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Do energy taxes decrease carbon dioxide emissions?

Abstract

This paper investigates the environmental effectiveness of the Swedish energy taxes. That is, whether these have decreased the CO_2 emissions and how they have changed the structure of the energy consumption. Time series data for the years 1960-2002 is used. The results show that the oil and coal taxes seem to favour a substitution towards less CO_2 intensive energy sources. For the natural gas tax however, the opposite is true. An energy saving effect is found for the oil tax and the petrol tax, but the electricity tax seems to increase energy consumption. Regarding the total effect on CO_2 emissions, the oil and coal taxes seem to decrease CO_2 emissions while the natural gas tax seems to increase them.

Cross-country regressions are also made to examine if countries with a higher petrol tax have lower a lower rate of CO_2 emissions on average. The results show that a higher petrol tax is significantly correlated to lower CO_2 emissions.

The results thus indicate that energy taxes do decrease CO_2 emissions. They also show that caution should be used before implementing a natural gas tax since it can have adverse effects on the CO_2 emissions.

Keywords: Sweden, OECD, energy taxes, carbon dioxide emissions

Figures and tables

Figure 1: The evolution of GDP per capita and CO_2 emissions per capita

Figure 2: The evolution of total energy consumption and consumption of fossil fuels

Figure 3: The evolution of the CO_2 intensity of the energy consumption

Figure 4: The evolution of the energy intensity of the economy

Figure 5: The evolution of GDP, CO_2 emissions, and energy taxes

Table 1a: How energy taxes affect the CO_2 intensity of the energy consumption

Table 1b: How energy taxes affect the CO_2 intensity of the energy consumption (adjusted for autocorrelation)

Table 2a: How energy taxes affect the energy intensity of the economy

Table 2b: How energy taxes affect the energy intensity of the economy (adjusted for autocorrelation)

Table 3a: How energy taxes affect CO_2 emissions per capita

Table 3b: How energy taxes affect CO_2 emissions per capita (adjusted for autocorrelation)

Table 4: How the petrol tax affect CO_2 emissions, a cross-country study

Abbreviations

CO_2 – Carbon dioxide

GDP – Gross Domestic Product

R&D – Research and development

IMF – International Monetary Fund

OECD – Organisation for Economic Co-operation and Development

Table of contents

1. Introduction 2
2. Theory 3
   2.1 Market failures 3
   2.2 Pigouvian tax 4
   2.3 The double dividend hypothesis 4
   2.4 The carbon tax 5
3. Energy taxes in Sweden 6
   3.1 Energy taxes 6
   3.2 The energy demand in the industry sector 7
   3.3 The energy demand for the households 8
4. Method 9
   4.1 The econometric model 9
   4.2 Data 12
   4.3 Data description 13
5. Results 17
   5.1 The importance of energy taxes in reducing CO_2 emissions per energy unit 17
   5.2 The importance of energy taxes in reducing energy consumption 20
   5.3 The importance of energy taxes in reducing CO_2 emissions 23
   5.4 A cross country study of the petrol tax in the OECD countries 25
6. Analysis and conclusions 27
   6.1 The importance of energy taxes in reducing CO2 emissions per energy unit 27
   6.2 The importance of energy taxes in reducing energy consumption 28
   6.3 The importance of energy taxes in reducing CO_2 emissions 28
   6.4 The environmental effectiveness of the petrol tax in the OECD countries 28
   6.5 Conclusions 29

References 30
   Books and publications 30
   Data and statistics 30

1. Introduction

Global warming is commonly believed to be one of the biggest challenges of this century. It is caused by emissions of greenhouse gases into the atmosphere. Carbon dioxide (CO_2) is the most important greenhouse gas, and therefore it is crucial to reduce the CO_2 emissions. Energy taxes or CO_2 taxes are instruments that are believed to reduce CO_2 emissions.

Sweden is one of the countries that has experimented the most with taxes on petrol, coal, natural gas, electricity, and oil. Already in 1924 the petrol tax was introduced and in the 1957 a tax on oil and coal saw its light. From now on these taxes will be referred to as energy taxes. The question is whether these taxes could be seen as effective environmental instruments when it comes to reducing CO_2 emissions.

The purpose of this study is to evaluate the environmental effectiveness of energy taxes. That is; to investigate if the taxes have decreased the CO_2 emissions and how they have affected the structure of the energy consumption. This will be done through an econometric analysis of time series data for Sweden for the years 1960-2002. It will also be done through an econometric analysis of cross-country data from 2003 for the OECD countries.

The remaining part of this paper is structured as follows: In section 2 the economic theory underlying the environmental taxes will be presented. The problem with public goods and externalities will be examined, and also how to correct for these shortcoming by using Pigouvian taxes. The double dividend theory will be presented also since this is the theory underlying the recent green tax reform in Sweden, where the revenues from environmental taxes has been used to decrease payroll taxes.

Section 3 will present the background concerning the Swedish energy taxes and how the energy system has evolved over time. It will also cover some previous studies concerning the price elasticities of the energy goods. Section 4 will describe how the study will be conducted, which econometric models and what data that will be used. In section 5 the results will be presented and after that they will be analyzed in section 6. Finally some conclusions will be made.

2. Theory

Neoclassical microeconomic theory states that the market mechanism leads to a Pareto optimal allocation of production factors under certain conditions. That is, utility-maximizing behavior of consumers and profit-maximizing behavior of producers will lead to efficiency in production and consumption. For this to be true, these conditions must be satisfied:

-perfect competition
-absence of public goods
-absence of externalities

A Pareto efficient allocation is one where the resources are allocated so that no one can become better off without others becoming worse off.[1] This is rarely satisfied in practice and therefore there is often a need for governmental interventions. Below some of these cases when the market fails in reaching a Pareto efficient allocation will be examined.

2.1 Market failures

If the conditions above are not met the market will fail in reaching a Pareto optimal allocation of resources. This is the case in the existence of public goods or externalities. A public good is a non-excludable and non-rival good, which means that no one can be excluded from consuming the good and one person's consumption does not diminish the amount available to others. Examples of public goods are national defense, clean air and clean water. Since a public good is non-excludable there is no market for it. This means that the good will be underprovided, because marginal benefits will exceed marginal costs, unless the good is provided publicly.[2]

An externality occurs when some costs of producing a good or service are not included in the price. Then the private cost of producing the good is not equal to the public cost. There are both positive and negative externalities. A negative externality implies that the private cost is lower than the social cost; the quantity produced of the good thus becomes too large. For positive externalities the opposite is true; the quantity produced will be too small. An example of a negative externality is air pollution.[3]

[1] Van Ierland, Ekko C., 1993, p. 56.
[2] Van Kooten, G. Cornelis, 2004, p. 17.
[3] Ibid, p. 17.

2.2 Pigouvian tax

To deal with the problems of externalities taxes can be a policy that equalizes marginal private costs to marginal social costs. In many circumstances economists favor taxes to other forms of environmental policies since the information requirements are low, the administration costs are small, and the economic incentives are strong. The theory behind the Pigouvian tax is that the optimal environmental tax rate is equal to the marginal environmental damage from pollution. This principle works well in a situation where no other taxes are available. However, in a more realistic situation where there are other taxes present the situation changes. This is because taxes interact; the gross costs of a new tax depend on existing taxes. Also, the presence of prior distortionary taxes creates the opportunity to use revenues from an environmental tax to cut some of these taxes.[4]

2.3 The double dividend hypothesis

The theory regarding the double dividend of environmental taxes has contributed to a reorientation of the tax system in some countries, with more emphasis on pollution taxes and less on taxes on labor and capital. The theory is that using the income from an environmental tax to decrease a distortionary tax creates a "double dividend". Besides from improving the environment it also reduces the efficiency losses of the tax system. There are different views on the double dividend issue regarding its effectiveness. The weak form of the double dividend is that in reducing a distortionary tax instead of returning the money in a lump sum fashion, one achieves cost savings in that the deadweight losses decrease. A stronger form of the double dividend theory states that using the revenue from an environmental tax involves a zero or negative gross cost. Thus, even without taken into account the better environment the change in the taxation system is still beneficial. However, there has been an intensive debate regarding this strong form of the double dividend and no consensus has been reached.[5]

[4] Folmer, Henry and Tietenberg, Tom, 1997, p. 28-29.
[5] Ibid, p. 30-32.

