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The Distributional Effects of a Carbon Tax: The Role of Income Inequality

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September 2020

Abstract

This paper addresses the question of the distributional burden of a carbon tax. It shows that, not only the income measure – annual or lifetime – matters for the incidence of the tax, but also the underlying distribution of income. The Swedish carbon tax on transport fuel is regressive between 1999-2012 when measured against annual income, but progressive when using lifetime income. The overall trend, however, is toward an increase in regressivity, which is highly correlated with a rise in income inequality. Analysis of the determinants of distributional effects lends support to our hypothesis that, for necessities – goods with an income elasticity below one – rising income inequality increases the regressivity of a consumption tax. To mitigate climate change, a carbon tax should be applied to goods that typically are necessities: transport fuel, food, heating, and electricity. Carbon taxation will thus likely be regressive in high-income countries, the more so the more unequal the distribution of income.

JEL classification:

Keywords: Carbon tax, distributional effects, income inequality, climate change

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1 Introduction

To mitigate climate change, economists recommend putting a price on carbon emissions, preferably using a carbon tax (Akerlof et al., 2019). That a carbon tax is an environmentally and economically efficient instrument is often highlighted, but the equity story is also of importance: who bears the burden of the tax?

A stylized fact in economics is that carbon taxes are regressive, and politicians and voters often argue against their implementation due to the relatively larger tax burden put on low-income households. The Hillary Clinton presidential campaign of 2016 abandoned the idea of implementing a $42 per ton carbon tax in the US partly due to its likely regressive impact (Holden, Hess, and Lehmann, 2016), and one of the arguments put forward when the Australian carbon tax was repealed in 2014 was that the move would reduce the cost of living for households. Similarly, the "Yellow Vests" movement that began in France in October of 2018, started as a protest against the proposed increase of the French carbon tax, claiming that it would put a disproportionately large burden on middle and working class households. Research also shows that voters are concerned about the distributional effects of environmental taxes, and prefer a carbon tax with a progressive cost distribution (Brännlund and Persson, 2012; Carattini et al., 2017; Tarroux, 2019). Distributional concerns is thus one important reason why only a few countries have adopted carbon taxes, and why these taxes only cover portions of the emitting sectors of the respective economies.

The purpose of this paper is to address the equity question of how a carbon tax affects households across the income spectrum: is there empirical evidence in favor of the common assertion that carbon taxes are regressive, and what are the most important determinants of carbon tax incidence?

We analyze empirically the distributional effects of a carbon tax, and the determinants of these effects, by studying the Swedish carbon tax on transport fuel. The tax was implemented in 1991, and we use empirical time-series data from 1999-2012 on carbon tax expenditure from a large annual household expenditure survey.[1] The full tax rate is applied to gasoline, diesel, heating fuels used by households, and fossil fuels used by industries that are not covered by the EU Emissions Trading System. However, due to a limited use of fossil fuels in the heating and non-trading industry sector, a clear majority of the carbon tax revenue today, around 90 percent, comes from the consumption of transport fuel (Ministry of Finance, 2018). Since the tax mainly affects the transport sector, our distributional analysis focuses only on the carbon tax part of households' expenditure on gasoline and diesel.

Carbon tax burden is measured as the percentage of a household's income that is

[1] The household survey is not carried out every year, so we have missing data for the years 2002, 2010, and 2011.

spent on the tax. We use two common measures of income: annual income, measured as disposable income in any given year; and lifetime income, where total expenditure in a year is used as a proxy. The differences in size of the carbon tax budget share across income groups determines the distributional effect. If the budget share decreases as we move up in the income distribution the tax will be regressive, and, similarly, the incidence will be progressive if the budget share increases with income.

The results show that the Swedish carbon tax on transport fuel is regressive in each year between 1999-2012 when measured against annual income, but progressive in each year when measured against lifetime income. The trend over time for both income measures, however, is toward an increase in regressivity, which is highly correlated with an increase in income inequality.[2]

Our research hypothesis is the following: for necessities – normal goods with an income elasticity below one – rising income inequality increases the regressivity of a consumption tax. Additionally, if the income elasticity of demand is heterogeneous across income groups, with decreasing elasticities as income increases, this would further amplify the increase in regressivity.

We test our research hypothesis by analysing the determinants of carbon tax incidence. First, we derive a formula that shows how income inequality and the income elasticity of demand can determine changes in distributional effects of a tax over time. Second, using a numerical exercise and descriptive evidence, we show that the assumption that transport fuel is a necessity with heterogeneous income elasticities across income groups, together with an increase in income inequality, can explain the increase in regressivity that we observe between 1999-2012. Lastly, using a regression model, we look at how variations in GDP per capita, income inequality, the gasoline price, urbanisation, and unemployment affects regressivity.

We find that the most important variable explaining variations in regressivity over time in Sweden is changes to income inequality; measured here by the Gini coefficient - taking values from 0, complete equality, to 100, complete inequality. There is a strong correlation between the two variables: growing inequality leads to an increase in regressivity, providing empirical support to our research hypothesis. A simple regression of carbon tax incidence on the Gini coefficient shows that at a Gini below 22 the Swedish carbon tax is progressive on both income measures, and that above a Gini of around 30 the tax is regressive. In 1991, Sweden had a Gini of 20.8, indicating that the carbon tax incidence was progressive, or at least proportional, at the time of implementation. Since implementation, however, income inequality has grown in Sweden, to a Gini of 26.9 in

[2]There are also differences in carbon tax incidence across geographical areas: the carbon tax is more regressive in rural compared to urban areas. See the appendix for an analysis on differences in tax incidence across geographical areas and age groups, and an analysis of long-run adjustments on the extensive margin – such as a switch to more fuel efficient vehicles and an increased use of public transport.

