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The Effect of the Gasoline Tax on Carbon Emissions in Sweden

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Abstract

Understanding the response of consumers to a gasoline price increase is an extremely important implication for environmental policies in order to reduce the carbon dioxide emissions associated with climate change. Together with gasoline tax, subsidy policy and regulation of carbon emission levels also play an important role in determining the kinds of vehicle and the long-run improvement in the energy efficiency of vehicles on the Swedish roads. The purpose of this study is to examine the impact of gasoline tax on carbon emissions in Sweden. Gasoline demand models are estimated by using time series analysis. We find that short-run gasoline demand is both price and income inelastic. A number of studies have shown that long-run gasoline demand is somewhat inelastic; however, this study shows the opposite. In fact, long-run gasoline demand is very elastic with respect to price and income which has an important implication for policy makers. Moreover, subsidy and regulation are found to have little impact on gasoline consumption while vehicle stock is found not to be statistically significant in affecting gasoline consumption.

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1. INTRODUCTION

1.1 Problem statement

Transport is a central part of any society in the world because moving from one place to another is the human basic need. This need is shared by passenger and freight transport. The demand for transportation tends to increase due to increasing population and economic growth. The transport sector accounts for numerous external effects, such as congestion, air pollution and carbon dioxide emission (CO_2). Since the transportation is responsible for approximately 35% of fossil fuel consumption, carbon dioxide emissions[1] from this sector are obviously significant (Johansson & Schipper, 1997). According to Chapman (2007), the transport sector contributed 26% of the total carbon dioxide emissions in the world. Carbon dioxide emissions from the transport sector in Sweden account for roughly 30% which was 19.2 million tonnes (SEA, 2010). Indeed, the contribution of carbon dioxide emissions from the transport sector to total carbon dioxide emissions is really significant.

Given interest in reduce gasoline consumption and transportation related to carbon dioxide emissions, gasoline price-based policy such as carbon tax is an interesting renewed. The carbon tax was introduced in Sweden in 1991, which is levied on the carbon dioxide quantity emissions from fossil-fuels such as gasoline. This policy made certain fuels more expensive as a result of reduced carbon emission from the transport sector (Sterner, Dahl, & Franzen, 1992). Sterner (2007) states that carbon tax is an important policy instrument in reducing carbon dioxide emissions. According to an estimate by the Swedish Institute for Transport and Communications Analysis (SIKA), tax raises on fuels implemented in the period 1990 - 2005 have decreased carbon dioxide emissions from the transport sector by 1.5 to 3.2 million tonnes of carbon dioxide per year, mostly from passenger cars (SIKA, 2005). Therefore, understanding the response of gasoline consumption to changes in gasoline tax has an important implication for policies related to climate change.

Several studies have examined the sensitivity of gasoline demand to changes in prices, for example, Dahl and Sterner (1991); D. Greene at al. (1999). However, simultaneously with the gasoline tax, a number of policy instruments such as regulation of carbon emission levels, subsidy for eco-cars, vehicle tax and other policies also contribute to reducing carbon

[1] "Carbon dioxide emissions" are sometimes abbreviated to "carbon emissions," however, the technically and more accurately term is "carbon dioxide emissions." The distinction between carbon dioxide emissions and carbon emissions is presented in appendix.

emission from the transport sector in Sweden. The problem is given herein how large these policy instruments simultaneous effects on reducing carbon emission are.

1.2 The purpose of the study

The objective of this study is to investigate the effect of a number of policy instruments on carbon emissions from the transport sector. Especially, we examine the response of gasoline consumption to tax changes through gasoline price.

Econometric models are used to estimate how large the effects of policy instruments would be in reducing gasoline consumption. The estimate captures the short and long-run responses resulting from reduced gasoline consumption. In the short-run, consumers could less responsive to the higher gasoline prices. Consumers, however, will react to higher gasoline prices in the long-run by purchasing more fuel-efficient vehicles or changing the car use result in the sensitivity of price elasticity. Therefore, long-run demand is expected to be more elastic than short run. If gasoline demand is highly price elastic, this would imply that gasoline tax will have a large influence on driving behavior and that it is an effective policy in reducing carbon dioxide emissions. Moreover, we also investigate the effects of income, vehicle stock, subsidy policy and regulation of carbon emission levels. These policy instruments could play a significant role in identifying the general carbon dioxide emission progression in response to policy interventions.

The research questions can be addressed with three sub-questions:

(1) Which policy instruments come into effect during the period of study 1991-2010?
(2) What are the effects of policy instruments on gasoline consumption?
(3) How much is the percentage of carbon emission reduced when increasing gasoline tax?

1.3 The structure of the thesis

The outline of this paper is organized as follows. Section 2 reviews a number of gasoline demand studies. This provides different points of view of gasoline models. Section 3 describes an overview of main policy instruments related to transport in Sweden during the period 1991-2010. Section 4 is the methods of our study (gasoline demand models) which divides into four sub-sections. These sub-sections describe the general theory demand for gasoline; the models of gasoline demand; unit root test for time series; and calculating the percentage of carbon dioxide reduction. Section 5 presents the data collection and the description of variables that can be used in the regressions. Results and discussions are presented in section 6 with two main parts. First, we consider and explain the characteristics of some variables in materials. Second, we focus on econometric analysis and results. The first part of econometric analysis and results is check unit root and cointegrated for time series and then estimated short and long run models. After that, the results of regressions are explained and compared with previous studies. Finally, we calculate the effects of gasoline tax on carbon dioxide emissions. Section 7 concludes and discusses some policy implications.

2. LITERATURE REVIEW

There is an extensive body of research devoted to analyzing the elasticities of gasoline price and income to changing in gasoline demand in the short and long-run. Elasticity is one of the important factors when discussing policy impacts in gasoline demand study. The most important studies of gasoline demand are reviewed in this study.

Drollas (1984) reviews many previous studies of gasoline demand elasticities. The different modeling techniques, including static cross-sectional specifications, time-series and panel data models, are overviewed in his study. According to the author, a variety of estimates is found in a number of studies and the international consensus view of scientists in long run elasticities of price and income are roughly -0.8 and 1, respectively. The author also calculates the elasticity of gasoline price for European countries over the period 1950 to 1980. The dynamic models in logarithmic form that related gasoline consumption to real income, the gasoline real price, other real price services of transportation, and the vehicle price are used. Drollas finds that in the short-run, price elasticities of gasoline demand are about -0.26 for the UK, -0.41 to -0.53 for West Germany, -0.44 for France, and -0.34 and -0.42 for Austria. In the long-run, the elasticities of price are approximately -0.6 for the UK, -0.8 to -1.2 for West Germany, -0.6 for France and -0.8 to -0.9 for Austria. These results confirm that price elasticities of gasoline demand are quite inelastic in the short-run; however, in the long-run price elasticities are much higher than in the short-term about three times. We see that these results are consistent with those of the previous studies. The contribution of his findings is that similarity rather than variety exists between countries in the fuel demand characteristics, and that inactiveness in gasoline use could be explained by the slowly changing car stock and by the continuity of ineffective habits.

Blum et al. (1988) study aggregate time series gasoline demand models for West Germany and Austria. The demand function forms, the time treatment, the structure of the error component, and the estimation techniques have been illustrated by different models. The authors concentrate on the short-run elasticities. Consequently, the authors find that the short-run price and income elasticities for Germany and Austria have huge ranges from -0.25 to -0.83 and from 0.86 to 1.90, respectively. Moreover, they examine their interest in the demand stipulations used to calculate these elasticities. The authors argue that while a number of previous studies have concerned model features and estimation techniques, they are also typically characterized by different forms of function, which have given an increase to much of the variation between estimates.

Sterner (1990) analyzes the sensitivity of gasoline consumption to changes in gasoline price and income in Organisation for Economic Cooperation and Development (OECD) countries. Data of the OECD countries from 1962 to1985 is used and then the author estimates a set of gasoline demand models. He finds in the long-run price elasticities a range from -1.0 to -1.4, and income elasticities in the interval 0.6 to 1.6, using pooled data. For time series data, the author finds that long-run elasticities of gasoline price range from -0.65 to -1.0 and income elasticities between 1.0 and 1.3. In the short-run, the elasticities are found to be around -0.2 to -0.3 for price, and 0.35 to 0.55 for income.

Sterner and Dahl (1992) expand the exploration of their study into the methodology. An overview of a number of different models that have been developed to clarify how the demand of gasoline is related to gasoline price, income of households, and other variables. The authors find that different model specifications could give large differences in the estimation results. They compare different model results by using them to the same OECD data set from 1962 to 1985. Long-run elasticities could be estimated with either static models on cross-section or with data dynamic models on time series data. The estimated results with static models for cross-section data give roughly unitary elasticity for both price and income. The dynamic models give price elasticities within the range -0.80 to -0.95, and income elasticities of between 1.1 and 1.3.

Sterner, Dahl and Franzén (1992) investigate the responsiveness of gasoline price to gasoline demand. The authors illustrate the huge degrees of variation in the short and long-run magnitude of price and income elasticities. The authors find that in short-run price elasticity of gasoline demand varies between -0.10 to -0.24 depending on the model estimated. The equivalent long-run figure is between -0.54 and -0.96. The short-run averaging price elasticity is about -0.23 and the long-run figure of -0.77. The income average short-run elasticity is found about 0.39 and the long run about 1.17. The authors note that the indication that the absolute value of the price elasticity is smaller than for income suggests that gasoline prices must increase faster than the rate of income growth if gasoline consumption is to be stabilized at existing levels.

Goodwin (1992) emphasizes the differences among studies by classifying estimates of the gasoline demand model regarding gasoline price into time-series or cross-section, and sub-dividing this difference into short-run, long-run or ambiguous. The results demonstrate the distinction in magnitude that exists for the elasticities of gasoline price increases on gasoline consumption between the short and long-run. Short-run elasticities are found inelastic and long-run elasticities tend to be three times higher than the short-run. However, Goodwin finds that a large variety of studies leads to the differences in methodological techniques, the magnitude of the differences in the elasticities across methods of cross-section and time-series in this case.

