ch1	-0.53	-0.01	0.12	0.08	0.31	0.20	0.25
	(-1.41)	(-0.07)	(0.31)	(0.67)	(1.66)	(1.28	(1.29)
Ch2	-0.01	-0.09	0.39	0.22	0.22	0.01	0.10
	(-0.07)	(-0.54)	(1.62)	(2.59)	(1.85)	(0.10	(0.85)
Ch3	0.12	0.39	-0.79	0.22	0.02	0.47	-0.07
	(0.31)	(1.62)	(-1.09)	(1.18)	(0.09)	(2.09)	(-0.28)
Quadratic expenditure coefficients							
Constant	-0.03	0.001	0.03	-0.01	0.004	0.007	0.01
	(-6.21)	(0.65)	(4.66)	(-4.87)	(1.07)	(2.33)	(2.81)
R1	-0.004	-0.01	-0.01	-0.001	-0.0001	-0.003	0.001
	(-0.73)	(-2.66)	(-1.28)	(-0.18)	(-0.03)	(-0.90)	(0.28)
R2	-0.01	-0.009	-0.002	-0.0001	-0.002	0.003	0.02
	(-1.61	(-1.89)	(-0.20)	(-0.03)	(-0.20)	(0.62)	(2.31)
R3	-0.008	-0.0004	-0.02	-0.003	0.003	0.002	-0.009
	(-1.29)	(-0.09)	(-2.13)	(-0.90)	(0.62)	(0.22)	(-1.61)
R4	-0.01	-0.004	0.003	0.001	0.02	-0.009	-0.004
	(-1.34)	(-0.90)	(0.25)	(0.28)	(2.31)	(-1.61)	(-0.37)
R5	-0.06	-0.02	0.01	-0.04	0.003	0.005	0.06
	(-2.58)	(-1.94)	(0.41)	(-3.61)	(0.21)	(0.45)	(3.14)
Ch1	0.02	0.001	-0.006	-0.004	-0.01	-0.008	-0.01
	(1.43)	(0.11)	(-0.37)	(-0.73)	(-1.61	(-1.29)	(-1.34)
Ch2	0.001	0.004	-0.02	-0.01	-0.009	-0.0004	-0.004
	(0.11)	(0.57)	(-1.56)	(-2.66)	(-1.89)	(-0.09)	(-0.90)
Ch3	-0.006	-0.02	0.34	-0.01	-0.002	-0.02	0.003
	(-0.37)	(-1.56)	(1.21)	(-1.28)	(-0.20)	(-2.13)	(0.25)

Notes: Ch1= 1 child below 18, Ch2= 2 children below 18, Ch3= more than 2 children below 18, R1 = Stockholm, R2=Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas.

Table A2: Parameter estimates from the demand model in 1988, t-ratio within parentheses.