2012, leading to a more regressive outcome.[3]

There is much support in the economics literature that carbon and transport fuel taxes are indeed regressive – see, for example, highly cited studies by Poterba (1991); Chernick and Reschovsky (1997); Metcalf (1999); Parry (2004); West and Williams III (2004); Hassett, Mathur, and Metcalf (2009); Bento et al. (2009); and, Grainger and Kolstad (2010). However, most of this earlier literature looks at a single country, the United States, and only for a single point in time – one year or an average over three years or so. And the US is not representative of an average OECD country when it comes to variables that are arguably important for carbon and fuel tax incidence. For instance, relative to the mean or median of all OECD countries, GDP per capita in the US is high, income is unequally distributed, CO_2 emissions per capita from the transport sector and in total are very high, the level of gasoline taxation is low, number of motor vehicles per person is high, and access to public transport is poor – especially compared to European countries. The results from US studies may thus have low external validity, and the distributional effects from carbon and gasoline taxation may be markedly different in more representative OECD countries. It is thus of interest to analyze carbon tax incidence in countries with, for instance, different levels and distributions of income, and, more importantly, to determine what the main drivers of distributional effects of carbon taxes are so that we can better understand why tax incidence may differ across countries. The latter is only possible, however, if we analyze tax incidence across multiple countries or for one country over multiple years.

We end the paper by analyzing previous studies of gasoline tax incidence across OECD countries and find a similar strong correlation between regressivity and income inequality. The cross-country study shows that below a Gini of 24 a gasoline tax will be progressive and above 29 it will be regressive, using both annual and lifetime income. The US has persistently had a Gini above 30, since at least the beginning of the 1960s, so it is not surprising that the earlier literature on carbon and fuel tax incidence using US data find that these taxes are regressive.

The important contribution from this study is that is shows that not only the income measure – annual or lifetime – matters for the estimated regressivity of a consumption tax, but also the underlying distribution of income. The paper thus highlights the importance of income inequality for tax incidence and adds to the expanding literature in economics on the economic effects of growing income inequality in high-income economies, as well as adding to the literature on the political economy of carbon taxation. Furthermore, by using eleven years of ex post data, we analyse fuel tax incidence over time and determine which explanatory variables are of importance for regressivity. This is thus the first empirical study of carbon and fuel tax incidence that looks at a longer time period than just one specific year. Lastly, the majority of earlier studies on carbon taxes are

[3] Section 3 explores in more depth how income inequality has changed during the sample period.

simulations, using price elasticities of demand to estimate changes in demand of goods and services and the distributional effect that follows an introduction of a carbon tax, or increasing the rate of an existing one, see e.g. Grainger and Kolstad (2010); Rausch, Metcalf, and Reilly (2011); Dissou and Siddiqui (2014); and, Beck et al. (2015). There is thus a lack of studies that use empirical posttreatment data.

The results in this paper may explain why carbon taxes were first introduced in the Nordic countries, in the early 1990s – income inequality was relatively, and historically, low there at the time, with Gini coefficients well below 24, and policy-makers thus didn't need to worry about possible regressive effects. Since then, however, income inequality in all high-income countries has risen, even in the Nordic countries (Aaberge, Atkinson, and Modalsli, 2020). This increase started in the 1970s-1980s and has in some cases risen to levels not seen since the late 19th century (Piketty, 2014). Policy-makers in high-income countries thus face two formidable long-term challenges: the need to mitigate climate change through emission reductions, and the social and economic effects of rising income inequality. To mitigate climate change, a price on carbon needs to be put on those consumption goods that are responsible for the majority of emissions: transport fuel, food, heating, and electricity. These goods are, however, typically necessities and the distributional effect of carbon taxation will hence likely be regressive, more so the more unequal the distribution of income.

Much has been written on the difficulties of implementing a carbon price due to the possibilities of countries to free-ride on an international public good and thus the need for international cooperation and coordination, but if growing income inequality increases the regresiveness of carbon taxation, this adds to the difficulties of reaching political cooperation and consensus also *within* countries. It will be harder politically to implement a carbon tax in a country with a relatively high Gini coefficient as the equity argument against taxation becomes more salient, providing opportunities for opponents to attack the tax. High, and growing, income inequality also increases the need for policy-makers to offset the regressive impact by revenue recycling, such as lump-sum transfers back to households, or the reduction of distortionary taxes such as the payroll tax, thus making the carbon tax policy more intricate.

The remainder of this article is organised as follows. Section 2 introduces the Swedish carbon tax, with emphasis on the discussion of distributional effects in government reports; presents the data and method used to measure tax incidence, and; gives the results on tax incidence over time. Section 3 develops the model underlying our main hypothesis of the role of income inequality, and analyzes the determinants of regressivity. Section 4 compares the result in Sweden over time with earlier studies across OECD countries of gasoline tax incidence. Finally, section 5 summarizes and concludes the paper.