2.4 The carbon tax

A tax on CO_2 emissions requires domestic emitters to pay a tax for their emissions of CO_2 into the atmosphere. This encourages reductions in the CO_2 emissions in response to the price increase. The emission reductions will take place where the measures to reduce emissions are less expensive than paying the tax. This results in that the least expensive reductions in the economy take place first, until the marginal cost of reducing emissions equals the emission tax. Unlike emission trading, an emission tax does not guarantee a certain level of emissions. Therefore, to meet internationally agreed emission commitments it might be necessary to adjust the tax level. An advantage with the emission tax is that it limits the cost of the emission reduction if the costs would rise unexpectedly high by allowing emissions to rise.[6]

[6] IPCC 2001, section 6.2.2.2.

3. Energy taxes in Sweden

3.1 Energy taxes

Energy taxes have been used in Sweden since 1924, when the petrol tax was introduced. Electricity has been taxed since 1951, and oil and coal since 1957. (SCB) The objective for these taxes was initially financial. But after the energy crisis in the 1970s, energy taxes were increasingly motivated by a desire to decrease the use of fossil fuels. Thus, the expansion of the oil taxes was accompanied by a significant expansion of electricity supply. The objective of this was to promote a different profile of the energy consumption.[7]

Not until the 1980s did environmental concerns enter the debate. This was later followed by the report *"SOU 1990:59"*, in which the Environmental Tax Commission recommended a rich array of environmental taxes. This report made the government propose a tax on CO_2 and sulphur in 1991. The general tax reform in the early 1990s included a reduction of income taxes, which was financed partly by the increased use of environmental and energy taxes.[8]

Concerns regarding international competitiveness led to a reform of the energy taxation in 1993. This implied that the manufacturing industry no longer paid energy tax on the use of fuels and electricity. There was also a reduction in the CO_2 tax for this industry.[9]

The total energy consumption was more or less at the same level in 1974 as 1995, despite the fact that the GDP had risen with about 43%. This implies that the Swedish economy had become less energy intensive. This can be illustrated by the fact that in 1995, the energy it took for the Swedish industry to produce a certain value of output required 33,3% less energy than in 1974.[10]

The composition of the energy consumption has also changed over the years. In 1974 the share of energy in the industry coming from oil was about 50%. But in 1993 the share had fallen to about 20%. At the same time the energy coming from electricity had risen from 50% to 70%.[11]

As noted above, after the energy crisis in the 1970s there was an explicit policy aimed at reducing the dependence on oil. Those policies consisted of taxes on oil as well as of a large increase in the supply

[7] SOU 1997:11, p.62
[8] Ibid, p. 62-63
[9] Ibid, p. 63
[10] Ibid, p. 201
[11] Ibid, p. 201

of electricity coming from nuclear power. This led to significant increases in the price of oil, while the price of electricity only increased slightly.[12]

3.2 The energy demand in the industry sector

The evolution of the energy consumption in the industry sector, where the energy intensity has declined as well as the use of fossil fuels, can probably be explained by the real increase in the energy prices, as well as by the change in relative prices between fossil fuels and electricity, where fossil fuels have become relatively more expensive. In other words, the industry seems to have changed its behavior due to the change in relative prices. It seems that the price elasticity for energy goods is negative, i.e. a price increase for a certain energy good decreases the demand for this good.[13]

Some previous studies have calculated the price elasticities for different energy sources in the industry sector. A price increase of 10% for electricity would decrease the demand for electricity with 0,3% in the short run and 1,4% in the long run. The same price increase for fuels would reduce the demand for fuels with 0,8% in the short run and 3,7% in the long run. A conclusion from these studies is that changes in prices for energy goods have a small, but significant, impact on the demand for energy. Using these results to calculate the impact of a 100% increase of the CO_2 tax, we get the results that the decrease in oil and coal consumption would be around 0,8-3,7%, depending on the time horizon. This would imply that the CO_2 emissions is reduced by around 0,6%.[14]

The demand for energy in the industry sector is quite inelastic, which means that the change in energy demand changes relatively less than the change in price. This is important for the case of environmental taxes. This implies that the tax base is quite solid for the energy sector. However, this also means that if the aim is to reduce the energy consumption in order to reduce emissions, there will only be limited effects on total energy demand. Thus, it will be hard to reduce the emissions by reducing total energy consumption.[15] The cross price elasticities for the energy goods are also quite small, which implies that there are small possibilities in substituting for example fossil fuels for electricity, in the short run.[16]

[12] SOU 1997:11, p. 203-204
[13] Ibid, p. 205
[14] Ibid, p. 210-211
[15] Ibid, p. 207-208
[16] SOU 1997:11, p. 221-224

3.3 The energy demand for the households

Regarding the demand for petrol by the households, previous studies conclude that the price elasticity is quite inelastic in the short run. In the long run the elasticity is slightly larger. One example show that a 100% increase in the CO_2 tax would increase the petrol price by 10%, which in turn would decrease the petrol consumption by 1,5%.[17]

Other studies show that a 100% increase in the CO_2 tax would reduce the households´ consumption of transportation with 2%, and the consumption of heating with 1,5%. The consumption of "other goods" would decline by 1,3%. The total decrease in petrol consumption would be 2%. This implies that the tax base for petrol is solid, which is good if the purpose of the tax is to raise revenue with small costs. However, this also implies that it would take quite large taxes to reach the environmental goals in the transport sector.[18]

One reason for the price inelasticity of the energy goods for the households could be that many energy goods are capital constrained. Examples of this are the choice of car and housing heating system. This implies that in the long run the price elasticity is probably noticeably higher. One important factor for the private energy consumption is the income evolution. Studies show that the petrol consumption increase at the same speed as the income, while the heating consumption increase to a lesser degree. This implies that to stabilize, or decrease, the CO_2 emissions the tax constantly needs to be increased to balance the increase in consumption due to higher income.[19]

[17] Ibid, p. 245-247
[18] Ibid, p. 250
[19] Ibid, p. 254

4. Method

The purpose of this study is to evaluate the environmental effectiveness of the Swedish energy taxes. The environmental effectiveness is defined as the degree to which the taxes help meeting the objective of reducing emissions. Measuring the environmental effectiveness is a key issue in evaluating emission taxes since the effectiveness of these depend on the responses of the polluters to a market signal.[20] The environmental effectiveness can be measured at several levels but in this paper I will use the impact on polluting emissions, measured in physical units.

One potential problem is that economic instruments often are implemented in conjunction with other environmental policy measures. In this case it may be difficult to separate the effect from the economic instrument, i.e. the carbon tax, from the other policy measures.[21]

To evaluate the environmental effectiveness of the energy taxes an econometric model will be used. This model will try to explain the CO_2 emissions using both the energy taxes and other economic variables.

4.1 The econometric model

4.1.1 Time series study (Sweden)

In the following equations time series data from Sweden for the years 1960-2002 will be used. The first equation will try to explain the CO_2 emissions:

$$Z = Z/E * E/Y * Y \quad (1)$$

where *Z* is the CO_2 emissions per capita, *E* is the total energy consumption, and *Y* is the GDP per capita for Sweden measured in US$. The variable *Z/E* states how much CO_2 is emitted for each unit of energy, and the variable *E/Y* states how much energy is used for each unit of GDP. Now we can use these as dependent variables to see how they are affected by the energy taxes.

$$Z/E = f(t_i, T) \quad (2)$$

Equation (2) states that the CO_2 emissions per unit of energy are dependent on the energy taxes and the time, t_i is the variable for the i:th energy tax and T is the time variable. Now we assume the following function:

[20] OECD, 1997, p. 89.
[21] Ibid, p. 90.

$$f(t,T) = A(t) * e^{-dT} \quad (3)$$

where $A(t)=at^{\beta}$, with α, β and d as parameters.