Bentzen (1994) estimates the short and long-run elasticities of gasoline demand for Denmark using annual time-series data from the period 1948-1991. In model, gasoline consumption per capita is explained by gasoline price, vehicle stock per capita, and increasing fuel efficiency which is represented by a time trend. The author finds a long-run stability relationship between the variables in his model and continues to estimate the error correction model (ECM) to make different short and long-run impacts. The results of regression show that short-run price elasticity is –0.32 and long-run price elasticity is –0.41. Also, income elasticities in short and long-term are 0.89 and 1.04, respectively. The price elasticity in the short-term is comparable with magnitude values estimated in many studies. However, the long-run price elasticity is somewhat lower. Besides differences in models and data, the author thinks that the lower elasticity could be at least fairly explained by the particular statistical technique used, with unambiguous treatment of the non-stationary properties of the variables.

Dahl (1995) overviews a number of the latest studies on gasoline demand from the United State to investigate how elasticity estimates have changed. Dahl finds the long-run price elasticity ranging from -0.7 to -1.0 and income elasticity between 1 and 1.4. The author notes that these results propose that the taxes will be effective tools of reducing pollution from gasoline consumption. The author believes that elasticities of gasoline demand have become smaller in magnitude over time, especially for income. Recent studies propose the long-run price and income responses of around –0.6 and 1.2, whereas most previous studies show the price and income elasticities are around –0.8 and 1.0, respectively, The reliability of these results, however, is normalized by the small number of estimates reviewed in Dahl and by the majority of static models.

Ramanathan (1999) analyzes the gasoline demand using a co-integration analysis to examine short and long-term behavior. The gasoline consumption model is explained by real gasoline price and GDP per capita. The estimation uses time series data from the period 1972-1973 to 1993-1994. The author found that in the short-run, the elasticities of gasoline demand are -0.21 for price and 1.18 for income. The co-integration model shows that the change of gasoline consumption towards its long-run equilibrium appears at a comparatively slow rate with 28% of the adjustment occurring within the first year. The long-run price and income elasticities of gasoline demand estimates are -0.32 and 2.68, respectively. The author believes that the gradual increasing economic growth and the low degrees of gasoline consumption can explain the differences between his results and those found elsewhere. The author concludes that gasoline over-price as a policy instrument is implausible to have a significant effect on gasoline demand in India.

Akinboade et al. (2008) analyze the gasoline demand for South Africa for the period 1978–2005 by using co-integration techniques. They find that there is the existence of a cointegrating relationship in their study. Gasoline demand in South Africa is inelastic with respect to price and income, since the estimated elasticities are -0.47 and 0.36, respectively.

To sum up, the gasoline demand studies largely estimated the price and income elasticities of demand using different methodologies and techniques. The estimates of gasoline demand elasticities have demonstrated to be quite robust in most studies. A number of studies show that short-run price elasticity of gasoline demand and income elasticity are quite inelastic and long-term elasticities tend to be about three times higher than the short-term. However, estimates of price and income elasticities do not provide a consensus on the short and long-run elasticity estimates.

A large number of studies have been clarified the responses of gasoline consumption to changes in gasoline prices through estimating price elasticities. However, these estimates are not suitable for evaluating the effectiveness of gasoline tax. First of all, most of these studies do not account for the endogeneity of the explanatory variables such as price and income. It can be explained that increases in the demand gasoline cause the price of gasoline to rise, leading to a spurious relationship between the price and the regression error, and biasing estimates of the price elasticity. This may lead to biases in the estimates in the single equation time-series methods. Moreover, the sensitivity of gasoline consumption to a change in tax is likely to differ from its response to an average change in price (Davis & Kilian, 2009). Price changes induced by tax changes are more persistent than other price changes and thus may induce larger behavioral changes. Therefore, in this paper we highlight these neglected issues in estimating the demand of gasoline with a two-step procedure which was introduced by Engle and Granger (1987), i.e. unit root tests and cointegration tests.

3. AN OVERVIEW OF MAIN POLICY INSTRUMENTS FOR TRANSPORT

There are a large number of instruments in the transport sector including gasoline tax, subsidy policy, regulation of carbon emission levels, vehicle tax, congestion tax, charges and fees for roads, and taxation of company cars for the transport sector that have been implemented in Sweden during the period of 1991 - 2010. In this study, we review gasoline tax policy, subsidy policy, regulation, vehicle tax, and taxation of company cars, since these policies are the main impact on carbon dioxide emission reduction in Sweden.

3.1 Gasoline tax policy

Tax policy for gasoline is the most important instrument in reducing carbon dioxide emissions from the transport sector in Sweden since 1991 (Sterner, 2007). Furthermore, gasoline tax is cost-effective because the taxes increase the cost of consuming gasoline which sends a clear sign to the consumers. In addition, energy and carbon taxes can be seen as economic incentives for reducing carbon dioxide emissions, which in turn promotes technological development (Christiansen, 2001).

The Swedish gasoline tax includes two main tax components which are energy and carbon taxes. The energy tax is mostly fiscal in its purpose, while the carbon dioxide tax is intended to reduce carbon dioxide emissions from fossil-fuels. The energy tax on gasoline is differentiated depending on the environmental class to which the fuel belongs. The classification of environment is based on the impact of the fuel on people´s health. Gasoline is classified as environmental class 1 or 2, with a special tax rate for alkylate gasoline.

In 1991, the Swedish government acknowledged the correlation between carbon emissions and a raised rate of global warming. As a result, Sweden began to implement a carbon tax policy for gasoline. Carbon tax could be imposed on carbon emissions resulting in global warming as well as environmental damage (Sterner, 2007). Sterner (2007) argues that the energy and carbon taxes make gasoline consumption more expensive and result in a reduction of total gasoline consumption. Without a doubt, tax policy might encourage more efficient energy use, as well as increased use of fuels from renewable sources like biofuels or ethanol. Sterner also shows that fuel taxes have restrained the growth in fuel demand and related carbon emissions. However, it is uncertain whether the use of taxes helps to achieve the carbon emission reduction target, since economic growth could affect the use of gasoline (Schipper & Marie-Lilliu, 1999). Moreover, another uncertainty is whether the tax rate is suitable. A failure of the carbon tax was its lack of ability to truly tax carbon emissions (Sterner, 2003). For a while, the majority fuels containing carbon were taxed, this tax did not reflect the actual level of carbon emitted from these fuels. For instance, low and high carbon emission gasoline uses were both taxed at the same level although causing different levels of environment damage.

The energy and carbon taxes are cost-effective, since they are related directly to the use of fossil-fuels in vehicles and, are separate from the tax rebate for renewable motor fuels. This means that the taxes have an incentive to cause consumers to take what they believe to be the cheapest measures first, whereas it also sends an obvious signal to the marketplace, which creates an incentive for technological development. Moreover, the taxes will change the consumer`s behavior because consumers face on the higher gasoline price and hence they will change their behavior in long-run (Baranzini, Goldemberg, & Speck, 2000). Therefore, the taxes give a long-term incentive to adjust consumption to take account of the cost imposed on the external impacts.

Energy and carbon taxes are economic incentives for carbon emission reduction which encourage investigation and implementation of treatment technology (Repetto & Institute, 1992). As a consequence, tax policy is an important instrument creating the most powerful incentives for technological development (Sterner, 2003). Moreover, fuel taxes are also a dynamically efficient instrument, since increasing the cost of fossil-fuels forces improvement and the introduction of more energy-efficient engines and vehicles. Furthermore, the taxes also convince the polluter pays principle (PPP), since the polluters must pay tax on all their emissions. However, this could leads to less competition in Swedish road haulage companies due to a higher fuel price than in other countries in Europe.

3.2 Subsidy polices

Subsidies could be seen as a negative tax. Subsidies are paid for cars that consume biofuels or ethanol. Moreover, tax exemption also a kind of subsidy policy. Therefore, in this section, we would clarify subsidy for eco-cars and tax exemption for new green cars and biofuel tax exemption.

3.2.1. Subsidy for eco-cars

According to the Swedish Energy Agency (2009), a purchasing discount for new cars classified as "environmentally cars" was introduced in 2007. A grant of SEK 10,000 has been offered to private purchasers of low pollution vehicles. Its purpose is to promote the purchase of fuel efficient vehicles and vehicles running on alternative motor fuels. The rebate was only directed to cars of private use which had to fulfill certain criteria according to the definition stated by the National Road Administration. As consequence, this policy is creating large incentives for customers to purchase more fuel-efficient or biofuels-run vehicles. It also gives incentive indirectly for technological improvement that manufactures research and produce eco-cars which consume biofuels.

In 2007, about 4 % of the energy use for road traffic was provided by renewable motor fuels (SEA, 2009). The costs of producing alternative motor fuels are currently exceeding the equivalent costs for gasoline and diesel oil. The dissimilarity in cost and the difference in cost of using such fuels instead of gasoline or diesel fuel, however, are falling as a result of technical development, the introduction of environmental taxes and a general rise in the price of gasoline and diesel. Currently, bio-based motor fuels are untaxed, which means that their cost at the pump can be less than that of conventional fuels despite a higher production cost.

3.2.2 Tax exemption for new "green cars" for five years.

New "green cars" will be exempt from vehicle tax for the first five years since buying a "green car" (GOS, 2009b). The current "green car premium" thereby is replaced by a long-term tax concession. The modification is proposed for cars taken into service as from 1st July 2009. The current definition of a "green cars" also applies to new gasoline and diesel powered passenger cars that emit less than an average of 120 grams of carbon dioxide per kilometer (GOS, 2009a). These cars will also be exempt from vehicle tax.