	Food	Beverages	Heating	Petrol	Other transport	Recreation	Clothes
Intercept of the expenditure equation							
Constant	-4.55	0.98	6.00	0.37	0.51	0.61	-0.71
	(-6.02)	(2.12)	(7.28)	(0.93)	(0.89)	(1.85)	(-1.20)
R1	-0.78	-0.27	0.69	-1.24	-1.08	0.68	-1.45
	(-1.01)	(0.50)	(0.76)	(-2.18)	(-1.87)	(1.60)	(-2.37)
R2	-1.66	-0.99	-1.17	-1.08	-1.63	-0.99	0.75
	(-1.45)	(-1.42)	(-0.95)	(-1.87)	(-1.44)	(-1.84)	(0.85)
R3	2.76	-1.15	-2.58	0.68	-0.99	-0.95	-0.95
	(3.83)	(-2.19)	(-3.05)	(1.60)	(-1.84)	(-1.81)	(-1.81)
R4	-0.55	-1.11	-1.31	-1.45	0.75	0.69	-0.72
	(-0.55)	(-1.52)	(-1.00)	(-2.37)	(0.85)	(1.23)	(-0.56)
R5	3.95	-1.87	-11.31	-2.52	7.52	-0.69	-0.47
	(1.93)	(-2.00)	(-5.53)	(-3.09)	(5.35)	(-0.93)	(-0.32)
Ch1	2.53	-0.98	3.27	-0.78	-1.66	2.76	-0.55
	(1.00)	(-0.95)	(1.63)	(-1.01)	(-1.45)	(3.83)	(-0.55)
Ch2	-0.98	0.15	-0.85	-0.27	-0.99	-1.15	-1.11
	(-0.95)	(0.12)	(-0.66)	(0.50)	(-1.42)	(-2.19)	(-1.52)
Ch3	3.27	-0.85	4.64	0.69	-1.17	-2.58	-1.31
	(1.63)	(-0.66)	(1.42)	(0.76)	(-0.95)	(-3.05)	(-1.00)
Linear expenditure coefficients							
Constant	0.89	-0.14	-0.88	-0.05	-0.08	-0.12	0.09
	(6.91)	(-1.83)	(-6.31)	(-0.71)	(-1.02)	(-1.82)	(0.97)
R1	0.13	0.05	-0.11	0.22	0.18	-0.11	0.25
	(0.95)	(0.54)	(-0.76)	(2.25)	(1.98)	(-1.46)	(2.42)
R2	0.26	0.17	0.21	0.18	0.28	0.18	-0.12
	(1.37)	(1.43)	(1.00)	(1.98)	(1.74)	(1.99)	(-0.79)
R3	-0.48	0.19	0.14	-0.11	0.18	0.17	-0.11
	(-3.92)	(2.09)	(2.98)	(-1.46)	(1.99)	(1.94)	(-1.17)
R4	0.08	0.19	0.20	0.25	-0.12	-0.11	0.14
	(0.42)	(1.52)	(0.91)	(2.42)	(-0.79)	(-1.17)	(0.61)
R5	-0.65	0.32	1.94	0.43	1.29	0.13	-0.47
	(-1.82)	(1.95)	(5.55)	(3.07)	(-5.28)	(0.98)	(-0.32)
Ch1	-0.41	0.16	-0.51	0.13	0.26	-0.48	0.08
	(-0.95)	(0.96)	(-1.51)	(0.95)	(1.37)	(-3.92)	(0.42)
Ch2	0.16	-0.04	0.13	0.05	0.17	0.19	0.19
	(0.96)	(-0.18)	(0.60)	(0.54)	(1.43)	(2.09)	(1.52)
Ch3	-0.51	0.13	-0.82	-0.11	0.21	0.14	0.20
	(-1.51)	(0.60)	(-1.49)	(-0.76)	(1.00)	(2.98)	(0.91)
Quadratic expenditure coefficients							
Constant	-0.04	0.005)	0.03	0.002	0.005	0.00	-0.003
	(-7.42)	(1.61)	(5.51)	(0.58)	(1.14)	(2.13)	(-0.60)
R1	-0.005	-0.002	0.005	-0.009	-0.008	0.004	-0.01
	(-0.91)	(-0.57)	(0.75)	(-2.30)	(-1.91)	(1.33)	(-2.45)
R2	-0.01	-0.007	-0.009	-0.008	-0.01	-0.008	0.005
	(-1.29)	(-1.43)	(-1.06)	(-1.91)	(-1.50)	(-2.13)	(0.74)
R3	0.02	-0.008	-0.02	0.004	-0.008	-0.008	0.005
	(4.00)	(-1.99)	(-2.90)	(1.33)	(-2.13)	(-2.07)	(1.13)
R4	-0.003	-0.008	-0.007	-0.01	0.005	0.005	-0.006
	(-0.39)	(-1.52)	(-0.82)	(-2.45)	(0.74)	(1.13)	(-0.65)
R5	0.03	-0.01	-0.08	-0.02	0.05	-0.006	0.08
	(1.72)	(-1.90)	-(5.39)	(-3.03)	(5.20)	(-1.03)	(0.33)
Ch1	0.02	-0.007	0.02	-0.005	-0.01	0.02	-0.003
	(0.90)	(-0.96)	(1.41)	(-0.91)	(-1.29)	(4.00)	(-0.39)
Ch2	-0.007	0.002	-0.005	-0.002	-0.007	-0.008	-0.008
	(-0.96)	(0.24)	(-0.55)	(-0.57)	(-1.43)	(-1.99)	(-1.52)
Ch3	0.02	-0.005	0.04	0.005	-0.009	-0.02	-0.007
	(1.41)	(-0.55)	(1.57)	(0.75)	(-1.06)	(-2.90)	(-0.82)

Notes: Ch1= 1 child below 18, Ch2= 2 children below 18, Ch3= more than 2 children below 18. R1 = Stockholm, R2=Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas.

Table A3: Parameter estimates from the demand model in 1996, t-ratio within parentheses.