We use the logarithm of this function and get this equation:

$$\ln(Z/E)_n = \ln(a) + \sum_i b_i * \ln(t_{i,n}) - d*T_n + \varepsilon_n \quad (4)$$

where $\ln(Z/E)_n$ is the CO_2 emissions per unit of energy in the n:th year, a, b, and d are parameters, $t_{i,n}$ is the i:th energy tax in the n:th year, T_n is a time variable for the n:th year, and ε_n is the error term. The same procedure is done for the other dependent variable which gives us:

$$\ln(E/Y)_n = \ln(a) + \sum_i b_i * \ln(t_{i,n}) - d*T_n + \varepsilon_n \quad (5)$$

Where $\ln(E/Y)_n$ is the energy use per unit of GDP in the n:th year. The other variables are the same as in equation (4). Since we have a long time span it is important to include the time variable to correct for changes that occur over time, for example technological changes.

Equation (4) is interesting because it tells us whether the energy taxes have affected the structure of the energy sector. The taxes make fossil fuels relatively more expensive than, for example, nuclear power or hydroelectric power. Therefore you might expect that the taxes have decreased the use of fossil fuels and thus decreased the level of CO_2 for each energy unit.

Equation (5) investigates whether the energy taxes have affected the energy use. Since the taxes make fossil energy more expensive one might expect that this translates into energy savings. If we assume that this doesn't affect GDP, the energy use per unit of GDP will decrease. However, we have seen that the price elasticities of the energy goods are quite inelastic. Therefore, we should not expect that the taxes have had a large impact.

Combining the equations above we can arrange an equation where the CO_2 emissions per capita are dependent on the taxes, the GDP level, and the time factor:

$$\ln(Z_n) = \ln(a) + b1*\ln(Y_n) + \sum_i b2_i * \ln(t_{i,n}) - d*T_n + \varepsilon_n \quad (6)$$

As before, Z_n is CO_2 emissions per capita in year n, Y_n is GDP per capita in year n, $t_{i,n}$ is the i:th tax in year n, and T_n is the time factor. We expect to find a positive correlation between CO_2 and GDP since economic growth usually are accompanied with more energy use and more emissions. Regarding the taxes we expect them to have a negative correlation with CO_2 emissions since they make them more

costly. The time factor might be significant if it captures the technological change, then it will probably have a negative sign.

Some autocorrelation corrected regressions will also be made for the equations above to get more precise standard errors. This will be done by using the Newey-West procedure to adjust for the time series persistence in the standard errors estimates.

4.1.2 Cross country study (OECD)

It will be quite hard to separate the effects of the taxes from the effects of other government policies, for example the construction of nuclear plants. Therefore a cross country study will also be performed. This will enable us to make the assumption that everything else is equal in the countries, except for the energy taxes, the CO_2 emissions and some control variables. The equation will look like this:

$$Z_{j,2003} = \ln(a) + b1*\ln(Y_{j,2003}) + b2*\ln(t_{j,2003}) + b3*\ln(v_{j,2003}) + \varepsilon_j \quad (7)$$

where $Z_{j,2003}$ is the CO_2 emissions per capita for the j:th country in the year 2003, $Y_{j,2003}$ is GDP per capita for the j:th country in 2003, $t_{j,2003}$ is the petrol tax for the j:th country in the year 2003, and $v_{j,2003}$ is a vector of control variables for the j:th country in the year 2003. The control variables are: the percentage of energy consumption coming from renewable energy sources, the Gini coefficient, the social expenditures as a share of GDP, and the share of environmental R&D expenditures as a share of GDP. The year 2003 was used because it was the last year for which complete data on CO_2 emissions could be found. The first control variable is included to correct for the fact that some countries have better endowments when it comes to renewable energy, Sweden for example has a lot of potential when it comes to hydro power. The Gini, social expenditures, and R&D variables are included as proxies for the political factor. Assuming that there is a political factor that influences the implementation of environmental policies, these variables would control for the fact that countries with high petrol taxes also might have implemented other environmental policies. The Gini and social expenditure variables could for example catch the difference in environmental friendliness between right wing and left wing governments.

The equation above will tell us whether countries with higher taxes on petrol have a lower level of CO_2 emissions on average. We will assume that all other characteristics are the same to be able to draw conclusions from this regression. The control variables will reduce this risk that the petrol tax catches the effect of political factors.

4.2 Data

4.2.1 Time series data for Sweden

The data for the CO_2 emissions comes from the World Bank[22], the data for the energy taxes comes from *Skatteverket*[23], and the data for energy consumption comes from British Petroleum[24]. The data for GDP per capita and population comes from the research of Angus Maddison at the University of Groningen[25]. All these sources are considered being reliable.

The base year 1960 was chosen because that is the first year from which the World Bank has data on CO_2 emissions. But it is also probably a good year to start with since a lot happened in Sweden during the 1970s when it comes to reducing the CO_2 emissions. The taxes on oil and coal had also earlier been introduced (in 1957). However, when using the energy data, 5 observations will be lost since data on energy consumption is only available from 1965 and onwards. This will be the case for tables 1 and 2.

Regarding the energy taxes in Sweden, sometimes the taxes were changed several times during a certain year. Therefore the tax at the start of the year is used. The taxes that will be used are the petrol tax, oil tax, coal tax, electricity tax and the natural gas tax. Sometimes the taxes are divided in different parts; often one part of the tax is a CO_2 tax for example. The numbers used in this paper will be the total amount of tax on the different energy sources.

4.2.2 Cross country data for OECD

Regarding the cross-country study, the data on CO_2 emissions, petrol tax, social expenditures, and gini coefficient all come from the OECD[26]. The data for the petrol tax also comes from the OECD[27]. The data on energy coming from renewable sources comes from British Petroleum[28]. Both these sources are considered being reliable.

[22] The World Bank Group, 2007, ”World Development Indicators Online”.
[23] Skatteverket, ”Historik skattesatser”.
[24] British Petroleum, ”Historical data series”.
[25] Maddison, Angus, 2007, ”World Population, GDP and Per Capita GDP, 1-2003 AD”.
[26] IEA/OECD, 2005. ”CO2 emissions from fuel combustion”.
[27] OECD, 2005. “Tax rates for unleaded petrol”.
[28] British Petroleum, ”Historical data series”.

4.3 Data description

4.3.1 An overview of the development in Sweden since the 1960s

This figure shows clearly how Sweden has managed to break the correlation between economic growth and CO_2 emissions. The following figures will hopefully explain better how this was achieved, using data from the World Bank, British Petroleum, Skatteverket, and the research of Angus Maddison.