3.2.3 Tax exemption for biofuels

Between 2004 and 2008, the energy and carbon dioxide taxes were exempted from biofuels for vehicles. Biogas is not exempted, since it has separate exemption from energy and carbon taxes. The Finance Bill 2006 integrated a suggestion to expand free tax until 2013. The main reason for tax exemption is to reduce carbon dioxide emissions from the transport sector and eventually to raise energy provide security by supporting production and consumption of biofuels for motor vehicles, especially at the primary stage. Currently, the production of biofuels for transportation is limited in Sweden, but research and development is in progress to build a Swedish industrial base for production of biofuels. It is very important that we evaluate not only tax exemption, but also the whole complicated existing instruments for biofuels and eco-cars. Tax exemption causes a sizeable loss in revenue of the Government; however, it might have a substantially greater impact in reducing carbon dioxide emissions.

Thus, subsidy policy can be an important tool that incentivises the use of clean energy which contributes to reducing carbon dioxide emission. There is a need to evaluate the complex of instruments governing biofuels for motor vehicles and eco-cars.

3.3. Vehicle tax

Vehicle tax is levied on cars, trucks, tractors, motorcycles and other means. The tax on cars is differentiated according to the type and weight of vehicle, and fuel used or its carbon dioxide emissions (Swedish EPA, 1997). Vehicle tax on cars from model year 2006 and cars qualifying for environmental class 2005 (electric and hybrid) is determined by the carbon dioxide emission of cars. Tax on other cars is based on the weight and the fuel used. Tax on gasoline-driven cars averages about SEK 1,500 per year, while diesel-driven cars are taxed much more heavily than gasoline-driven ones. The reason is that diesel fuel is subject to lower energy tax than gasoline. The tax on heavy-duty vehicles varies depending on the number of wheel axles, vehicle configuration and weight.

Vehicle tax is mainly a fiscal tax; however since the year 2006 the vehicle tax has been qualified to provide an incentive to purchase more energy efficient vehicles or vehicles running on alternative motor fuels. Vehicle tax should be differentiated for cars according to their emissions of carbon dioxide to provide an incentive for choosing a new car with low carbon dioxide emissions (SEA, 2010). The introduction of a carbon dioxide differentiated vehicle tax for new cars of model year 2006 and for cars belonging to environmental class 2005 was implemented with effect from October, 2006, which provides an incentive for new car buyers to choose more energy-efficient cars. The Government Bill on Tax Relief for Cars (2005) proposes that vehicle tax on cars be based on three elements. The first element is a "*basic fiscal tax of SEK 360 on all cars*". The second is a "*carbon dioxide component of SEK 15/gram carbon dioxide emissions per kilometer exceeding 100 gram/km*". The third is "*an environmental factor of 1.3 and a fuel factor of 2.7, i.e. 3.5 in total (1.3 x 2.7) for diesel cars, to be multiplied by components 1 and 2*". However, vehicle tax is a fixed annual cost and has no marked environmental effect on existing vehicles. Carbon dioxide differentiated tax on cars could be designed to have far greater environmental impact without raising the overall tax take (Swedish EPA, 2004b).

Vehicle tax could impact the behavior of consumers when buying a new car. Introduction of carbon dioxide differentiated vehicle tax would make it possible to reduce carbon dioxide emissions from new cars by up to 4% percent without any major negative consequences for Swedish trade and industry (Swedish EPA, 2004b). A carbon dioxide differentiated vehicle tax would be socio-economically beneficial. Moreover, according to the Swedish EPA (2002), a study on carbon dioxide differentiated vehicle tax concluded that the positive environmental effects of introducing carbon dioxide related vehicle taxes in Sweden would be substantially counteracted by the current Swedish tax rules on company cars.

3.4 Regulation on cars

Regulation of emission levels for cars was discussed in many countries in Europe (SEA, 2010). The most general system is to regulate the levels of emission for new cars by setting a degree for emissions that must not be exceeded that is Europe emission standards with EU categories. Regulation EC No. 443/2009 requires setting new carbon dioxide emission performance standards for light duty vehicles. *"The objective of this Regulation is to set emission performance standards for new passenger cars registered in the Community, which forms part of the Community's integrated approach to reducing CO_2 emissions from light-duty vehicles while ensuring the proper functioning of the internal market"*. Car manufactures must commit that "*new passenger cars sold within the EU must not emit more than 130g CO_2/kilometre since 2009*". Producers' regular emissions are decided based on a ratio of their new passenger cars registered that year; this ratio has been mandated at 65% in 2012, rising to 100% by 2015. If targets are exceeded manufacturers must pay an excess emissions premium. The legislation also outlines a longer term target of 95g CO_2/kilometre set for 2020.

The regulation of carbon dioxide emission for cars could lead to reducing carbon dioxide emissions. This regulation could give an incentive to technological improvement. However, regulation creates no economic incentive for reducing emissions by more than is desired (Tietenberg, 1990).

3.5 Taxation of company cars

The principles of taxation of company cars have no environmental aim which are alternatively planned to encourage the sale of heavy, powerful cars with above-average fuel consumption (Swedish EPA, 2003). An estimated 25 percent of all new cars are company cars, so the company car tax rules play a major part in determining the energy efficiency of cars on the road in Sweden.

A study on carbon dioxide differentiated vehicle tax commissioned by the Swedish EPA concluded that the positive environmental effects of introducing carbon dioxide-related vehicle taxes in Sweden would be significantly counteracted by the present Swedish tax policy on company cars (Swedish EPA, 2002). The harmful effect of the company car tax regulations on the environment is that the taxable value of the vehicle is based on a the calculation, which is only partly contingent on the new car price, so that there is a relatively small difference between the tax cost of more expensive, heavy and powerful company cars and lighter cars with low carbon dioxide emissions. On the instructions of the Swedish EPA (Swedish EPA, 2004a), the environmental impact on the structure of increased demand for more fuel-efficient cars, eco-cars and alternative fuels were estimated by Inregia in 2005. The author also examined the effects of changes in the company car tax policy to establish a closer association with vehicle carbon dioxide emissions. The author concludes that the adjustments to the regulations in 1997 had no effect on the fuel efficiency of company cars.

According to the Swedish Petroleum Institute, ethanol cars were run 55% on E85 and gas-driven cars 60% on gas in 2004. However, these percentages depend on the ethanol and gas price relative to gasoline. If the cost of fuel per kilometre using gasoline were higher than it would be using ethanol and gas, the percentage use of gasoline in these cars would perhaps fall. However, it has not been possible to discriminate the effect of the decrease of the gain value of eco-cars on the amount of new eco-cars from other components simultaneously affecting many new eco-cars being purchased, such as free parking for eco-cars in some municipalities, a larger part of producers selling eco-cars and gasoline and diesel price rises.

Company car taxation is not related to determine either its cost-effectiveness or the degree to which it has achieved its primary purpose, since taxation of company car is not intended to be an environmental instrument. However, tax differentiation on company cars would help to accomplish the climate goal which has the potential to be a cost-effective instrument. Since company cars are usually new cars, changes in the tax regulations on company cars also have a major impact on the second-hand car market.

4. GASOLINE DEMAND MODELS

4.1 The theory of demand

Demand refers to the effective desire for a commodity which was constrained by the ability and the willingness to pay for it (Mankiw, Kneebone, McKenzie, & Rowe, 1999). Demand for gasoline is in principle no different than that of any other commodity and the statistical analysis is based on the same economic conception. The social demand function was based on individual demand.

Individual demand refers to the demand for a commodity from an individual point of view. Gasoline demand is the quantity of gasoline that a consumer would buy at a given price during a given period of time. Gasoline consumption by a household or individual depends on income and price of gasoline, transportation costs, and other factors. With appropriate assumptions on market conditions, for example, the demand function that depends on prices and incomes for consumers can be derived from "marginal condition". Some of the components, such as price, income, tax and other policy instruments change results in a new equilibrium position in demand.

The demand function for a group of consumers is referred to as the market demand function which means the total demand of the entire buyer taken together. How much quantity the consumers in general would buy at a given price during a given period of time constitutes the total market demand for the product. Market demand is the sum total of individual demands. The gasoline demand function can be described as depending on a number of independent variables such as gasoline price, income, car stocks, subsidy policy and vehicle tax and so on.

Demand elasticities refer to measures of the responsiveness of quantity demanded to changes in the determinants of demand. The elasticity is the percentage change in quantity demanded resulting from a given percentage change in the price of good in question, assuming all other factors affecting demand remain constant. The demand is called inelastic if the price elasticities are less than one in absolute terms. The elasticity is one that was called unit elastic. The demand is called elastic if the price elasticities are larger than one in absolute terms.

The cross price elasticities are important when handling energy products. Consumer demand for gasoline has a cross elasticity relationship with the price of automobiles, price of diesel, and the price of public transportation and so on. Moreover, demand of gasoline also was affected by technological car change and another policy such as subsidy on green cars.

The distinction between 'short-run' and 'long-run' effects is determined. According to Goodwin at al. (2004), short-run refers to responses made within one period of the data used for the study, most commonly, in this context, within 1 year, whereas the long-run means the asymptotic end state when responses are completed, and might vary in accordance with what a sort of manner is under consideration: for a number of the previous studies, such as Sterner (1990); Bentzen (1994); Alves et al. (2003), periods of 5–10 years are estimated empirically, within which the greatest part of the response is in the first 3–5 years.

Characteristic of gasoline demand: The fact that a gasoline product is not consumed for its own benefit; however, in conjunction with energy using equipment it gives the modeling some specific features. Demand for a specific fuel such as gasoline is interrelated with demand for end-use services and the demand for fuel-using equipment. The demand for the service depends on cost, the demand for fuel specific equipment depends on equipment prices and on relative operating costs, the demand for each fuel depends on the total demand for services and the choice of fuel-using equipment. There is an interrelationship among fuel prices, characteristics of stocks of fuel-using equipment, and the amount of each fuel consumed. Another major factor for gasoline demand is that it is time dependent. Consumers have limited ability to respond immediately to a price change. Individuals often have strong habits related to transportation, driving, and car ownership and so on. Therefore, it takes a long time to adapt to a new situation.