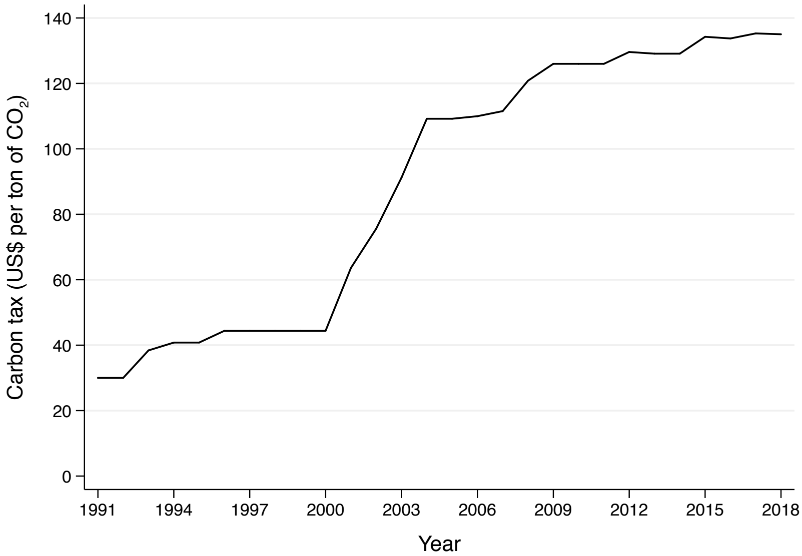


Figure 1: Carbon Tax Rate in Sweden 1991-2018

2 Distributional Effects of the Swedish Carbon Tax

In June of 1988, the Swedish Government appointed the Environmental Charge Commission (ECC) with the stated objective of analyzing the potential for an increased use of economic instruments in environmental policies. In October 1989, the ECC published their interim report that included a proposal to implement a charge on emissions of carbon dioxide, making Sweden "the first country in the world to introduce a carbon-dioxide charge" (SOU, 1989:83, p. 23). Regarding distributional effects, the final report, released in July 1990, states that the "ECC has applied a number of criteria in assessing whether an economic measure is best recommended as a supplement or as an alternative to other measures," where one criteria is "distribution effects" (SOU, 1990:59, p. 28). In an appendix, distributional effects of environmental taxation of energy and transport fuel are analyzed across income and geographical areas using a survey from 1985 of households' expenditure (SOU, 1989:84). The analysis finds that gasoline tax expenditure's share of disposable income is lower in cities compared to rural areas, but no difference is found across income groups, indicating that the gasoline tax incidence was roughly proportional. They also find that the energy tax share of disposable income does not vary notably by household income, type or region.

Judging from the ECC reports, a possible regressive effect of the Swedish carbon tax was likely not a major concern among policy makers. There is support for this interpretation when we consider that in the final proposition regarding the carbon tax there is no mention at all of possible distributional effects (Swedish Parliament, 1989-1990).[4]

[4]The interim report from the ECC included a proposal to exempt households in rural parts of northern

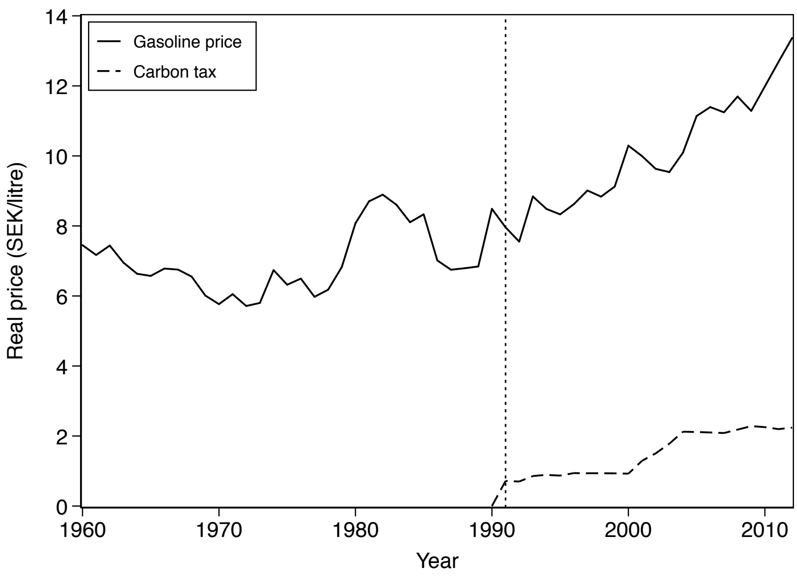


Figure 2: Real Gasoline Price in Sweden 1960-2012

In 1990, the Social Democratic government signed the carbon tax into law and implemented it in January of 1991. The tax was introduced at US\$30 per ton of CO_2 and later increased quite rapidly in the early 2000s, see Figure 1. In 2019, the rate was above US\$130 per ton of CO_2, making it the world's highest carbon tax imposed on households and non-trading sectors.