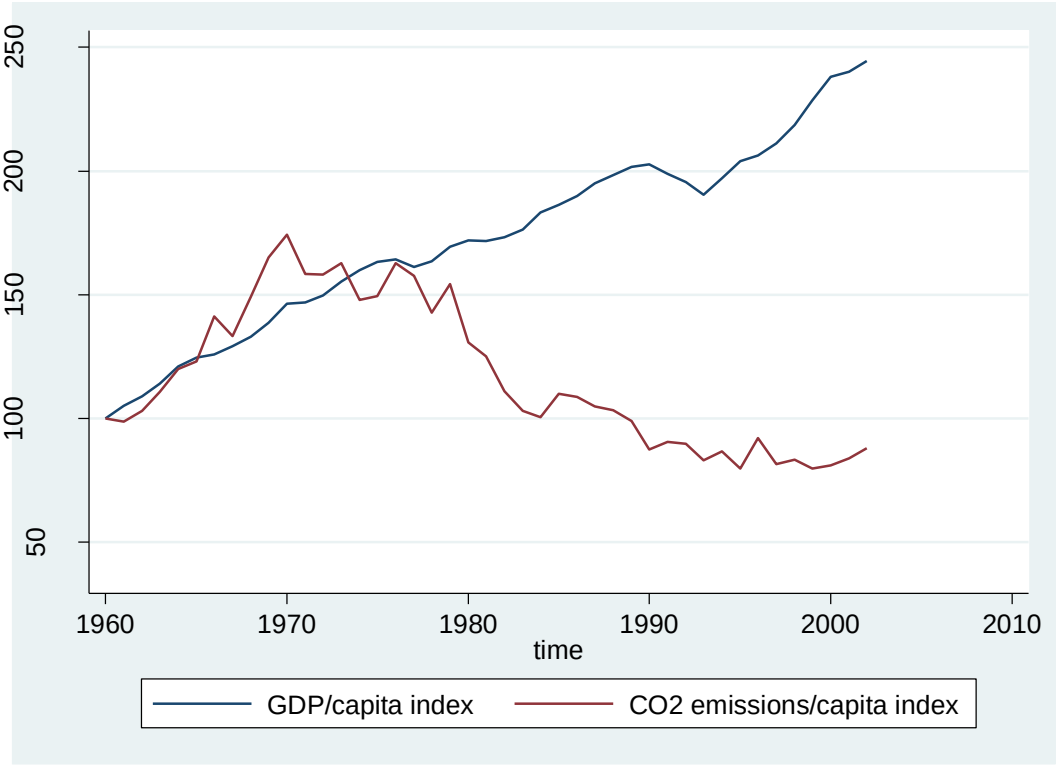

Figure 1: The evolution of GDP per capita and CO_2 emissions per capita in Sweden

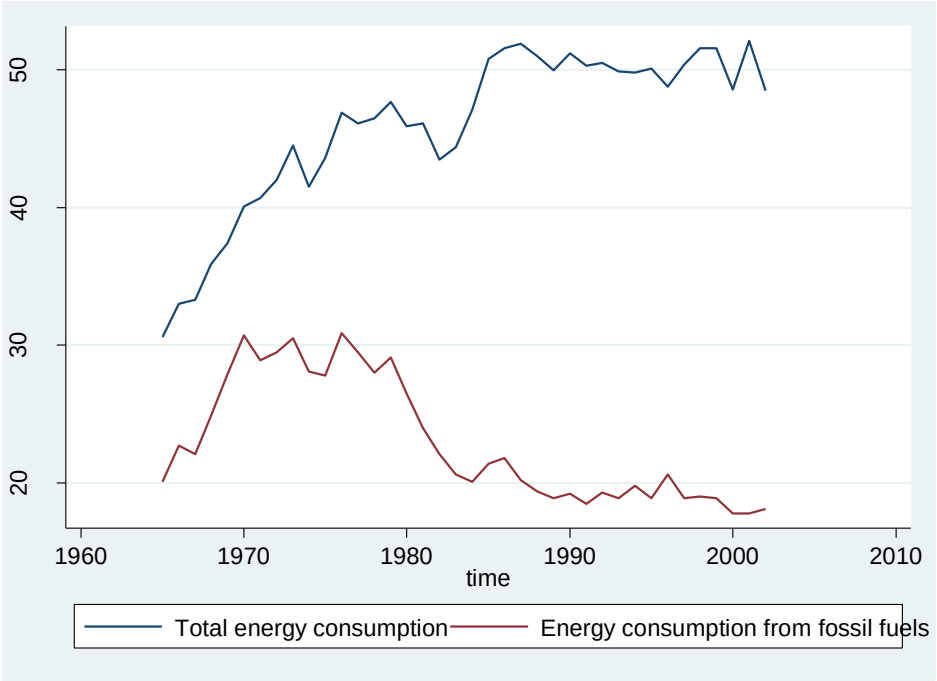

Figure 2: The evolution of total energy consumption and consumption of fossil fuels in Sweden

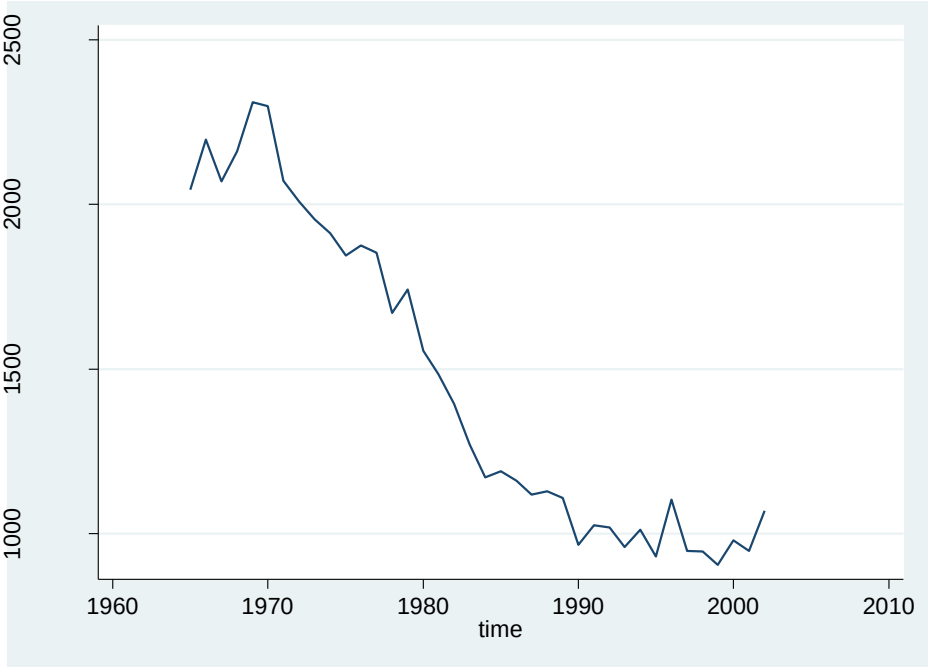

Figure 3: The evolution of the CO_2 intensity of the Swedish energy consumption

Figures 2 and 3 show that one reason behind the decrease in CO_2 emissions is that there has been a shift away from fossil fuels. Figure 2 shows that in the 70s and 80s the total energy consumption increased while the energy consumption from fossil fuels decreased. The result from this, which is

very obvious in Figure 3, is that the CO_2 emissions per energy unit decreased a lot during these two decades. This seems to be a main reason for the decrease in total CO_2 emissions.

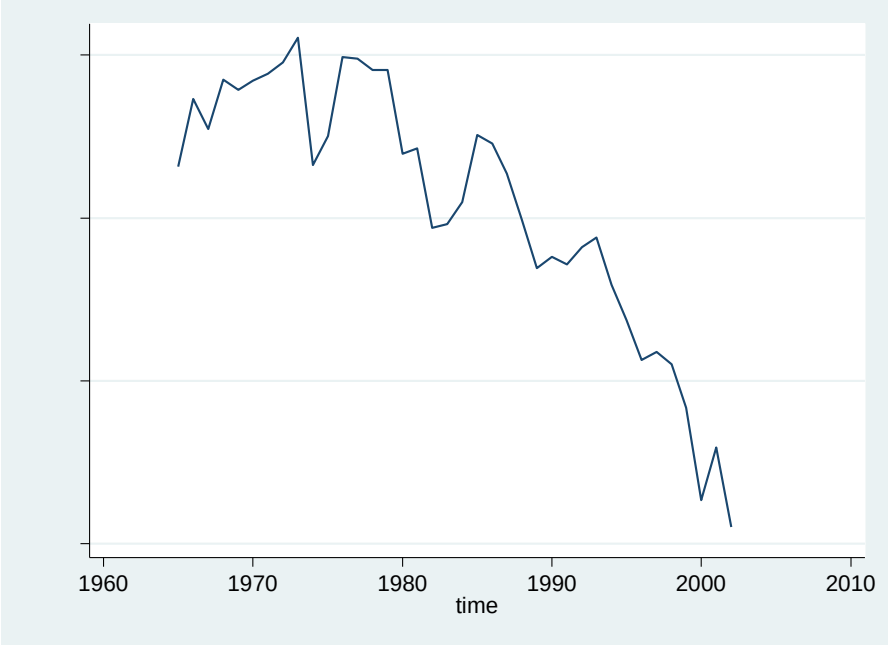

Figure 4: The evolution of the energy intensity of the Swedish economy

In Figure 2 we saw that the total energy consumption increased steadily until mid 80s. After that the energy consumption remained constant more or less. Since the GDP has increased steadily even after that, the result is that the energy it takes to produce one unit of GDP has decreased a lot since the mid 80s. This is visible in Figure 4 and seems to be another reason for the divergence between GDP and CO_2 emissions. The question of what caused the CO_2 intensity in the energy sector to decrease, and the energy required to produce a unit of GDP to decrease, remains an open issue however.