4.2 Least square estimates

4.2.1 Short run and long run models

Some previous studies (Bentzen, 1994; Eltony and Al-Mutairi, 1995; Ramanathan, 1999; Akinboade et al, 2008) have analysed gasoline demand using time series techniques. They have been using the following model which we will use in this study.

$$\text{Log}G_t = \alpha_0 + \alpha_1 \log P_t + \alpha_2 \log I_t + \varepsilon_t \qquad (1)$$

Where: G_t: gasoline consumption at time t; P_t: real price of gasoline at time t; I_t: real GDP per capita at time t; α_1, α_2: elasticities of price and income; ε_t - error term.

This model is based on price of gasoline and GDP per capita as dependent variables to explain the change in gasoline consumption. Sterner (1990) has found price and income are the main parameters in determining the demand of gasoline. However, the gasoline quantity consumed in reality depends not only on current income and price but also on a number of other variables such as energy taxes, subsidy policy, vehicle tax, taxation of companies, congestion tax, charge and fee, and regulation emission level for cars. Therefore, in this study we try to analyze a number of factors that affect gasoline consumption. Due to lack of data as well as information, we would not include all policies which we describe in section 3. We assume that gasoline demand (G) is mainly affected by the following components:

- Gasoline price (P),
- GDP per capita or income (I),
- Car stock or vehicle stock (V),
- Subsidy policy (D_{sub}),
- Regulation of carbon emission levels for light duty vehicles (D_{reg})

The static models of gasoline demand are described as a log-log function form with two models below:

Model without car stock: $\text{Log}G_t = \beta_0 + \beta_1 \log P_t + \beta_2 \log I_t + \beta_3 D_{Sub} + \beta_4 D_{reg} + \delta_t$ **(2)**

Model with car stock: $\text{Log}G_t = \alpha_0 + \alpha_1 \log P_t + \alpha_2 \log I_t + \alpha_3 \log V_t + \alpha_4 D_{Sub} + \alpha_5 D_{reg} + \varepsilon_t$ **(3)**

Where: G_t: gasoline consumption at time t,

P_t: real gasoline price at time t,

I_t: real GDP per capita or income at time t,

V_t: vehicle stock at time t,

D_{Sub}: 1 = if there is subsidy for eco-cars;

0 = otherwise

D_{reg}: 1 = if there is regulation of CO_2 emission level of car (130gCO_2/km);

0 = otherwise

$\beta_{1...}$ $\beta_{4:}$ elasticities of independent variables in **(2)**

α_1 ....α_5: elasticities of independent variables in **(3)**

β_0, α_0: constants,

δ_t, ε_t - error terms

Gasoline, together with most other fuels that are consumed to generate power, clearly needs vehicle stocks to exist for consumption to be probable. If we include the number of cars explicitly in the demand equation for gasoline, we would possibly underestimate the total influence from gasoline prices because the gasoline price and income levels explain the utilization of the vehicle stocks but also in the long-run the number of cars and the characteristics of the stocks (Franzén, 1992). Therefore, in this study the car stock is treated as an explicit variable and an implicit variable with two models with and without car stock, respectively.

Since gasoline consumption takes a long time to adjust, the static model will not capture the adjustment. Consequently, the gasoline demand model is required to adapt in the long-run (see Sterner, 2007). Dynamic long-run relationships can be addressed as:

$$LogG_t = \alpha_0 + \alpha_1 logP_t + \alpha_2 logI_t + \beta_1 logG_{t-1} + \varepsilon_t \qquad \textbf{(4)}$$

Where: G_t: gasoline consumption at time t; P_t: real gasoline price at time t; I_t: real GDP per capita or income at time t; β_1, α_1 and α_2 are parameters.

The lagged endogenous variable G_{t-1} can be seen as representing the inertia of economic behavior. In the formulation, β_1, α_1 and α_2 are three parameters to be estimated which α_1 represent the price elasticity, α_2 represents the income elasticity, and parameter β_1 is the discount rate. The price and income elasticities in the long-run are $\alpha_1/(1- \beta_1)$ and $\alpha_2/(1- \beta_1)$.[2]

4.2.2 Unit root test

We use time-series analysis and variables with time-series which are often non-stationary that may result in spurious regressions. This phenomenon is dealt with in the following through Dickey-Fuller tests for stationary and a cointegration test for the long term properties of the model.

[2] In the formula (4), parameters α_1 and α_2, respectively, may be explained as short-run percentage change of gasoline demand from one percent increase in gasoline price and income. The long-run effects are achieved by dividing the short run estimate by (1-β_1) (See Johnston, 2001; W. Greene, 2003).

We consider first whether the time series data is stationary[3] or not. A test of stationary (or non-stationary) that has become widely popular is the unit root test. The starting point is the unit root (stochastic) process. We assume that:

$$Y_t = \rho Y_{t-1} + u_t \qquad -1 \leq \rho \leq 1$$

Where: Y_t is time series data, such as gasoline consumption, vehicle stock, price of gasoline, and income in the time period 1991-2010, u_t is a white noise error term.

We know that if ρ = 1, that is, in the case of the unit root, the equation becomes a random walk model without drift, which we know is a non-stationary stochastic process. Therefore, we simply regress Y_t on its (one period) lagged value Y_{t-1} and find out if the estimated ρ is statistically equal to 1, Y_t is nonstationary.

If a time series has a unit root, the first-differences of such time-series are stationary. Therefore, the solution here is to take the first-differences of the time-series. Now we subtract Y_{t-1} (this is the first-difference) as formula below:

$$Y_t - Y_{t-1} = \rho Y_{t-1} - Y_{t-1} + u_t = (\rho - 1)\ Y_{t-1} + u_t$$

This can be alternatively written as:

$$\Delta Y_t = \delta Y_{t-1} + u_t$$

Where: $\delta = (\rho - 1)$ and Δ, as usual, is the first-difference operator.

We estimate and test the (null) hypothesis that $\delta = 0$. If $\delta = 0$, then $\rho = 1$, that is we have a unit root, meaning the time-series under consideration is non-stationary.

After that, we continue by considering whether the time series in our study is integrated or not. A variable is said to be integrated of order *d*, written *I(d)*, if it must be differenced *d* times to be made stationary (Gujarati Damodar, 1999). Thus a stationary variable is integrated of order zero, written $I(0)$, a variable which must be differenced once to become stationary is said to be $I(1)$, integrated of order one, and so on.

The methods for testing cointegration[4] use in this study is the Dickey-Fuller (DF) or Augmented Dickey-Fuller (ADF) unit root test on the residuals estimated from the

[3] A time series is said to be stationary if its mean and variance between two time periods depends only on the distance or gap or lag between the two time periods and not the actual time at which the covariance is computed (see Gujarati Damodar, 1999).

[4] Cointegration refers to a statistical property of time series variables. The time series are cointegrated if they each share a common type of stochastic drift i.e. to a limited degree they share a certain type of behaviour in terms of their long run fluctuations, but they do not essentially move together and could be otherwise unrelated.

cointegrating regression. This is based on Engle–Granger (EG) or Augmented Engle–Granger (AEG) Test. All we have to do is estimate a regression, obtain the residuals, and use the DF or ADF tests. Since the estimated u_t is based on the estimated cointegrating, the DF and ADF critical significant values are not quite appropriate. Engle and Granger have calculated these values, therefore, the DF and ADF tests in the present context are known as Engle–Granger (EG) and Augmented Engle–Granger (AEG) tests. If the time series are found to be cointegrated, we can conclude that they have a long run relationship.

After checking the unit root and cointegration of the time series, if they are found to be non-stationary and cointegrated, gasoline demand was estimated by the error correction model (ECM)[5] which uses the first-difference for equation **(4).**

4.2.3 Calculate gasoline taxes on reducing carbon emissions

The percentage of reducing carbon dioxide emissions in Sweden is calculated based on price elasticities (which are estimated by our model in the short and long-run); gasoline tax; gasoline price and average carbon dioxide emission coefficient (which is calculated by U.S EPA (2005)). The calculation follows these steps below:

First of all, we based on price elasticity, gasoline tax and gasoline price to calculate the quantity gasoline consumption reduction due to the tax increase. And then, a number of tonnes carbon dioxide emission reductions are computed by multiplying consumption quantity of gasoline reduction with the average carbon dioxide emission coefficient. Finally, the percentages of carbon dioxide emission reduction are calculated by dividing a number of tonnes carbon dioxide emission reductions by a number of tonnes carbon dioxide emissions in Sweden.

5. THE DATA

In this study, we use time-series data from 1991 to 2010. The data such as gasoline consumption, gasoline price (including energy tax and carbon tax), GDP per capita and vehicle stocks is bought from *Statistics Sweden*[6]. This time period is chosen because carbon tax was implemented in 1991. Gasoline price and GDP per capita have been deflated using the consumer price index (CPI). Moreover, subsidy policy and regulation of carbon emission

[5] The estimated the long run relationship from the cointegration analysis is used as an ECM term. Estimating ECM i.e. parameters in model are treated (see Charemza and Deadman, 1992) .

[6] To make sure that data is reliable, we bought the data from Statistics Sweden (http://www.scb.se)

levels are used as explanation variables in the models. The explanatory variables in this study are shown in Table 1.

Table 1: Variables for model estimation

Variables	Descriptions
G_t	Gasoline consumption at time t ($1000m^3$)
P_t	Gasoline price at time t (SEK per liter)
I_t	GDP per capita at time t (SEK 1000)
V_t	Vehicle stock at time t (1000 cars)
D_{sub}	D_{sub}: 1 = there is subsidy for eco-cars (SEK 10,000 per car) 0 = otherwise *Note: Subsidy was implemented in 2007*
D_{reg}	D_{reg}: 1 = there is regulation of CO_2 levels (130g CO_2/km for car) 0 = otherwise *Note: regulation was implemented in 2009*

As shown in Table 1, we would clearly clarify all variables in our study:

Gasoline consumption (G) is the dependent variable. Gasoline consumption is defined as the total gasoline volume which is consumed by vehicles in Sweden every year from 1991 to 2010. Gasoline consumption depends on a number of variables that we will address below:

The first independent variable is gasoline price (P). Gasoline price is defined as the final price (including energy and carbon taxes) that consumers face on the market when buying gasoline. The variable P is calculated as the nominal consumer gasoline price deflated by using CPI. Gasoline price is one of the main parameters in any gasoline demand. Gasoline tax will make gasoline price more expensive. In fact, increasing the tax would have a direct impact on consumers of gasoline. We assume that a higher gasoline tax will reduce gasoline consumption because of the higher gasoline price. High gasoline price at the pumps has also provided consumers with incentives to consume less gasoline. When the price of gasoline increase, the consumers respond to the higher price, whereby people begin to drive less and to exchange their less efficient vehicles for more efficient ones (Drollas, 1984).