Due to the rather limited use of fossil fuels in the heating and non-trading industry sector, our analysis focuses on the transport sector and households' consumption of gasoline and diesel. Figure 2 plots the real price of gasoline in Sweden from 1960-2012. The real price increased from around 8 SEK per litre in 1991 to more than 13 SEK per litre in 2012. Of this increase, a bit more than 2 SEK is due to the carbon tax. During the same time period, new passenger cars sold in Sweden became increasingly fuel efficient (Swedish Transport Administration, 2017). In 1991, the average fuel efficiency of all gasoline and diesel cars sold was 9.2 liters per 100 kilometers (9.2 for gasoline and 7.1 for diesel). By 1999, fuel efficiency had improved to 8.3 liters per 100 km, and even further in 2012 to 5.5 liters per 100 km (6.1 for gasoline and 5.2 for diesel). As a result, between 1999-2012, Swedish households spent every year, on average, about 4 percent of their disposable income on transport fuel. The share is stable around 4 percent during the entire time period, but the variance across income deciles increases a lot from 2008 and onwards.

A follow-up study in 2003 by the Ministry of Finance (SOU, 2003:2) finds that, overall, the carbon tax is regressive when measured against annual disposable income. The main analysis uses a simulation approach to establish the possible effect of a doubling of the

Sweden from vehicle tax, to somewhat offset the difference in carbon tax burden between urban and rural households, however this particular proposal was never implemented.

Table 1: USA vs. Sweden vs. OECD

			OECD		Ranking	
Variables	USA	Sweden	Mean	Median	USA	Sweden
GDP per capita	59532	50208	43594	41980	5th	11th
Income inequality	38.4	26.1	31.2	30.3	4th	29th
Urban population	82.1	87.4	77.9	80.1	14th	9th
Gasoline tax rate	14.0	114.0	91.5	95.0	1st	26th
Motor vehicles	786	525	528	565	1st	23rd
CO_2 from transport per capita	5.3	2.4	2.1	1.9	1st	10th
CO_2 total per capita	17.0	5.5	8.1	7.3	2nd	26th

Note: GDP per capita is adjusted for purchasing power (2017 data). Income inequality is measured as the Gini coefficient (most recent data available). Urban population is measured as percentage of total population (2017 data). Gasoline tax rate is measured in cents per litre (q4 of 2014). Number of motor vehicles are per 1000 people (2011 data). CO_2 emissions from transport, and the total, are measured in metric tons (2011 data). The last two columns ranks USA and Sweden in comparison to the entire sample of 36 OECD countries, from highest to lowest value. For the gasoline tax rate the ranking is reversed.

carbon tax rate in 1998, coupled with different forms of revenue recycling. The simulation builds on own- and cross-price elasticities of demand for transport fuel, public transport, heating, and ”other goods”, estimated using household survey data from the years 1985, 1988 and 1992. A later study, by Ahola, Carlsson, and Sterner (2009), uses empirical data on household expenditure in 2004-2006 and finds that the energy and carbon tax on gasoline and diesel is regressive when measured against annual income, but progressive when measured against lifetime income.

The results in the studies by the Ministry of Finance (SOU, 2003:2) and Ahola et al. (2009) matches the stylized fact in economics that carbon and gasoline taxes are regressive, especially when measured against annual income. This result is found in a number of highly cited studies from the last thirty years. Similarly, most of the older generation of studies of environmental taxes, from the 1970s and 1980s, found that environmental taxes typically are regressive (SOU, 2003:2). Note, though, that the majority of all these studies share the characteristic that they use US data, and a potential issue is that, for variables that are important to consider when analyzing tax incidence from carbon and fuel taxes, US numbers are far from the mean (or median) of all OECD countries. USA is ranked in the top-5 of countries for the variables listed in Table 1, except for degree of urbanization. Access to public transport is also generally poorer in US cities compared to, for instance, cities in Europe (ITF, 2017), and access to public transport affects tax incidence by providing low-cost substitutes to gasoline and diesel for daily transportation. The results from US studies may thus have low external validity, and it is possible that carbon and gasoline taxes are less regressive, even progressive, in more "average" OECD countries.[5]

2.1 Data and Methodology

To empirically analyse the distributional effects of the Swedish carbon tax we use data from a household expenditure survey (HUT) for the years 1999-2012. HUT is a large survey that is carried out since 1958 by Statistics Sweden, although not every year. Due to changes in methodology over time we unfortunately only have comparable data from 1999 and onwards – the survey was also conducted in 1992, 1995, and 1996. The survey was conducted every year between 1999-2001 and again between 2003-2009, and the latest survey took place in 2012. Our final sample is thus eleven years of data, with a total of N=22624 households surveyed (around two thousand households each year).

The HUT survey includes households with at least one person between the age of 0-79, and great effort is put into drawing a representative sample of the larger population. Expenditure data on goods and services is collected with the help of either a journal, where the household registers all their expenditures over a two-week period, or for certain items through telephone interviews, where they are asked about their expenditure over the last twelve months. Data on transport fuel expenditure is collected with the use of telephone interviews. Lastly, the survey collects information about disposable income. This data is available from public registers that are provided by the Swedish Tax Agency. Expenditure on transport fuels, total expenditure on goods and services, and disposable income are the three key variables needed to analyze distributional effects in this study.