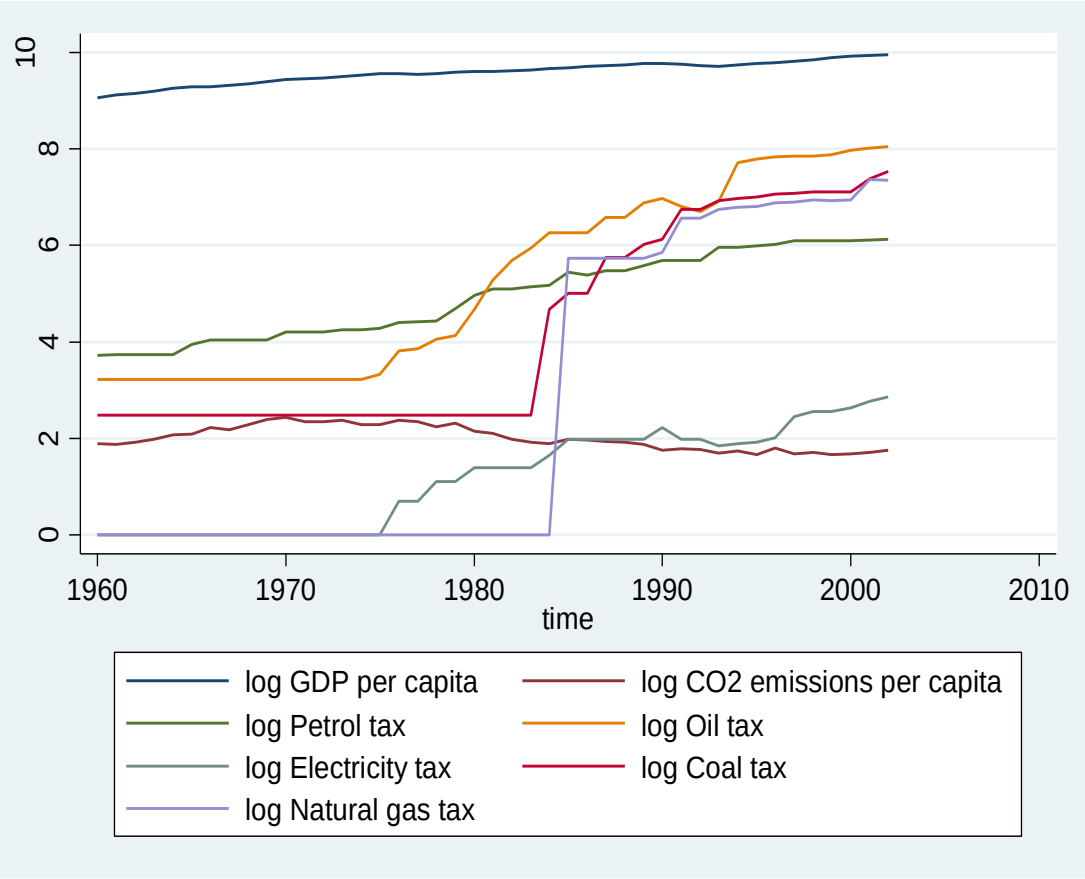

Figure 5: The evolution of GDP, CO_2 emissions, and energy taxes in Sweden

Figure 5 shows the evolution of GDP per capita, CO_2 emissions per capita, and the energy taxes. There seem to be a correlation between the energy taxes. We also note that when the energy taxes increase, the CO_2 emissions seem to decrease. Whether this is a statistically significant correlation will be investigated in the upcoming regressions.

5. Results

5.1 The importance of energy taxes in reducing CO_2 emissions per energy unit

One characteristic of taxes on fossil fuels is that they make fossil fuels relatively more expensive compared to other energy sources. This might result in a change towards other energy sources that emit less, or no, carbon dioxide. Thus, you might expect a negative correlation between the taxes on fossil fuels and the CO_2 intensity of the energy consumption. The electricity tax will not be included in these regressions since it is a general tax and doesn't alter the relative prices between different energy sources.

In table 1a the results from the regressions are presented. First the model will be estimated using the energy taxes separately. Then the model will be estimated as in equation (4), using all the energy taxes simultaneously. The energy taxes will be added gradually, to be able to identify changes that occur when new variables are included. The estimates for the energy taxes when included separately are interesting, although the main results are the ones in the last regression when all the variables are included. The cross-term variables are included to correct for the fact that the energy taxes are correlated to each other.

Table 1a: How energy taxes affect the CO_2 intensity of the energy consumption

	Dependent variable: log (CO2 emissions / energy consumption)							
Independent variables	1	2	3	4	5	6	7	8
time	-0.028***	-0.003	0.006	-0.022***	-0.023***	-0.000	-0.012*	-0.015**
	[0.001]	[0.004]	[0.006]	[0.004]	[0.003]	[0.005]	[0.007]	[0.006]
log Oil tax		-0.153***				-0.259***	-0.076	-1.000*
		[0.026]				[0.077]	[0.307]	[0.539]
log Petrol tax			-0.488***			-0.363***	0.275	-0.406
			[0.080]			[0.128]	[0.294]	[1.182]
log petrol tax * log oil tax						0.033***	-0.042	-0.048
						[0.012]	[0.065]	[0.074]
log Coal tax				-0.036*			-0.216	-4.189
				[0.019]			[0.295]	[2.496]
log oil tax * log coal tax							0.062**	0.445**
							[0.025]	[0.165]
log petrol tax * log coal tax							-0.034	0.267
							[0.057]	[0.473]
log Natural gas tax					-0.020*			2.830
					[0.011]			[1.701]
log oil tax * log natural gas tax								-0.249**
								[0.106]
log coal tax * log natural gas tax								-0.002
								[0.017]
log petrol tax * log natural gas tax								-0.236
								[0.300]
Constant	62.737***	13.558	-2.250	50.193***	52.344***	10.250	30.888**	47.482***
	[2.880]	[8.734]	[10.878]	[7.215]	[6.248]	[10.447]	[12.197]	[14.139]
Observations	38	38	38	38	38	38	38	38
R-squared	0.91	0.95	0.96	0.92	0.92	0.97	0.98	0.98
Standard errors in brackets								
* significant at 10%; ** significant at 5%; *** significant at 1%								
Source: The World Bank, Skatteverket, British Petroleum, and Angus Maddison								

The results in Table 1a show that the time factor seems to be negatively correlated to the CO_2 intensity of the energy consumption. The CO_2 intensity falls as time goes by, maybe due to technological progress. When all the variables are included the time factor is significant at the 5% level.

The oil tax also seems to be negatively correlated to the CO_2 emissions per energy unit. Without other energy taxes, the oil tax is significant at the 1% level. When all the variables are included it is significant at the 10% level. It thus seems that the oil tax decreases the CO_2 intensity per energy unit.

The petrol tax is negatively correlated to the CO_2 emissions per energy unit at the 1% level when there are no other energy taxes included. When all the variables are included the petrol tax is no longer significant. It seems that the petrol tax does not have an effect on the CO_2 emissions per energy unit, maybe because historically there haven't been many substitution possibilities to using petrol in cars.

The coal tax and natural gas tax are negatively correlated to the CO_2 emissions per energy unit at the 10% level when no other energy taxes are included. However, when all the variables are included there is no significant correlation.

Table 1b below is similar to the previous table, except that it will correct for autocorrelation to get more precise standard errors. This might also change the significance level of some variables since this depends on the standard errors.