GDP per capita or income (I) is the second independent variable that is also deflated by using CPI. An income increase will contribute to raising a number of vehicle ownerships. This means that the relationship between income and gasoline consumption is positive.

Vehicle stock (V) is the total number of cars with engines that use gasoline. This is the third independent important variable that explicitly affects gasoline consumption. However, gasoline price and income indirectly impact on a number of cars which we will consider in both models with and without car stock above. The difficult problem is that different cars do not have homogeneity in size, weight, and year olds.
Therefore, we assume that the car stock is homogeneous and the expectation of the vehicle stock is positively correlated with gasoline consumption.

The fourth independent variable is the subsidy dummy variable (D_{sub}). Subsidy for eco-cars was implemented in 2007. It provides an incentive for people to purchase fuel-efficient cars and vehicles running on alternative motor fuels. Moreover, subsidy could indirectly impact on car engine improvement. Therefore, we expect that the correlation between subsidy and gasoline consumption is negative.

The final independent variable is the regulation dummy variable (D_{reg}). Regulation was implemented in 2009. Regulation of carbon emission levels for duty light cars could reduce carbon emissions from transportation since the car emission limit applies. Regulation would have a direct impact on manufactures by requiring them to follow a carbon dioxide emission level standard. Moreover, regulation could indirectly affect to car buyers through changes in the car characteristics that manufacturers sold and the prices they charged. Indeed, regulation could provide an incentive for technological improvement resulting in reduced gasoline consumption. We expect that if regulation is implemented, the use of gasoline decrease. It means that carbon emission will be reduced.

6. RESULTS AND DISCUSSION

6.1. Materials

Gasoline consumption is mainly a source of carbon dioxide emissions from this sector. As shown in Figure 1, road traffic in Sweden consumed a total of 4.55 million m^3 of gasoline in 2010. Gasoline consumption has remained steady since the early 1995s. However, the gasoline consumption has been somewhat reduced from 2003 to 2006. The Swedish Petroleum Institute (2006) has reported the gasoline consumption reduction of 4% for the first quarter of 2006, as compared with the same period in 2005. The use of gasoline in the transport sector in recent years has significantly declined which can be partly explained by an increased use of low-blended ethanol. Moreover, technological advances in car engines contribute to reduce gasoline consumption. Subsidy for biofuels could also result in decrease in gasoline consumption.

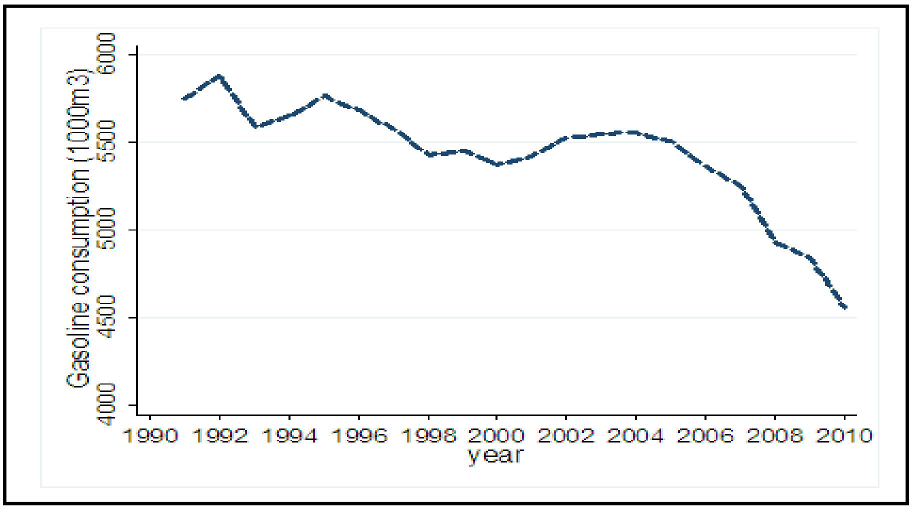

Figure 1: Gasoline consumption during the period 1991-2010
Source: Swedish Petroleum Institution, 2010.

However, Figure 2 shows that the car stock has increased during the period. The number of cars in Sweden in 1991 was around 3.62 million which is 2.39 persons per car. There was a slight decreased from 1991 to 1993 and then the car stock increased significantly from 1993 to 2010 due to the increasing population and economic growth. Car stock was approximately 4.3 million which is 2.19 persons per car in 2010.

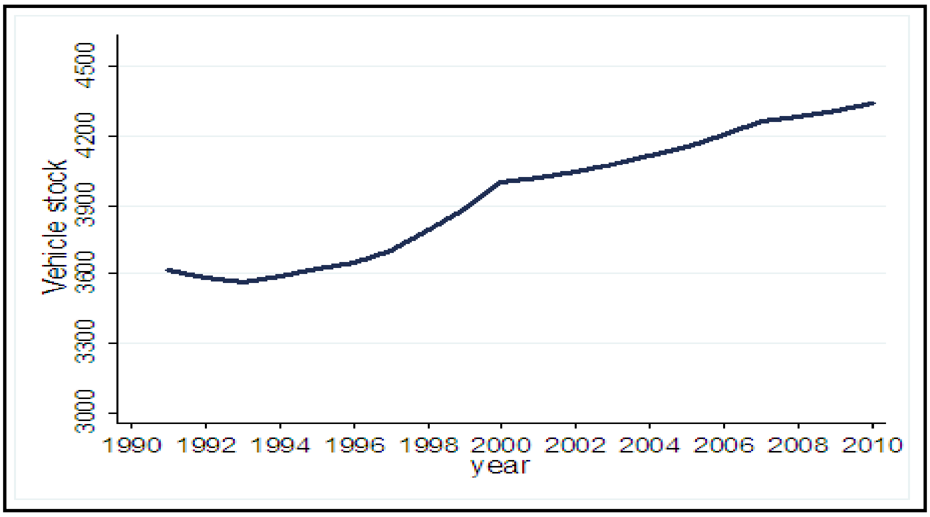

Figure 2: Car stocks trend during the period 1991-2010
Source: Statistics Sweden, 2010.

Figure 3 describes gasoline price indices during the period 1991 - 2010. The gasoline real price increased substantially from SEK 5.90 per liter in 1991 to SEK 12.80 per liter in 2010.

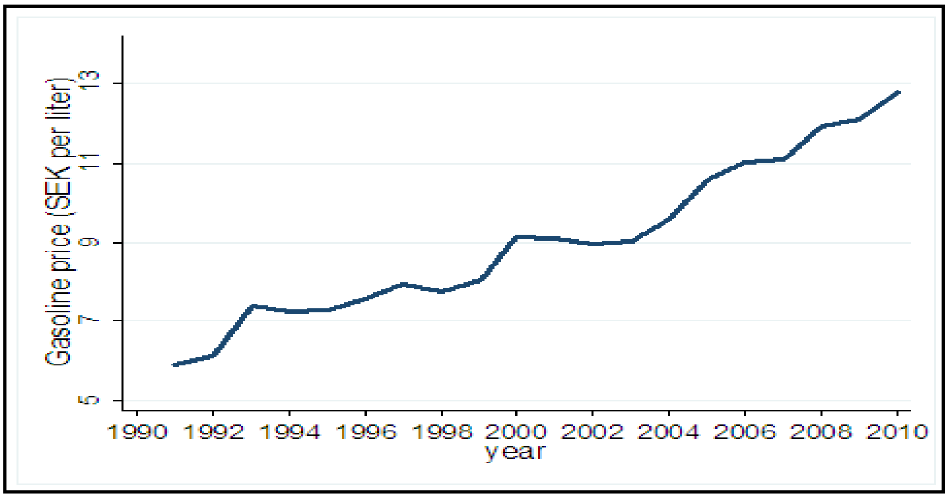

Figure 3: Trending of gasoline price during the period 1991-2010
Source: Swedish Petroleum Institution and Statistics Sweden, 2010

The gasoline price is one of the main components that influences on motor gasoline consumption. Substantial upward shifts in gasoline prices have been main components in demand decline in some ways. They have directly reduced demand in the short-run by decreasing vehicle miles travelled and indirectly reduced demand by contributing to the substitute of biofuels, and influenced consumers to purchase smaller vehicles.

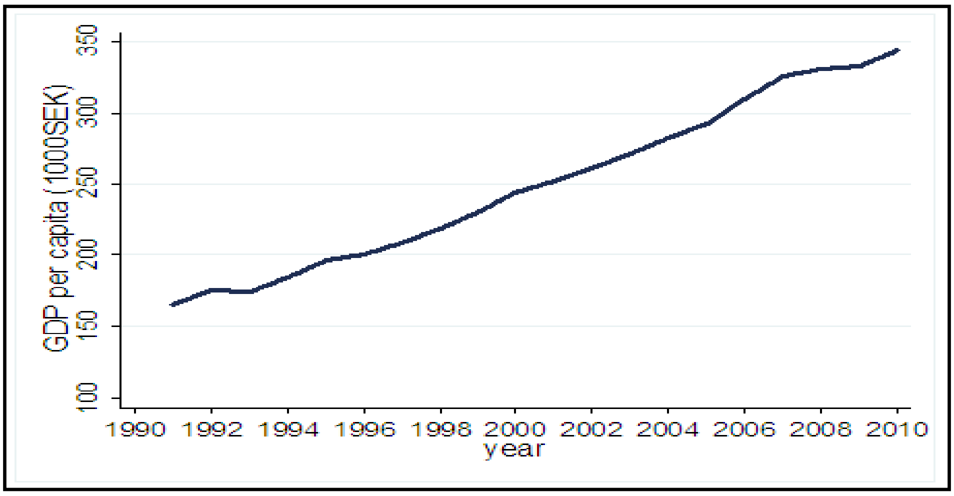

Figure 4: Trending of GDP per capita during the period 1991-2010
Source: Statistics Sweden, 2010

Figure 4 depicts the GDP per capita from 1991 to 2010. Annual real GDP per capita increased significantly from SEK 165,000 in 1991 to SEK 342,000 in 2010. Income growth could indirectly contribute to increased gasoline consumption because growing real income per household has led to increasing vehicle ownership.