Although annual disposable income may seem to be the obvious income measure, many researchers argue that tax incidence should instead be measured against lifetime income (see, e.g., Poterba 1989, 1991). The reasoning is that annual income may overestimate the regressiveness of a tax since many households in the lowest income deciles have low earnings today but high potential future earnings (e.g. young households), or are retired with low pensions but large savings, and thus not poor in the common meaning of the word. Furthermore, according to the permanent income hypothesis, consumers wish to smooth out consumption over their life cycle and thus focus mainly on lifetime income when making consumption decisions. Taken together, this would speak in favour of using lifetime income when we measure distributional effects. Since we cannot measure lifetime income directly, however, many researchers use total expenditure for each household as a

[5] Ahola et al. (2009) notes that since the concern regarding the possibly regressive nature of gasoline taxes builds upon early US studies done in the 1980s and 90s, it is important to examine the question of regressivity by studying countries with different income levels and distribution of income. It is, furthermore, important to consider the source-side – how a tax affects wages, capital income, and transfer incomes. A simulation study by Goulder et al. (2019) shows that a carbon tax in the US would be regressive on the use-side but progressive on the source-side, potentially fully offsetting the regressiveness. Empirical studies of source-side impacts are thus needed and an interesting area for further research.

proxy; based on the argument that if consumption is always a fraction of lifetime income, total expenditure provides a useful proxy. We follow this approach, using total expenditure as a measure for lifetime income, but other than that we make no judgement on which income measure is the most appropriate and use both when presenting the results (for an interesting discussion on the merits and limitations of both income measures, see Chernick and Reschovsky (1997); Attanasio and Pistaferri (2016); McGregor, Smith, and Wills (2019)). In general, studies find that carbon and gasoline taxes are less regressive when measured against lifetime income compared to annual income.[6]

To be able to make comparisons across households with different sizes and compositions we make use of an equivalence scale, known as "consumption units". The weights, provided by Statistics Sweden, make up for the fact that expenditures on goods and services don't grow proportionally with the number of people in a household - there are economies of scale for large households. Different weights are, for instance, given to children and adults in a household.[7]

The carbon tax budget shares, and how these differ across income groups, determines the overall distributional effect. If the budget shares are equal, the tax is proportional, and if the budget shares decrease (increase) with income, the tax is regressive (progressive).

To measure carbon tax incidence, we use the Suits index (Suits, 1977), the most common summary statistic. The index varies from +1 to -1. If the total tax burden is borne only by households in the highest income bracket, we have extreme progressivity and a Suits index of +1. If all the tax burden falls on households with the lowest income, we have extreme regressivity and an index of -1. A proportional tax receives an index of 0. The index allows us to easily compare different taxes on the basis of regressivity, and to compare the incidence from the same tax over time and across countries.[8]

2.2 Results

When measuring carbon tax incidence using annual income, we find that the Swedish carbon tax is regressive in each year between 1999-2012, with an average Suits index of -0.057, see Figure 3. Furthermore, the trend over time is toward increasing regressivity. For the years 1999-2006, the Suits index using annual income is above -0.05, whereas for the years 2007-2012 the index is around -0.10.

If we instead use lifetime income, with total expenditure as a proxy, we now find that

[6]The study by Rausch, Metcalf, and Reilly (2011) is an exception. They find that a carbon price implemented in the US would be as regressive when measured against lifetime income as when using annual income. However, the authors use a different way to capture lifetime income compared to earlier studies, making their results not directly comparable.

[7]Note that Statistics Sweden used one set of weights for the years 1999-2001 and a different set of weights for the years 2003-2012. The differences are very small though and the impact on the estimated distributional effects of the carbon tax, from switching from one set of weights to the other, is insignificant.

[8]see the Appendix for more details on how the Suits index is computed.

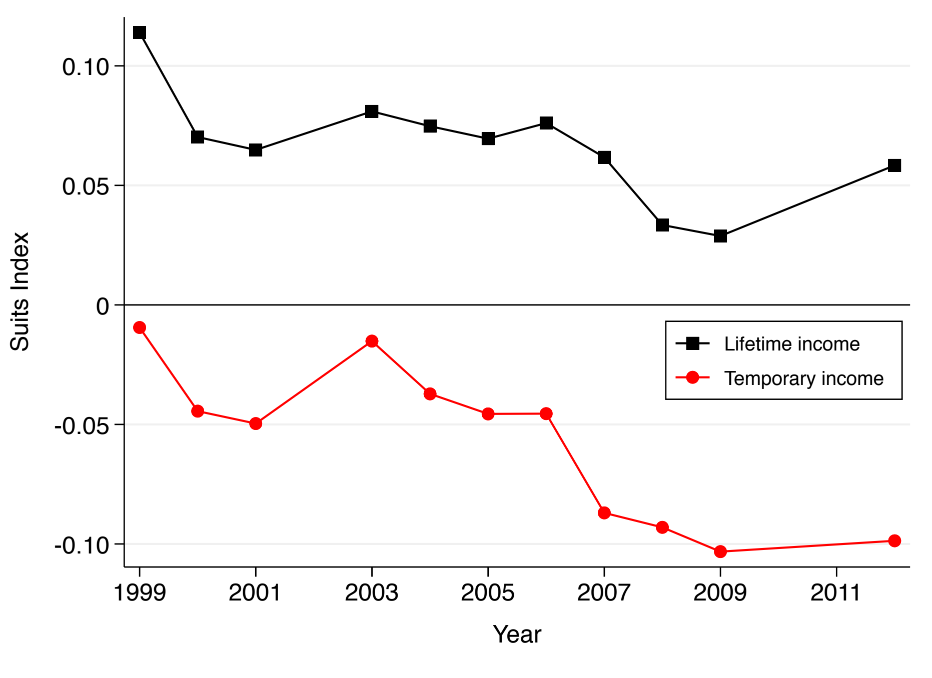


Figure 3: Carbon Tax Incidence in Sweden during 1999-2012

the carbon tax is progressive, with an average Suits index of +0.067. However, the trend over time here is also in the direction of an increase in regressivity.