Table 1b: How energy taxes affect the CO_2 intensity of the energy consumption (adjusted for autocorrelation)

	Dependent variable: log (CO2 emissions / energy consumption)							
Independent variables	1	2	3	4	5	6	7	8
time	-0.028***	-0.003	0.006	-0.022***	-0.023***	-0.000	-0.012*	-0.015**
	[0.002]	[0.006]	[0.007]	[0.005]	[0.005]	[0.006]	[0.006]	[0.006]
log Oil tax		-0.153***				-0.259***	-0.076	-1.000***
		[0.030]				[0.043]	[0.277]	[0.334]
log Petrol tax			-0.488***			-0.363*	0.275	-0.406
			[0.101]			[0.212]	[0.167]	[0.629]
log petrol tax * log oil tax						0.033***	-0.042	-0.048
						[0.010]	[0.056]	[0.063]
log Coal tax				-0.036			-0.216	-4.189***
				[0.026]			[0.258]	[1.233]
log oil tax * log coal tax							0.062***	0.445***
							[0.015]	[0.070]
log petrol tax * log coal tax							-0.034	0.267
							[0.040]	[0.245]
log Natural gas tax					-0.020			2.830***
					[0.017]			[0.759]
log oil tax * log natural gas tax								-0.249***
								[0.045]
log coal tax * log natural gas tax								-0.002
								[0.010]
log petrol tax * log natural gas tax								-0.236
								[0.140]
Constant	62.737***	13.558	-2.250	50.193***	52.344***	10.250	30.888**	47.482***
	[4.892]	[11.317]	[13.798]	[10.298]	[10.406]	[11.115]	[12.039]	[12.115]
Observations	38	38	38	38	38	38	38	38
Standard errors in brackets								
* significant at 10%; ** significant at 5%; *** significant at 1%								
Source: The World Bank, Skatteverket, British Petroleum, and Angus Maddison								

As we can see, correcting for autocorrelation changes the results noticeably. The oil tax is now significant at the 1% level when all the variables are included. This strongly suggests that the oil tax decreases the CO_2 intensity of the energy consumption. A 1% increase in the oil tax would decrease the CO_2 emissions per energy unit by 1%, ceteris paribus.

The coal and natural gas taxes are also significant at the 1% level. There seem to be a strong negative correlation between the coal tax and the CO_2 emissions per energy unit. Thus, the coal tax also seems

to decrease the CO_2 intensity of the energy consumption. A 1% increase in the coal tax would imply a 4,19% decrease in the CO_2 emissions per energy unit, ceteris paribus.

The natural gas tax however is positively correlated to the CO_2 intensity. A 1% increase in the natural gas tax would increase the CO_2 emissions per energy unit by 2,83%, ceteris paribus. This is quite unexpected; the tax on natural gas seems to increase the CO_2 emissions per energy unit. One explanation could be that this tax increases the consumption of oil and coal at the expense of natural gas. This would increase total CO_2 emissions since oil and coal emit more CO_2 per energy unit than natural gas.

5.2 The importance of energy taxes in reducing energy consumption

The next two tables are based on equation 5. They investigate whether the energy taxes have had an impact on energy consumption per GDP unit. Since these taxes make energy more expensive it is reasonable to expect a negative correlation between the energy taxes and the energy intensity of the economy.

Table 2a: How energy taxes affect the energy intensity of the economy

	Dependent variable: log (energy consumption / GDP)									
Independent variables	1	2	3	4	5	6	7	8	9	10
time	-0.009***	-0.008*	-0.015***	-0.013***	-0.007***	-0.009***	-0.010**	-0.013**	-0.011	-0.014*
	[0.001]	[0.004]	[0.005]	[0.003]	[0.002]	[0.002]	[0.004]	[0.005]	[0.007]	[0.007]
log Oil tax		-0.010					0.129**	-0.305	-1.850***	-1.108
		[0.023]					[0.054]	[0.185]	[0.587]	[1.163]
log Petrol tax			0.078				0.402***	0.311*	-0.550*	-0.962
			[0.070]				[0.090]	[0.166]	[0.317]	[1.312]
log petrol tax * log oil tax							-0.040***	0.034	0.392***	0.315
							[0.008]	[0.028]	[0.139]	[0.229]
log Electricity tax				0.040				0.939**	2.520***	3.443**
				[0.035]				[0.431]	[0.663]	[1.301]
log petrol tax * log electricity tax								-0.225*	-0.583***	-0.492**
								[0.124]	[0.186]	[0.222]
log oil tax * log electricity tax								0.042	-0.018	-0.116
								[0.045]	[0.099]	[0.122]
log Coal tax					-0.012				0.867*	0.711
					[0.012]				[0.445]	[2.065]
log oil tax * log coal tax									-0.074***	-0.161
									[0.024]	[0.110]
log electricity tax * log coal tax									0.145	-0.289
									[0.088]	[0.376]
log petrol tax * log coal tax									-0.119	0.165
									[0.098]	[0.528]
log Natural gas tax						-0.000				-0.172
						[0.007]				[1.346]
log oil tax * log natural gas tax										0.073
										[0.076]
log electricity tax * natural gas tax										0.346
										[0.250]
log coal tax * log natural gas tax										-0.003
										[0.014]
log petrol tax * log natural gas tax										-0.168
										[0.338]
Constant	3.667**	0.587	14.105	10.384	-0.495	3.541	2.768	10.792	9.782	13.246
	[1.773]	[7.511]	[9.436]	[6.193]	[4.599]	[4.032]	[7.309]	[10.381]	[12.869]	[14.737]
Observations	38	38	38	38	38	38	38	38	38	38
R-squared	0.75	0.75	0.76	0.76	0.76	0.75	0.88	0.91	0.96	0.97
Standard errors in brackets										
* significant at 10%; ** significant at 5%; *** significant at 1%										
Source: The World Bank, Skatteverket, British Petroleum, and Angus Maddison										

The results show that there does not seem to be any significant negative correlation between the energy taxes and the energy intensity of the economy. The electricity tax is even positively correlated to the energy use per unit of GDP, significant at the 5% level. All this is quite unexpected, but maybe the results will change when we correct for autocorrelation in the next table.

Table 2b: How energy taxes affect the energy intensity of the economy (adjusted for autocorrelation)

	Dependent variable: log (energy consumption / GDP)									
Independent variables	1	2	3	4	5	6	7	8	9	10
time	-0.009***	-0.008	-0.015	-0.013***	-0.007*	-0.009**	-0.010	-0.013*	-0.011	-0.014
	[0.002]	[0.008]	[0.010]	[0.005]	[0.004]	[0.004]	[0.007]	[0.007]	[0.008]	[0.010]
log Oil tax		-0.010					0.129**	-0.305*	-1.850***	-1.108**
		[0.038]					[0.056]	[0.158]	[0.317]	[0.466]
log Petrol tax			0.078				0.402**	0.311	-0.550**	-0.962**
			[0.136]				[0.148]	[0.194]	[0.224]	[0.388]
log petrol tax * log oil tax							-0.040***	0.034	0.392***	0.315***
							[0.011]	[0.021]	[0.080]	[0.096]
log Electricity tax				0.040				0.939**	2.520***	3.443***
				[0.040]				[0.395]	[0.555]	[0.891]
log petrol tax * log electricity tax								-0.225*	-0.583***	-0.492**
								[0.116]	[0.168]	[0.179]
log oil tax * log electricity tax								0.042	-0.018	-0.116
								[0.044]	[0.070]	[0.098]
log Coal tax					-0.012				0.867***	0.711
					[0.018]				[0.279]	[0.822]
log oil tax * log coal tax									-0.074***	-0.161***
									[0.013]	[0.054]
log electricity tax * log coal tax									0.145**	-0.289**
									[0.070]	[0.118]
log petrol tax * log coal tax									-0.119**	0.165
									[0.058]	[0.224]
log Natural gas tax						-0.000				-0.172
						[0.011]				[0.345]
log oil tax * log natural gas tax										0.073**
										[0.034]
log electricity tax * natural gas tax										0.346**
										[0.125]
log coal tax * log natural gas tax										-0.003
										[0.007]
log petrol tax * log natural gas tax										-0.168
										[0.123]
Constant	3.667	0.587	14.105	10.384	-0.495	3.541	2.768	10.792	9.782	13.246
	[3.745]	[15.050]	[20.076]	[9.134]	[8.048]	[7.875]	[12.618]	[13.087]	[15.715]	[20.369]
Observations	38	38	38	38	38	38	38	38	38	38
Standard errors in brackets										
* significant at 10%; ** significant at 5%; *** significant at 1%										
Source: The World Bank, Skatteverket, British Petroleum, and Angus Maddison										

Correcting for autocorrelation changes the results remarkably. The electricity tax becomes even more significant, now at the 1% level. And the oil and petrol tax are now significant at the 5% level. Both are negatively correlated to the energy consumption per unit of GDP. It thus seems that the oil and petrol tax decrease the energy intensity in the economy. A 1% increase in the oil tax would imply a 1,11% decrease of the energy consumption per GDP unit. The figure for the petrol tax is almost as high. For electricity, a 1% increase in the tax would increase the energy consumption per GDP unit with 3,44%.