Gasoline is subject to energy tax and carbon dioxide tax. If gasoline tax increases, it leads to a rise in the price of gasoline that consumers will face on the market. Gasoline tax makes increase in gasoline price. Thus, gasoline tax is quite a burden to consumers in Sweden.

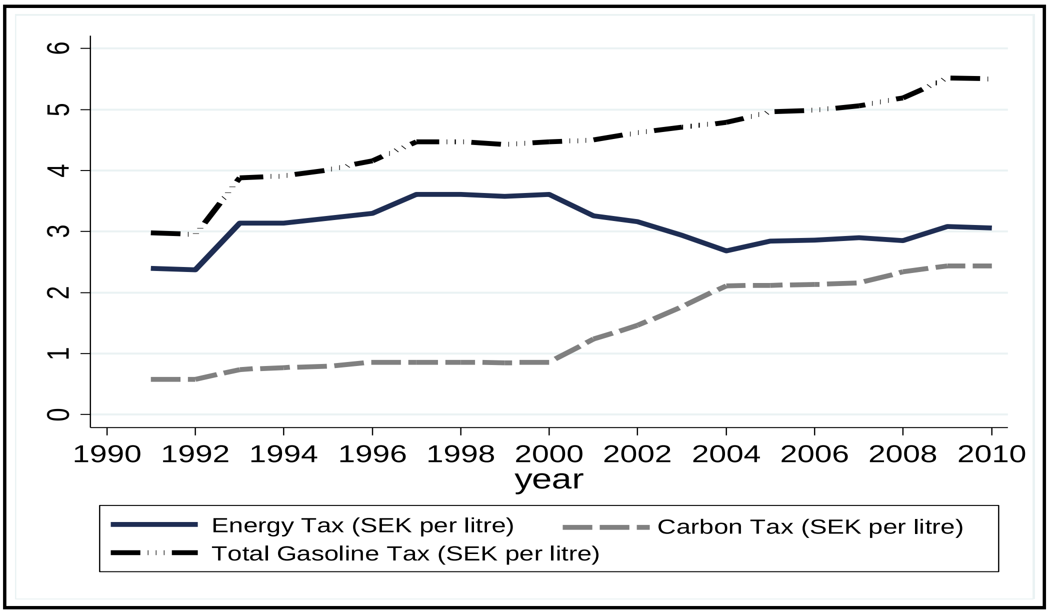

Figure 5: Gasoline tax in Sweden from 1991 to 2010
Source: Swedish Petroleum Institution and Statistics Sweden, 2010

Figure 5 describes the variation in tax rate since 1991. At the beginning, carbon tax was lightly increased until 2000. The increase in the carbon dioxide tax is substantial, while energy tax on gasoline is significantly reduced from 2000 to 2004. Overall, total gasoline tax has increased over time from 2.98 SEK per liter in 1991 to 5.52 SEK per liter in 2010.

Figure 1, 2, 3 and 4 are plot of the data for the gasoline consumption, car stock, price of gasoline, and GDP per capita, respectively. The impression that we get from the Figure 1 that the time series of gasoline consumption tends to downward trend whereas Figure 2, 3 and 4 have the time series that seem to upward trend. We will see that over the period of study gasoline use, car stock, gasoline price and income have been changing, suggesting perhaps that the means and variance of those have been changing. This may be an indication that these time-series are non-stationary.

6.2 Econometric analysis and results

6.2.1 The unit root test and cointegrated test

The first step in our analysis is to check for the stationarity of all the variables, both dependent and independent. Unit root test for times series of gasoline consumption (G), vehicle stock (V), gasoline price (P) and income (I) can be done in many ways. The first way that we run regression of G_t, V_t, P_t and I_t on its (one period) lagged value and find out if the estimated ρ is statistically equal to 1, G_t, V_t, P_t and I_t are non-stationary. Note that all series have been converted to natural logarithms for the purpose of cointegration analysis.

The functions can be written as:

$$G_t = \rho G_{t-1} + u_t$$

$$V_t = \rho V_{t-1} + u_t$$

$$P_t = \rho P_{t-1} + u_t \qquad -1 \leq \rho \leq 1$$

$$I_t = \rho I_{t-1} + u_t$$

The unit root tests and all other regression analyses presented in this paper have been conducted using the econometric software package, Stata, Version 10. The estimate *ρ coefficients* of gasoline use, car stock, gasoline price and income are 0.81, 0.99, 0.95 and 0.98, respectively. The estimate results show that *ρ coefficients* are less than 1; however, *ρ coefficients* of vehicle stock and income are nearly equal to 1. This suggests that we need to have another check for stationarity.

Furthermore, the ADF test is used to check unit root that the functions can be written as:

$$\Delta Y_t = \delta Y_{t-1} + u_t$$

Where: $\delta = (\rho - 1)$; Δ is the first-difference operator; Y_t could be gasoline use, car stock, gasoline price and income, respectively. The result of the ADF test is presented in Table 2.

Table 2: Tests for stationarity of the variables

Variables	Levels		First differences	Test statistic
	t-statistics	lags	t-statistics	
G_t	-2.01***	$(1)^{\alpha}$	0.34	-2.009
V_t	2.84*	$(2)^{\alpha}$	2.44**	-2.817
P_t	2.76**	$(1)^{\alpha}$	-0.64	2.756
I_t	3.74*	$(1)^{\alpha}$	-0.27	8.176

$^{\alpha}$ Figures in parentheses represent the number of lags used in the ADF test.
*significant at 1% level
**significant at 5% level
***significant at 10% level
Note: all series have been converted to natural logarithms

The t=tau value of the G_{t-1}, V_{t-1}, P_{t-1}, and I_{t-1} coefficients is extremely important in order to find out whether the time series is stationary or non-stationary. The ADF critical tau with 1%, 5%, and 10% statistic values of all three are -2.660, -1.950, and -1.600, respectively. As presented in Table 2, the estimated tau values are -2.009 for G_{t-1}, 2.817 for V_{t-1}, 2.756 for P_{t-1}

and 8.176 for I_{t-1}, which are bigger than the critical tau value of -1.950 at 5% in absolute value.

Table 2 also gives the *t*-statistics of the variables by employing the ADF test. The *t*-statistics for the variables in levels are statistically significant, which means that the null hypothesis that the variables in levels are non-stationary can be rejected. In contrast, the *t*-statistics for the first difference of the variables are not statistically significant except for the vehicle stock variable. Thus, all the variables have been checked to be stationary variables.
To sum up, the time series under consideration do not have a unit root, i.e., they are stationary.

The second step is to estimate cointegrating relationships using the ADF unit root test on the residuals estimated from the cointegrating regression shown in equation (5) which we take from equation (1).

$$\varepsilon_t = \log G_t - \alpha_0 - \alpha_1 \log P_t - \alpha_2 \log I_t \qquad (5)$$

Table 3: Results of cointegrated analysis

Explanation	ε_t value
T-statistic of residual in the unit root test (without intercept).	-1.860[b]

[b] ε_t value is residual based test for cointegration in a formula in (5) without intercept. The ADF critical tau with 1%, 5%, and 10% statistic values are -2.660, -1.950, and -1.600, respectively.

As can be seen from the data in Table 3, the ADF test on the residuals, with trend, shows that the null of cointegration is accepted at 10% level because ε_t value is above the critical value at 10%. Therefore, the residual ε_t has been found to be stationary I(0), indicates that the variables are cointegrated. We can conclude that there is the existence of the long-run relationship among the variables.

6.2.2 Short and long run regressions.

The results of regressions in Table 4 show that two models are highly significant with adjust $R_{\text{-squared}}$ 0.88 and 0.89, respectively.

For model without car stock, the estimated coefficients are significant at the 5% level and have the expected signs for gasoline price, regulation and subsidy, whereas income variable is not statistically significant. The sensitivity of gasoline price is found about -0.21 while the marginal effects of subsidy and regulations on gasoline consumption are about -0.05 and -

0.06, respectively. The Durbin-Watson statistic value is 1.77 which shows no sign of autocorrelation in the model.

The result of model with car stock shows that the elasticity of gasoline price demand is -0.26 and income elasticity of gasoline demand is 0.29. The sign of both variables is the same as our expectation. While the gasoline price coefficient is statistically significant with 5%, the parameter of income is not statistically significant. The sign of the coefficient car stock variable is the opposite of our expectation; however, it is not statistically significant at the end. The coefficients of subsidy and regulation are the same signs as expected which are – 0.05 and – 0.06, respectively. There is no evidence of autocorrelation because of the Durbin-Watson statistic value of 1.79.

Table 4: Results of regressions for short-run model with and without vehicle stock

Variables	Explanation	Model without V	Model with V
LnP	Gasoline price (SEK/liter)	-0.21**	-0.26**
		(-2.12)	(-2.45)
LnI	Income (1000SEK)	0.09	0.29
		(0.94)	(1.58)
LnV	Car stock (1000 cars)	-	-0.57
			(-1.27)
D_{reg}	Dummy variable	-0.06*	-0.06**
	1: regulation, 0: no	(-3.04)	(-2.88)
D_{sub}	Dummy variable	-0.05**	-0.05**
	1: subsidy, 0: no	(-2.45)	(2.62)
Constants		8.61*	12.29*
		(29.48)	(4.23)
Adj R-squared		0.88	0.89
Durbin-Watson		1.77	1.79

*Significant at 1% level
** Significant at 5% level
*** Significant at 10% level
Note: Parameter estimates with t-values in parenthesis

There is a little difference of price elasticities in the two models. The elasticity of price in the model without car stock is about – 0.21 whereas price elasticity in the model with car stock is slightly higher which is – 0.26. A gasoline price increase of 10% reduces gasoline consumption by 2.1% for the model without car stock and 2.6% for model with car stock.