The interesting and important question is then: what is driving this trend toward an increase in regressivity?

Our main research hypothesis is the following: for necessities – consumption goods with an income elasticity below one – rising income inequality increases the regressivity of a consumption tax. Additionally, if the income elasticity of demand is heterogeneous across income deciles, with lower elasticities for higher income groups, this would further amplify the increase in regressivity. The income elasticity of demand for a good, together with the level of income inequality thus determines the distributional effect of a tax, and changes in inequality affects regressivity over time.

3 The role of Income Inequality

To understand how changes in income inequality affects regressivity we start by deriving a simple formula that shows the relationship between budget shares and income growth.

First, assume that the consumer decides how much to purchase of a certain good q_i, given prices p and total expenditure x:

$$q_i = d_i(x, p) \tag{1}$$

We refer to this function as a Marshallian demand function. Furthermore, the consumer faces a linear budget constraint:

$$x \geq \sum_k p_k q_k \tag{2}$$

and the Marshallian demand function is subject to the adding-up restriction:

$$\sum_k p_k d_k(x, p) = x \tag{3}$$

The use of the equality here indicates that all of income is spent and the total value of Marshallian demands is equal to total expenditure.

Now, the budget share for good i are defined by

$$w_i = \frac{p_i q_i}{x} \tag{4}$$

where we know from the Marshallian demand function that q_i depends on both prices and total expenditure.

Then, taking logs of both sides of (4) and the derivative with respect to x gives

$$\frac{1}{w_i}\frac{\partial wi}{\partial x} = \frac{1}{q_i}\frac{\partial q_i}{\partial x} - \frac{1}{x} \tag{5}$$

Lastly, multiplying both sides by x we get

$$e_{i,w} = e_i - 1 \tag{6}$$

where $e_{i,w}$ is the income elasticity of the budget share for good i and e_i is the familiar income elasticity of demand for good i.

From (6) we see that the budget share of a good will increase or decrease with changes to total expenditure (or income) depending on the size of the income elasticity of demand. If the good has an income elasticity above one, $e_i > 1$, the budget share increases as income increases, and similarly, if $e_i < 1$ the budget share decreases. Thus, whether or not e_i is above or below unity is often used to define goods as either luxuries or necessities, respectively.

Now, by introducing changes to the underlying distribution of income over time, we can develop a simple dynamic model of the changes to regressivity that follows.

First, consider an economy composed of two types of households, labeled A and B. Income in time period t is $x^A(t)$ and $x^B(t)$ and we assume that $x^A(t) < x^B(t)$, i.e. there is some existing level of inequality in the distribution of income.[9]

Furthermore, we assume that prices are fixed and p_i is normalised to unity. The

[9] We can view households A and B as representing the bottom and top half of the income distribution, respectively.

budget share of good i for household B, in time period t, is thus:

$$w_i^B(t) = \frac{q_i^B(t)}{x^B(t)} \tag{7}$$

Then, if the percentage change of the budget share differs for households A and B over time:

$$\frac{w_i^B(t+1) - w_i^B(t)}{w_i^B(t)} \neq \frac{w_i^A(t+1) - w_i^A(t)}{w_i^A(t)} \tag{8}$$

this will lead to a change in the distributional effect of a tax on good i. For example, if the percentage change of the budget share for household B is smaller ($<$) compared to the percentage change for A, we will get a more regressive outcome.

We can formalise this by starting with the case of *no* change in the distributional effect:

$$\frac{w_i^B(t+1) - w_i^B(t)}{w_i^B(t)} = \frac{w_i^A(t+1) - w_i^A(t)}{w_i^A(t)} \tag{9}$$

Note that, by adding 1 to both sides we get:

$$\frac{w_i^B(t+1)}{w_i^B(t)} = \frac{w_i^A(t+1)}{w_i^A(t)} \tag{10}$$

and that:

$$q_i(t+1) = q_i(t)\left(\frac{x(t+1)}{x(t)}\right)^{e_i} \tag{11}$$

where e_i is the income elasticity of demand for good i.

Using (7) and (11), we can rewrite the left hand side of (10) as:

$$\frac{q_i^B(t)\left(\frac{x^B(t+1)}{x^B(t)}\right)^{e_i^B}}{x^B(t+1)}\frac{x^B(t)}{q_i^B(t)} = \left(\frac{x^B(t+1)}{x^B(t)}\right)^{e_i^B}\frac{x^B(t)}{x^B(t+1)} \tag{12}$$

Then, taking logs of (12) and collecting like terms we get:

$$e_i^B \ln\left(\frac{x^B(t+1)}{x^B(t)}\right) + \ln\left(\frac{x^B(t)}{x^B(t+1)}\right) = (e_i^B - 1)\ln\left(\frac{x^B(t+1)}{x^B(t)}\right) \tag{13}$$