5.3 The importance of energy taxes in reducing CO_2 emissions

The following two tables will investigate whether the energy taxes are correlated to the CO_2 emissions per capita. They are based on equation (6). We have seen earlier that the oil and coal tax decrease the CO_2 emissions per energy unit, while the opposite is true for the natural gas tax. We have also seen that the oil and petrol tax seem to decrease total energy consumption, while the electricity tax seems to increase the energy consumption. Now let's see how the energy taxes affect the CO_2 emissions per capita.

Table 3a: How energy taxes affect CO_2 emissions per capita

	Dependent variable: log CO2 emissions per capita									
Independent variables	1	2	3	4	5	6	7	8	9	10
log GDP per capita	2.834***	1.572***	2.433***	2.550***	2.298***	2.523***	1.453***	1.248**	1.429**	1.721**
	[0.299]	[0.280]	[0.322]	[0.264]	[0.376]	[0.346]	[0.362]	[0.517]	[0.637]	[0.711]
time	-0.065***	-0.015*	-0.037***	-0.045***	-0.048***	-0.055***	-0.019	-0.028**	-0.039*	-0.049**
	[0.006]	[0.008]	[0.012]	[0.007]	[0.009]	[0.008]	[0.012]	[0.013]	[0.021]	[0.024]
log Oil tax		-0.184***					-0.200**	-1.087***	-2.106*	-2.915
		[0.028]					[0.096]	[0.258]	[1.239]	[2.435]
log Petrol tax			-0.307**				0.221*	0.161	-0.241	-0.464
			[0.121]				[0.124]	[0.256]	[0.611]	[2.860]
log petrol tax * log oil tax							-0.006	0.135***	0.410	0.396
							[0.016]	[0.047]	[0.288]	[0.483]
log Electricity tax				-0.190***				2.159***	3.033**	3.460
				[0.047]				[0.572]	[1.121]	[2.615]
log petrol tax * log electricity tax								-0.564***	-0.728**	-0.720*
								[0.170]	[0.284]	[0.372]
log oil tax * log electricity tax								0.148**	-0.064	-0.114
								[0.072]	[0.183]	[0.244]
log Coal tax					-0.049**				0.616	-2.216
					[0.022]				[0.957]	[4.410]
log oil tax * log coal tax									-0.028	0.362
									[0.048]	[0.233]
log electricity tax * log coal tax									0.251	0.126
									[0.179]	[0.813]
log petrol tax * log coal tax									-0.159	-0.041
									[0.208]	[1.124]
log Natural gas tax						-0.020*				1.836
						[0.012]				[2.881]
log oil tax * log natural gas tax										-0.254
										[0.162]
log electricity tax * natural gas tax										0.108
										[0.541]
log coal tax * log natural gas tax										-0.001
										[0.030]
log petrol tax * log natural gas tax										-0.079
										[0.721]
Constant	102.921***	17.220	52.776**	66.557***	74.664***	85.858***	25.830	47.212**	67.619*	92.400*
	[8.182]	[14.006]	[21.252]	[11.416]	[15.038]	[12.880]	[21.387]	[22.700]	[36.580]	[44.959]
Observations	43	43	43	43	43	43	43	43	43	43
R-squared	0.84	0.92	0.86	0.89	0.86	0.85	0.93	0.95	0.96	0.96
Standard errors in brackets										
* significant at 10%; ** significant at 5%; *** significant at 1%										
Source: The World Bank, Skatteverket, and Angus Maddison										

There is a strong positive correlation, significant at the 5% level, between GDP per capita and CO_2 emissions per capita. A 1% increase in GDP per capita would imply a 1,72% increase in the CO_2 emissions.

The time factor seems to decrease CO_2 emissions, maybe thanks to technological progress. These results are significant at the 5% level.

All the energy taxes are significantly negatively correlated to the CO_2 emissions per capita when there are no other energy taxes included in the regressions. However, when all are included, none of the energy taxes are significantly correlated to the CO_2 emissions per capita. This is quite surprising considering the previous results. The next table will show if the results change when we correct for autocorrelation.

Table 3b: How energy taxes affect CO_2 emissions per capita (adjusted for autocorrelation)

	Dependent variable: log CO2 emissions per capita									
Independent variables	1	2	3	4	5	6	7	8	9	10
log GDP per capita	2.834***	1.572***	2.433***	2.550***	2.298***	2.523***	1.453***	1.248**	1.429**	1.721**
	[0.487]	[0.209]	[0.520]	[0.306]	[0.618]	[0.541]	[0.384]	[0.463]	[0.574]	[0.638]
time	-0.065***	-0.015***	-0.037**	-0.045***	-0.048***	-0.055***	-0.019	-0.028**	-0.039	-0.049*
	[0.009]	[0.005]	[0.016]	[0.009]	[0.016]	[0.013]	[0.013]	[0.012]	[0.023]	[0.025]
log Oil tax		-0.184***					-0.200*	-1.087***	-2.106***	-2.915*
		[0.019]					[0.109]	[0.201]	[0.652]	[1.485]
log Petrol tax			-0.307**				0.221*	0.161	-0.241	-0.464
			[0.127]				[0.119]	[0.164]	[0.350]	[1.314]
log petrol tax * log oil tax							-0.006	0.135***	0.410**	0.396
							[0.020]	[0.037]	[0.151]	[0.311]
log Electricity tax				-0.190***				2.159***	3.033***	3.460
				[0.066]				[0.437]	[0.776]	[2.073]
log petrol tax * log electricity tax								-0.564***	-0.728***	-0.720**
								[0.118]	[0.197]	[0.274]
log oil tax * log electricity tax								0.148***	-0.064	-0.114
								[0.048]	[0.110]	[0.145]
log Coal tax					-0.049				0.616	-2.216*
					[0.036]				[0.562]	[1.208]
log oil tax * log coal tax									-0.028	0.362***
									[0.022]	[0.100]
log electricity tax * log coal tax									0.251*	0.126
									[0.130]	[0.350]
log petrol tax * log coal tax									-0.159	-0.041
									[0.109]	[0.314]
log Natural gas tax						-0.020				1.836*
						[0.020]				[0.934]
log oil tax * log natural gas tax										-0.254***
										[0.075]
log electricity tax * natural gas tax										0.108
										[0.298]
log coal tax * log natural gas tax										-0.001
										[0.020]
log petrol tax * log natural gas tax										-0.079
										[0.236]
Constant	102.921***	17.220**	52.776**	66.557***	74.664***	85.858***	25.830	47.212**	67.619	92.400*
	[13.007]	[7.839]	[26.065]	[15.371]	[25.532]	[21.306]	[22.735]	[21.079]	[40.971]	[47.121]
Observations	43	43	43	43	43	43	43	43	43	43
Standard errors in brackets										
* significant at 10%; ** significant at 5%; *** significant at 1%										
Source: The World Bank, Skatteverket, and Angus Maddison										

Correcting for autocorrelation did change the results. Now the oil tax is negatively correlated to CO_2 emissions per capita, significant at the 10% level. A 1% increase in the oil tax would decrease the CO_2 emissions per capita by 2,92%, ceteris paribus.