Two interesting variables are subsidy and regulation which are similar in both models. Indeed, the marginal effects of subsidy and regulation on gasoline consumption in both are -0.06 and 0.05, respectively. This means if regulation and subsidy policies are applied, gasoline consumption would have been reduced by 0.06% and 0.05% respectively. Definitely, gasoline consumption can be reduced through subsidy and regulation. The indirect impacts of subsidy on technological improvements that is manufacturers could produce the fuel-efficient vehicles or make vehicles that use alternative fuels, such as ethanol. Regulation of carbon dioxide emission levels gives producers a strong incentive to enhance technological improvement through improving the average fuel economy of the vehicles that they sell to the market. Thus, we find that regulation and subsidy policies have little impact on gasoline consumption.

Estimates of the short-run price elasticity of gasoline demand for the period from 1991 to 2010 is nearly similar to many previous studies, for instance, Dahl and Sterner, (1991), Bentzen, (1994). The short-run price elasticity is a measure of the change in driving behavior as a result of a change in gasoline price. A consumer’s response to higher prices is largely composed of a reduction in the amount of driving and an increase in the fuel-efficiency of driving. Hence, gasoline consumption is less responsive to changes in gasoline price in the short-run.

It is necessary to mention that these results quantify the responses of consumers to short-run changes in gasoline prices. The short-run analysis of price elasticity of gasoline demand gives several insights into long-run behavior. The sum of short-run changes such as miles driven and long-run changes such as fuel economy of the vehicle fleet is the response of long-run to gasoline price rises (Johansson & Schipper, 1997). In the short-run, consumers are less reactive in adjusting miles driven to a rise in the price of gasoline. This may contribute to inelasticity of gasoline price in the short-run.

However, the elasticity in long-run response is the main component in determining which policy is most suitable for gasoline consumption reduction. We have been shown that there is the existing long-run relationship between gasoline demand and other variables such as gasoline price, income and car stock. Therefore, the sensitivities of gasoline price and income for gasoline consumption in the long-run are explored and presented in Table 5.

Table 5: Long run gasoline demand regression

Variables	Coefficients	Long-run elasticities
lnP_t	-0.34*	-3.77[a]
	(-3.95)	
lnI_t	0.24*	2.83[b]
	(3.18)	
lnG_{t-1}	0.91*	
	(6.12)	
Adj R-squared	0.91	
Durbin-Watson	1.75	

* Significant at 1% level
[a] Long-run price elasticity is calculated based on equation $\alpha_1/(1- \beta_1)$
[b] Long-run income elasticity is calculated based on equation $\alpha_2/(1- \beta_1)$
Note: Parameter estimates with t-values in parenthesis

The result of the regression is highly significant at 1% level for all variables. Adjust $R_{squared}$ is high with the explanation of 91% in the model. Also, there is no evidence of autoregression in the model with the Durbin-Watson value of 1.75. We find that long-run elasticities of gasoline price and income are approximately -3.77 and 2.83, respectively. These elasticities refer to measures of the responsiveness of quantity gasoline consumption to changes in the gasoline price and income in the long-run. The high price elasticity proposes that gasoline tax reduces gasoline consumption, whereas the high income elasticity suggests that we can expect gasoline consumption to continue growing.

Long run-price elasticity of gasoline demand in Sweden is quite elastic, -3.77, while many previous studies find around -1.0 (see review by Graham and Glaister, 2004). There are two reasons could explain this issues. Firstly, consumers in the period 1991-2010 are purchased more fuel-efficient vehicles and eco-cars to response to higher gasoline prices, since Sweden implemented a number of policy instruments for transport sector. Thanks to technological development, the reaction of customers to higher gasoline is selecting electric cars, hybrid cars and eco-cars. In fact, the long-run price elasticity is more elastic than in some previous studies, larger reductions in gasoline consumption will occur for any given gasoline tax. Secondly, the difference in the long-run price effect by using different time periods or different econometric techniques which would result in different estimates.

Long-run income elasticity is found about 2.83 which is much higher than in most previous studies, for example, Dahl (1995), Eltony and Al-Mutairi (1995). However, the elasticity of income in our study is comparable with a study by Ramanathan (1999) who finds the income elasticity of 2.68. The increasing income could make consumers tend to buy gasoline cars, and offsets the adverse influence of a gasoline price rise.

Indeed, the long-run income and price elasticities for Sweden are of much higher magnitude than found previously. Taxes are significant in order to accomplish an equivalent reduction in gasoline consumption. The absolute value of price elasticity is obviously higher than that for income which is in contrast to previous studies. These results show that Sweden perhaps is heading towards independence on fossil-fuel use.

6.2.3 Calculating the effects of gasoline tax on carbon dioxide emissions

After the models are estimated both in the short and long-run, the price elasticity of gasoline demand is the main component to explain the impact of the gasoline tax on gasoline consumption. The difference between short and long-run elasticities is an important factor in this context.

Based on the price elasticities in the short and long-run, we can calculate the reduction of carbon emissions. The price elasticities can describe as:

$$\gamma_i = \%\Delta P / \%\Delta Q$$

Whereas:

$\boldsymbol{\gamma_i}$ = gasoline price elasticities in the short or long-run

$\%\Delta P$ = % change in gasoline price

$\%\Delta Q$ = % change in gasoline consumption

We assume that if we increase the gasoline price through increasing the carbon tax with 1% (1% increase in gasoline price corresponds to in actual increase in tax about SEK 0.128), the short-run gasoline consumption will reduce for models with and without car stock about 0.26% and 0.21% respectively, whereas long-run gasoline consumption will decrease approximately 3.77%.

As show in Table 6, if today the government increases the carbon tax with 1% (which corresponds to SEK 0.128 per liter), the short-run gasoline consumption will reduce 11,830 m^3 and 9,555m^3 (which correspond to 27,563 and 22,135 tonnes of carbon dioxide emissions) in models with and without car stock. The percentages of carbon dioxide emissions are reduced in the short-run for both models with and without car stock about 0.05% and 0.04%, respectively. In the long-run, carbon dioxide emission is reduced about 0.67% which corresponds to 399,677 tonnes.

Table 6: The effects of gasoline tax on reducing carbon dioxide emissions

	%ΔP	%ΔQ	Gasoline use reduction (m^3)	CO_2 reduction (tonnes)	CO_2 reduction (%)
The short-run (1)	1	-0.26	11,830	27,563	0.05
The short-run (2)	1	-0.21	9,555	22,135	0.04
The long-run	1	-3.77	171,535	399,677	0.67

(3) Gasoline consumption in 2010 is about 4.55 million m^3

(4) CO_2 average emission coefficient for gasoline is about 2.33kg per liter

(5) Total CO_2 emission in Sweden in 2010 is about 60 millions tonnes

(1) The model with car stock
(2) The model without car stock
(3) The data from Statistics Sweden
(4) See appendix
(5) Swedish Energy Agency, 2010

During the period of 1991-2010, carbon tax was increased about SEK 1.86 which contributed to gasoline price increase about 14.5%. As can be seen from the data in Table 7, the percentages of carbon dioxide emission reduction in the short-run are calculated at about 0.75% and 0.63%, which correspond to about 0.48 million and 0.39 million tonnes of carbon dioxide emissions, for the model with and without car stock.

Table 7: The effects of carbon tax on reducing CO_2 during the period 1991-2010

	%ΔP	%ΔQ	Gasoline use reduction (m^3)	CO_2 reduction (tonnes)	CO_2 reduction (%)
The short-run [a]	14.5	-3.77	204,786	477,152	0.75
The short-run [b]	14.5	-3.05	165,676	386,025	0.63
The long-run	14.5	-54.66	2,969,402	6,918,708	10.80

(c) Average gasoline consumption of the period 1991-2010 is about 5.432 millions m^3

(d) CO_2 average emission coefficient for gasoline is approximately 2.33kg per liter

(e) Average CO_2 emission of the period 1991-2010 is about 64 millions tonnes

[a] The model with car stock
[b] The model without car stock
(c) The data from Statistics Sweden
(d) See appendix
(e) Swedish Energy Agency, 2010

The existence of a long-run relationship between price and demand of gasoline allows us to estimate the long-run carbon dioxide emission reduction. We find that in the period of 1991-2010, long-run gasoline price increase 14.5% (which correspondent to SEK 1.86) leads to carbon dioxide emission reduction about 10.8% which is approximately 6.9 million tonnes of carbon dioxide.

In fact, there is a little carbon dioxide reduction in the short-run; however, carbon emission reduction in the long-run is extremely significant. Our findings agree with Sterner (2007) that gasoline tax is the most powerful instrument in reducing carbon dioxide emissions. Moreover, this result is somewhat comparable with a study by Davis and Kilian (2009). The authors found that a 10 cent per gallon[7] raise in the gasoline tax would decrease carbon emissions from vehicles in the United States by about 1.5%.

7. CONCLUSION and IMPLICATION

In this paper we investigate the effects of many policy instruments on reduced gasoline consumption in Sweden for the period 1991-2010. A number of policy instruments for the transport sector from the period of study are overviewed. We estimate the short-run response with two models, with and without car stocks. The gasoline model in the long-run is also considered.

We find that there is no evidence for non-stationarity in our time series data. However, the long-run relationships among variables are existent. The short-run price elasticity of gasoline demand is inelastic similar to several previous studies. However, the long-run responses of gasoline demand are quite elastic for both price and income. This finding is very different to many previous studies. Perhaps the incentives to use more energy efficiency and less carbon-emitting vehicles make price elasticity of gasoline demand more responsive. We also find that there is little impact of the marginal effects of subsidy and regulation on reducing gasoline consumption in the short-run. Vehicle stock is not found statistically significant in our model.