Now, using (6), and noting that $\ln(x^B(t+1)/x^B(t))$ is the same as the growth rate of income for B, the left hand side of (10) can be expressed as:

$$e_{i,w}^B g_x^B \tag{14}$$

The same applies to the right hand side of (10) and we can thus write (10) as:

$$e_{i,w}^B g_x^B = e_{i,w}^A g_x^A \tag{15}$$

Equation (15) shows that changes to the budget share for good i depends on two variables: the income elasticity of the budget share for good i and the growth rate of income. For instance, for necessities, $e_i < 1$ (and $e_{i,w} < 0$), the budget share decreases faster the lower the income elasticity of demand is and the larger the growth rate of income is. If the budget share decreases faster for household B, relative to the poorer household A:

$$e_{i,w}^B g_x^B < e_{i,w}^A g_x^A \tag{16}$$

a tax on good i will become increasingly regressive over time. Conversely, if the budget share increases faster for B relative to A:

$$e_{i,w}^B g_x^B > e_{i,w}^A g_x^A \tag{17}$$

the tax will become more progressive over time.

Equation (15) gives the criteria for when changes to the underlying distribution of income doesn't result in a change in the distributional effect of a tax on good i. This occurs if the ratio of income elasticities of demand for households A and B is equal to the opposite ratio of the two growth rates of income[10], or if the income elasticity of demand is unit-elastic for all households: $e_i^A = e_i^B = 1$ (because then $e_{i,w}^A = e_{i,w}^B = 0$).

We can now derive the conditions that are needed for a change in the distributional effect, equations (16) and (17), in the special case when income elasticities are equal across income groups, and the more general case where the elasticities may differ.

1. Special case: $e_i^A = e_i^B = e_i$, (and $e_i \neq 1$)

When income elasticities of demand are equal for households A and B, we get a more *regressive* outcome, $e_{i,w}^B g_x^B < e_{i,w}^A g_x^A$, if income inequality increases, $g_x^B > g_x^A$, and the good is a necessity, $e_i < 1$ (and thus $e_{i,w} < 0$), or if income inequality decreases, $g_x^B < g_x^A$, and the good is a luxury, $e_i > 1$. Similarly, we get a more *progressive* outcome if income inequality increases and the good is a luxury, or if income inequality decreases and the good is a necessity.

2. General case: $e_i^B \neq e_i^A$

In the general case, when income elasticities are heterogeneous across households, we get a more *regressive* outcome if the ratio of income elasticities of the budget share, $e_{i,w}^B / e_{i,w}^A$, is smaller than the opposite ratio of the growth rates of income, g_x^A / g_x^B, and more progressive outcome if the converse is true. For example, if $g_x^A = g_x^B$, giving an income growth ratio of 1, we get a more regressive outcome if $e_{i,w}^A > e_{i,w}^B$, that is, if the good is a relative luxury for the poorer household A compared to B. If the good instead is a relative necessity for household A ($e_{i,w}^A < e_{i,w}^B$), we get a more progressive outcome.

[10]If $g_x^A = 0$ and $g_x^B \neq 0$, then we need $e_{i,w}^B = 0$, i.e. the income elasticity of demand for household B need to be unity.

Table 2: Income Elasticities and Income and Expenditure Data for Numerical Exercise

Income decile	1	2	3	4	5	6	7	8	9	10	Average e_i
Unit-elastic	1	1	1	1	1	1	1	1	1	1	1
Necessity	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Heterogeneous	1.5	1.5	1	1	1	1	0.75	0.5	0.25	0.25	0.875
1999											
Disposable income	67	105	127	158	187	228	256	297	349	508	
Total expenditure	122	144	178	176	201	228	266	303	322	397	
Carbon tax expenditure	0.16	0.39	0.61	0.57	0.75	1.04	1.18	1.31	1.42	1.55	
Consumption units	1.28	1.26	1.43	1.56	1.96	2.31	2.31	2.80	2.85	2.93	
2009											
Disposable income	64	137	181	222	262	314	382	458	541	833	
Total expenditure	139	149	177	198	242	272	308	360	413	501	
Consumption units	1.09	1.14	1.17	1.36	1.45	1.58	1.84	1.97	2.16	2.28	

Note: The top part of the table gives the income elasticities of demand for transport fuel, across income deciles, that are used to simulate the distributional effect in 2009. The bottom part of the table gives the annual income and expenditure per household unit across the deciles in 1999 and 2009, measured in nominal Swedish kronor (thousands).

3.1 Numerical Exercise

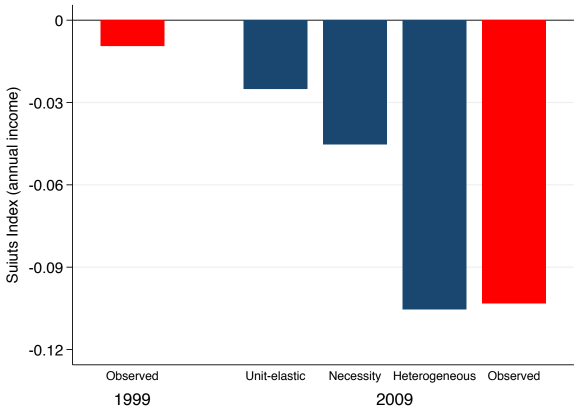
The largest increase in regressivity during the sample period occurred in the decade between 1999-2009, see Figure 3. The Suits index then dropped by around -0.09 for both income measures. As a way to test our research hypothesis of the role of income inequality and the income elasticity of demand, we perform a numerical exercise: trying to replicate the drop in the Suits index between 1999-2009 by assuming either that transport fuel is a necessity with homogenous income elasticities across the income spectrum, or; the general case of heterogeneous income elasticities – with transport fuel being a relative luxury good among low-income households compared to richer households. We also include a base-case scenario with unit-elastic demand across all income groups.[11]