The coal tax is also negatively correlated to the CO_2 emissions per capita, significant at the 10% level. A 1% increase in the coal tax would decrease the CO_2 emissions per capita by 2,22%, ceteris paribus. Thus, it seems that the oil and coal tax have reduced the Swedish CO_2 emissions.

The natural gas tax is positively correlated to the CO_2 emissions per capita, significant at the 10% level. A 1% increase in the natural gas tax would increase the CO_2 emissions per capita by 1,84%, ceteris paribus.

The petrol tax and electricity tax do not seem to be correlated to the CO_2 emissions per capita when we include all the variables.

5.4 A cross country study of the petrol tax in the OECD countries

This regression is based on equation (7) and uses data from the year 2003. It will investigate whether countries with a high petrol tax have lower CO_2 emissions on average. Some control variables will be included as proxies for the political factor. We will assume that all other factors are equal.

Table 4: How the petrol tax affect CO_2 emissions, a cross-country study

	Dependent variable: log CO2 emissions per capita					
Independent variables	1	2	3	4	5	6
log Petrol tax	-0.368**	-0.414***	-0.409***	-0.465***	-0.457***	-0.434***
	[0.160]	[0.130]	[0.122]	[0.105]	[0.108]	[0.133]
log GDP per capita		0.320***	0.351***	0.154	0.187	0.161
		[0.082]	[0.082]	[0.136]	[0.148]	[0.147]
log % renewables			-0.116**	-0.113**	-0.102**	-0.081
			[0.048]	[0.043]	[0.047]	[0.049]
log R&D env. expenditures				0.078	0.092	0.145
				[0.079]	[0.084]	[0.092]
log Social expenses					-0.103	-0.642
					[0.168]	[0.403]
log Gini coefficient						-0.844*
						[0.471]
Constant	1.872***	3.137***	3.042***	2.191***	2.646***	7.083**
	[0.163]	[0.348]	[0.353]	[0.511]	[0.910]	[2.513]
Observations	29	29	28	23	23	21
R-squared	0.16	0.48	0.58	0.64	0.65	0.72
Standard errors in brackets						
* significant at 10%; ** significant at 5%; *** significant at 1%						
Source: OECD and British Petroleum						

There is a strong negative correlation, significant at the 1% level, between the petrol tax and CO_2 emissions per capita. A 1% increase in the petrol tax seems to decrease CO_2 emissions by 0,43%, ceteris paribus. The first regression shows that the petrol tax alone explains 16% of the variation in

CO_2 emissions. These results strongly suggest that it is possible to decrease CO_2 emissions by increasing the petrol tax.

There is a positive correlation between GDP per capita and CO_2 emissions per capita, as expected. However, in the last regressions the correlation is not statistically significant. There is a negative correlation between the share of energy coming from renewable energy sources and CO_2 emissions, also expected. However, neither this correlation is significant in the last regressions.

There is a positive correlation between the share of environmental R&D as a percentage of GDP and CO_2 emissions per capita. However, this correlation is not statistically significant so these results won't be further analysed. Both the social expenditures and Gini coefficient variables are negatively correlated to CO_2 emissions per capita. The Gini coefficient is even significant at the 10% level. This could be because of the political factor that was discussed above.

6. Analysis and conclusions

6.1 The importance of energy taxes in reducing CO2 emissions per energy unit

When it comes to the structure of the energy consumption, the results show that the oil tax and the coal tax are efficient taxes if the aim is to decrease the amount of CO_2 emissions per energy unit. It seems that these taxes have induced a shift away from CO_2 intensive sources. Previous studies have found that the cross price elasticities between the energy goods are quite low. However, these results indicate that there are substitution possibilities between the energy goods and that energy taxes can be an efficient instrument when it comes to altering the structure of the energy consumption.

One potential problem is that several environmental policies often are implemented at the same time. Thus, it might be hard to separate the effect of energy taxes from other measures. For this case, one problem is that the energy taxes (in particular the oil tax) were accompanied by an increase in the electricity coming from nuclear power. This increase was not provoked by the energy taxes; it was an effect of the government's plan to decrease the dependence on oil. Therefore, what might seem to be an effect of the oil tax is possibly an effect of this government policy. However, it is hard to control for this without completely taking away the substitution effect of the energy taxes.

The fact that the natural gas tax seems to increase the CO_2 intensity of the energy consumption is interesting. As noted above, one explanation could be that the tax doesn't shift the demand in favour of energy sources with less CO_2 emissions per energy unit, but rather the contrary. If there are few substitution alternatives with low CO_2 emissions, the tax might make oil and coal more attractive at the expense of natural gas. Since oil and coal have a higher degree of CO_2 emissions per energy unit, this would increase the CO_2 intensity of the energy consumption. Thus, it seems that the natural gas tax has an adverse effect in that it increases the CO_2 emissions per energy unit. Therefore, a tax on natural gas should be preceded by an evaluation of the possible consequences of the tax. If there are no feasible substitution alternatives with low CO_2 emissions, the tax will probably have an adverse effect and increase the CO_2 emissions instead of decreasing them.

6.2 The importance of energy taxes in reducing energy consumption

The results imply that the oil tax and coal tax have contributed to decrease the energy intensity in the economy. Assuming that these taxes do not affect the growth in GDP, this is equal to stating that these taxes have decreased the total energy consumption. Previous studies show that the price elasticities of the energy goods are quite inelastic. However, these two taxes do seem to lower the demand for energy in a substantial way.

6.3 The importance of energy taxes in reducing CO_2 emissions

The results suggest that the oil tax and coal tax have decreased the CO_2 emissions per capita. For the oil tax this is probably due to both the substitution effect (shown in table 1) and the energy saving effect (shown in table 2). For the coal tax this is probably due to the substitution effect (shown in Table 1).

The petrol tax has not decreased the CO_2 emissions, even though we found an energy saving effect in Table 2. Neither the electricity tax has had any effects on the CO_2 emissions per capita.

The natural gas tax actually seems to have increased the CO_2 emissions per capita. This is probably due to the substitution effect shown in table 1. These findings could be of importance for other countries that are considering a tax on natural gas. Further research should be conducted before implementing similar taxes in the future.

6.4 The environmental effectiveness of the petrol tax in the OECD countries

The results in Table 4 show that the petrol tax seems to be an effective instrument in decreasing CO_2 emissions. This implies that it is possible to decrease CO_2 emissions using a petrol tax.

However, it is reasonable to believe that countries with a high tax on petrol are quite environmentally friendly, and that they might have implemented other environmental policies as well. The result might be that it is not the petrol tax that decreases CO_2 emissions but other environmental instruments. The cross-country model has reduced this problem by including some political variables that might capture these other effects. And even if there are other environmental policies that are the real reason behind the lower CO_2 emissions, the results would still be of importance since they show that it is possible to decrease CO_2 emissions using proper policies.

6.5 Conclusions

The results in this paper indicate that it is possible to decrease CO_2 emissions with the use of energy taxes. The oil tax and coal tax have probably contributed to the reduction in CO_2 emissions in Sweden during the past decades. This is mostly due to the substitution effect towards less CO_2 intensive energy sources, but an energy saving effect has also been found for the oil tax. The results also indicate that taxes on natural gas should be used with caution; they might actually increase CO_2 emissions. The effect of the natural gas tax on CO_2 emissions would be an interesting topic for future research.

One limitation to these results is that the models fail to take into account the expansion of the nuclear energy that accompanied the increase in the oil tax. Controlling for this might yield different results, especially regarding the tax on oil.

The cross-country studies show that countries with a high petrol tax have significantly lower CO_2 emissions. These results hold even after controlling for some political factors. However, it is still possible that there are other political factors that are the real reason behind the lower CO_2 emissions. In any case, the results still show that it is possible to reduce CO_2 emissions by using the right policies.

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