We believe that the effect of gasoline tax on carbon emissions is very significant. We demonstrate that a 0.128 SEK per liter increase in the gasoline tax would reduce carbon dioxide emissions from vehicles in Sweden by about 0.04% to 0.05% in the short-run and approximately 0.67 % in the long-run.

[7] 1 US gallon = 3.78 liters

During the period of 1991-2010, carbon tax has significantly contributed to reduce carbon emissions. The short-run carbon dioxide emissions reduced about from 0.63% to 0.75% whereas the percentage of carbon dioxide emission reduction in the long-run is about 10.8% of total carbon dioxide emissions in Sweden.

This study provides some important findings for policy makers implementing gasoline tax adjustments. Firstly, the implications for policy are that a gasoline tax can play a significant role in reducing carbon dioxide emissions in the long-term. We show that the long-run response of consumers to gasoline tax is quite sensitive. Secondly, subsidy policy and regulation of carbon emission levels provide an incentive to reduce gasoline use. However there is little effect of subsidy and regulation on reducing gasoline consumption in the short-run.

The limitation of this study is not concentrating on the aspects of political issues and the impact of oil price come from outside Sweden. Also, there is lack of data for some variables such as vehicle tax, taxation of company cars and so on.

Obviously, carbon dioxide emissions come from not only gasoline use but also different sources such as diesels and other fuels. Therefore, this suggests for further research that focuses on the relationship among kinds of energy to reduce carbon dioxide emission through relative price. Since gasoline consumption has been reduced in recent years, the use of other energy sources such as diesels, biofuels and ethanol probably will continue to increase.

8. APPENDIX

At the normal condition (25^0C), assume that one liter of gasoline weighs about 737 grams. It is composed principally of carbon and hydrogen with a ratio of 2 carbon per 2 (and a bit) hydrogen or 24 units of mass carbon per 2 units of mass hydrogen. This means that for every 737 grams (one litre) of fuel you have (24/26) x 737 = 680 grams of carbon. Since 1 carbon atom combines with 2 oxygen atoms each 12 atomic mass units carbon combines with 32 atomic mass units oxygen to make 44 atomic mass units carbon dioxide. So for every litre of fuel (which weighs 737 grams), we have 680 grams carbon and require 1814 grams of oxygen to combust it. This produces 680 + 1814 = 2494 grams of CO_2. Therefore, burning one liter of gasoline releases around 0.68 kg carbon or 2.49 kg carbon dioxide.

The U.S. Environmental Protection Agency (2005) calculated the carbon dioxide emission coefficient from transportation and mobile sources for gasoline as:

"Carbon content per gallon of gasoline and diesel fuel which EPA uses in calculating the fuel economy of vehicles is 2,421 grams per gallon. The Intergovernmental Panel on Climate Change (IPCC) guidelines for calculating emissions inventories require that an oxidation factor be applied to the carbon content to account for a small portion of the fuel that is not oxidized into CO_2. For all oil and oil products, the oxidation factor used is 0.99 (99 percent of the carbon in the fuel is eventually oxidized, while 1 percent remains un-oxidized.)
Finally, to calculate the CO_2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12): 44/12. CO_2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12) = 8,788 grams = 8.8 kg/gallon."

We know that a gallon equals 3.78 liters, therefore, CO_2 emissions from a liter of gasoline = 2.33kg.

9. REFERENCES

Akinboade, O. A., Ziramba, E., & Kumo, W. L. (2008). The demand for gasoline in South Africa: An empirical analysis using co-integration techniques. *Energy Economics, 30*(6), 3222-3229.

Alves, D. C. O., Bueno, R. D. S. (2003). Short-run, long-run and cross elasticities of gasoline demand in Brazil. *Energy Economics* 25, 191-199.

Baranzini, A., Goldemberg, J., & Speck, S. (2000). A future for carbon taxes. *Ecological economics, 32*(3), 395-412.

Bentzen, J. (1994). An empirical analysis of gasoline demand in Denmark using cointegration techniques. *Energy Economics, 16*(2), 139-143.

Blum, U. C. H., & Foos Marc, J. (1988). Aggregate time series gasoline demand models: Review of the literature and new evidence for West Germany. *Transportation Research Part A: General, 22*(2), 75-88.

Chapman L (2007) Transport and climate change: A review, *Journal of Transport Geography* 15: 354-367.

Charemza, W.W., Deadman, D.F. (1992). New Direction in Econometric Practice: General to Specific Modeling, Cointegration and Vector Autoregression. Edward Elgar Publishing Limited, Hants, England

Christiansen, A. C. (2001). Climate policy and dynamic efficiency gains: A case study on Norwegian CO2-taxes and technological innovation in the petroleum sector. *Climate Policy, 1*(4), 499-515.

Dahl, C. (1995). Demand for transportation fuels: a survey of demand elasticities and their components. *The journal of energy literature, 1*(2), 3-27.

Dahl, C., & Sterner, T. (1991). Analyzing gasoline demand elasticities: a survey. *Energy Economics, 13*(3), 203-210.

Davis, L., & Kilian, L. (2009). Estimating the effect of a gasoline tax on carbon emissions. *Journal of Applied Econometrics*.

Drollas, L. P. (1984). The demand for gasoline* 1:: Further evidence. *Energy Economics, 6*(1), 71-82.

Eltony, M. N., Al-Mutairi, N. H. (1995). Demand for gasoline in Kuwait: An empirical analysis using cointegration techniques. *Energy Econ* 17 (3), 249 - 253.

Engle, R.F., Granger, C.W.J., (1987). Co-integration and error correction: Representation, estimation and testing. *Econometrica* 55, 251-276.

Franzén, M. (1992). Gasoline demand models, PhD dissertation.

Goodwin, P. B. (1992). A review of new demand elasticities with special reference to short and long run effects of price changes. *Journal of Transport Economics and Policy, 26*(2), 155-169.

Goodwin, P., Dargay, J., Hanly, M., (2004). Elasticities of road traffic and fuel consumption with respect to price and income: a review. *Transport Reviews,* 24 (3), 275–292.

Graham, D., & Glaister, S. (2004). Road traffic demand elasticity estimates: a review. *Transport Reviews, 24*(3), 261-274.

Government Bill 2005/06: 65, New Road Tax Act.

Greene, D., Kahn, J., & Gibson, R. (1999). Fuel economy rebound effect for US household vehicles. *Energy Journal 20,* 1-31.

Greene, W. (2003). *Econometric analysis 4th ed*: Upper Saddle River, N.J.: Prentice Hall.

Gujarati Damodar, N. (1999). Basic econometrics. *McGraw-Hill Book Company, New York.*

Johansson, O., & Schipper, L. (1997). Measuring the long-run fuel demand of cars: separate estimations of vehicle stock, mean fuel intensity, and mean annual driving distance. *Journal of Transport Economics and Policy, 31*(3), 277-292.

Johnston, J. (2001), Econometric Methods*, McGraw Hill,* Singapore.

Mankiw, N. G., Kneebone, R. D., McKenzie, K. J., & Rowe, N. (1999). Principles of microeconomics. (1st Canadian ed.). *Toronto, Canada: Dryden-Harcourt Brace*.

Ramanathan, R. (1999). Short-and long-run elasticities of gasoline demand in India: An empirical analysis using cointegration techniques. *Energy Economics, 21*(4), 321-330.

Repetto, R., & Institute, W. R. (1992). *Green fees: How a tax shift can work for the environment and the economy*: World Resources Institute.

Schipper, L., & Marie-Lilliu, C. (1999). *Carbon-Dioxide Emissions from Transport in IEA Countries: Recent lessons and long-term challenges*: Swedish Transport and Communications Research Board.

Swedish Energy Agency (2009). Energy Efficiency Policies and Measures in Sweden Monitoring of Energy Efficiency in EU 27, Norway and Croatia

Swedish Energy Agency (2010). Energy in Sweden, annual report.

Swedish Institute for Transport and Communications Analysis (2005), Effect of changes in prices of fuels 1990 – 2005 and the estimated effects in 2010 – 2020, PM 2005:NC4.

Swedish Environmental Protection Agency (1997), Environmental Taxes in Sweden – Economic Instruments of Environmental Policy, Report 4745.

Swedish Environmental Protection Agency (2002), Carbon dioxide-related tax cars (COWI consultant), Report 5187th

Swedish Environmental Protection Agency (2003), Economic instruments in environment, Report 5333rd

Swedish Environmental Protection Agency (2004a), *Styrmedel för ökad utskrotning av gamla bilar (Inregia)*, Report 5414.

Swedish Environmental Protection Agency (2004b), Continuous green tax - proposals for the design, Report 5390th

Swedish Government (GOS) (2009a), An integrated climate and energy policy, a report.

Swedish Government (GOS) (2009b), Sweden Biofuels Annual Report number: SW9008.

Swedish Tax Agency (2005), Guide to excise, Fritzes, Stockholm.

Sterner, T. (1990). *The pricing of and demand for gasoline*: Swedish Transport Research Board [Transportforskningsberedningen].

Sterner, T. (2003). *Policy instruments for environmental and natural resource management*: Rff Press.

Sterner, T. (2007). Fuel taxes: An important instrument for climate policy. *Energy Policy, 35*(6), 3194-3202.

Sterner, T. (2010). Distributional effects of taxing transport fuel. *Energy Policy*.

Sterner, T., & Dahl, C. (1992). Modelling transport fuel demand. *International energy economics*, 65–79.

Sterner, T., Dahl, C., & Franzen, M. (1992). Gasoline tax policy, carbon emissions and the global environment. *Journal of Transport Economics and Policy, 26*(2), 109-119.

Tietenberg, T. H. (1990). Economic instruments for environmental regulation. *Oxford Review of Economic Policy, 6*(1), 17.

U.S. EPA (2005), Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel, EPA420-F-05-001, Office of Transportation and Air Quality. Available at http://www.epa.gov/oms/climate/420f05001.pdf

Others

Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles (1)5.6.2009 EN Official Journal of the European Union L 140/1.