	Food	Beverages	Heating	Petrol	Other transport	Recreation	Clothes
				Intercept of the expenditure equation			
Constant	-0.69	1.84	-0.74	-3.23	1.48	3.72	-0.15
	(-0.66)	(2.38)	(-0.55)	(-4.53)	(2.96)	(3.30)	(-0.15)
R1	-1.13	-1.07	1.84	3.24	-0.35	-1.41	0.14
	(-0.92)	(-1.30)	(1.64)	(2.74)	(-0.55)	(-1.12)	(0.11)
R2	-2.35	-2.50	-2.18	-0.35	1.44	0.25	1.20
	(-2.73)	(-3.64)	(-2.22)	(-0.55)	(2.14)	(0.30)	(1.09)
R3	2.57	-1.48	-2.95	-1.41	0.25	2.32	0.04
	(1.33)	(-1.316)	(-1.99)	(-1.12)	(0.30)	(0.86)	(0.02)
R4	2.44	-1.32	-5.72	0.14	1.20	0.04	-0.90
	(1.27)	(-0.85)	(-2.61)	(0.11)	(1.09)	(0.02)	(-0.26)
R5	0.04	-4.71	-9.42	0.61	9.46	-1.66	7.84
	(0.005)	(-1.23)	(1.94)	(0.11)	(3.23)	(-0.18)	(1.22)
Ch1	0.24	0.22	-2.58	-1.13	-2.35	2.57	2.44
	(0.09)	(0.18)	(-1.65)	(-0.92)	(-2.73)	(1.33)	(1.27)
Ch2	0.22	-0.38	-1.25	-1.07	-2.50	-1.48	-1.32
	(0.18)	(-0.24)	(-0.73)	(-1.30)	(-3.64)	(-1.316)	(-0.85)
Ch3	-2.58	-1.25	1.91	1.84	-2.18	-2.95	-5.72
	(-1.65)	(-0.73)	(0.38)	(1.64)	(-2.22)	(-1.99)	(-2.61)
				Linear expenditure coefficients			
Constant	0.26	-0.24	0.11	0.59	-0.26	-0.73	0.009
	(1.40)	(-2.19)	(0.72)	(4.73)	(-3.02)	(-3.69)	(0.05)
R1	0.19	0.17	-0.33	-0.57	0.06	0.27	-0.03
	(0.92)	(1.23)	(-1.71)	(-2.72)	(0.58)	(1.42)	(-0.13)
R2	0.41	0.43	0.39	0.06	-0.24	-0.04	-0.23
	(2.87)	(3.61)	(2.34)	(0.58)	(-2.05)	(-0.29)	(-1.17)
R3	-0.46	0.25	0.53	0.27	-0.04	-0.40	-0.003
	(-1.36)	(1.28)	(2.06)	(1.42)	(-0.29)	(-0.85)	(-0.01)
R4	-0.40	0.25	1.06	-0.03	-0.23	-0.003	0.17
	(-1.21)	(0.94)	(2.67)	(-0.13)	(-1.17)	(-0.01)	(0.28)
R5	-0.005	0.18	1.68	-0.08	-1.63	0.37	-1.43
	(0-003)	(2.10)	(1.98)	(-0.09)	(-3.19)	(0.22)	(-1.28)
Ch1	0.006	-0.03	0.44	0.19	0.41	-0.46	-0.40
	(0.12)	(-0.14)	(1.62)	(0.92)	(2.87)	(-1.36)	(-1.21)
Ch2	-0.03	0.06	0.21	0.17	0.43	0.25	0.25
	(-0.14)	(0.23)	(0.73)	(1.23)	(3.61)	(1.28)	(0.94)
Ch3	0.44	0.21	-0.32	-0.33	0.39	0.53	1.06
	(1.62)	(0.73)	(-0.38)	(-1.71)	(2.34)	(2.06)	(2.67)
				Quadratic expenditure coefficients			
Constant	-0.01	0.01	-0.005	-0.03	0.01	0.04	0.001
	(-1.83)	(2.10)	(-0.79)	(-4.81)	(3.09)	(4.17)	(0.14)
R1	-0.008	-0.007	0.02	0.02	-0.01	-0.01	0.001
	(-0.93)	(-1.16)	(1.77)	(2.68)	(-1.33)	(-1.33)	(0.16)
R2	-0.02	-0.02	-0.02	-0.003	0.01	0.002	0.01
	(-2.84)	(-3.58)	(-2.44)	(-0.59)	(1.96)	(0.28)	(1.25)
R3	0.02	-0.01	-0.02	-0.01	0.002	0.02	-0.001
	(1.39)	(-1.26)	(-2.10)	(-1.33)	(0.28)	(0.83)	(-0.01)
R4	0.01	-0.01	-0.04	0.001	0.01	-0.001	-0.008
	(1.15)	(-1.03)	(-2.71)	(0.16)	(1.25)	(-0.01)	(-0.30)
R5	0.0002	-0.03	-0.07	0.002	0.07	-0.02	0.06
	(0.003)	(-1.21)	(-2.01)	(0.06)	(3.15)	(-0.28)	(1.33)
Ch1	-0.002	0.001	-0.02	-0.008	0.02	0.02	0.01
	(-0.11)	(0.09)	(-1.59)	(-0.93)	(1.39)	(1.39)	(1.15)
Ch2	0.001	-0.003	-0.008	-0.007	-0.01	-0.01	-0.01
	(0.09)	(-0.21)	(-0.69)	(-1.16)	(-1.26)	(-1.26)	(-1.03)
Ch3	-0.02	-0.008	0.01	0.02	-0.02	-0.02	-0.04
	(-1.59)	(-0.69)	(0.38)	(1.77)	(-2.10)	(-2.10)	(-2.71)

Notes: Ch1= 1 child below 18, Ch2= 2 children below 18, Ch3= more than 2 children below 18. R1 = Stockholm, R2=Gothenburg/Malmö, R3= major towns, R4=southern areas, R5= major towns northern areas.