Table 2 lists the income elasticities used in the three simulated scenarios and the survey data on disposable income and total expenditure in the years 1999 and 2009. There was a noticeable increase in income inequality during the time period: disposable income increased more than 60 percent for the top decile but decreased slightly for the poorest decile. Table 2 also reports the carbon tax expenditure for the year 1999, and using this data – together with the change in disposable income, total expenditure, and the assumed income elasticities – we can compute the carbon tax expenditure in 2009, and thus the simulated Suits index numbers that follow.[12]

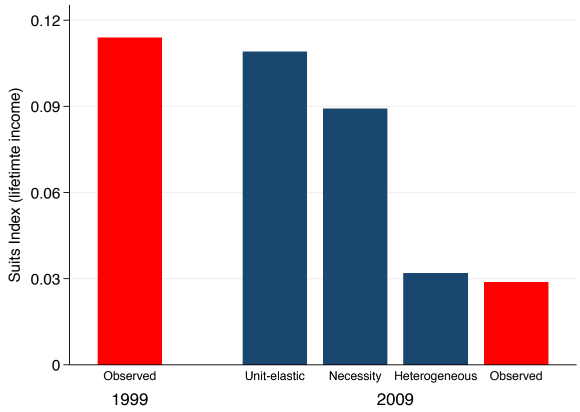
The red bars in Figure 4 depict the actual (observed) Suits index numbers in 1999 and 2009, and the blue bars shows the simulated Suits index in 2009. In the unit-elastic case, there is only a slight increase in regressivity, -0.016 using annual income and -0.005 using

[11]From equation (15) we see that if income elasticity of demand is unit-elastic for all households, then a change in income inequality should *not* result in a change in the distributional effect.

[12]We use equation (11) to compute the demand for transport fuel in 2009.



(a) Annual Income



(b) Lifetime Income

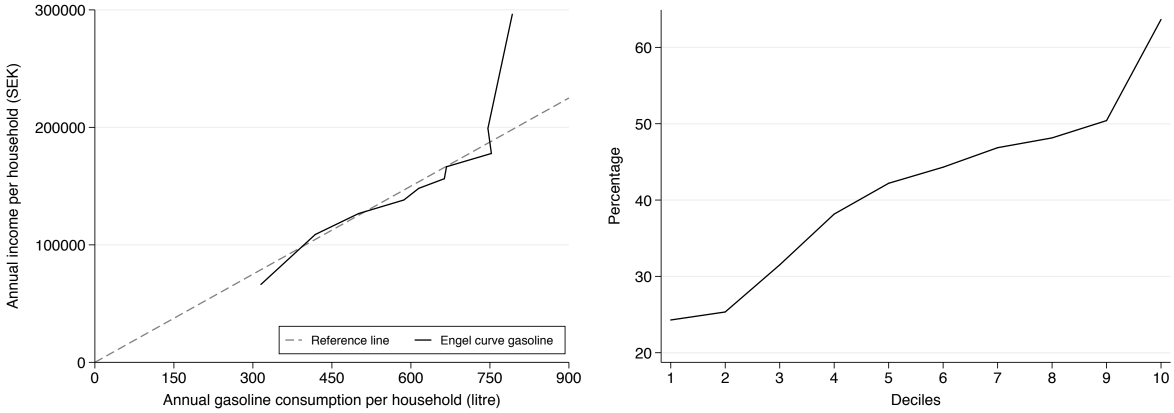
Figure 4: Numerical Exercise: Suits Index in 1999 and 2009

Note: The red bars depicts the computed (observed) Suits index numbers in 1999 and 2009. The blue bars show the simulated Suits index in 2009 – using the assumed income elasticities and survey data on disposable income, total expenditure and carbon tax expenditure, presented in Table 2.

lifetime income, showing that with unit-elastic demand, a change in income inequality has little impact on the distributional effect of a tax. When we instead assume that transport fuel is a necessity, we get an increase in regressivity between 1999 and 2009, -0.036 using annual income and -0.025 using lifetime income. However, this increase in regressivity is not even half the size of the drop of -0.09 that we actually observe.[13] But if we instead assume that income elasticities are heterogeneous across income groups, with transport fuel being a relative luxury good among low-income households, we can replicate the observed change in regressivity. The simulated case with heterogeneous income elasticities gives an increase in regressivity of -0.09 for both income measures, which matches the observed change in the Suits indices.

Figure 5 shows the average Engel curve for gasoline demand in Sweden for the years 1999-2012 and the growth in real disposable income across income deciles over the same time period. The Engel curve gradient is positive, and gasoline is thus a normal good. For high-income households the curve bends toward the x-axis, indicating that gasoline is a necessity - with an income elasticity below one. For low-income households, the curve instead bends toward the y-axis, making gasoline a luxury good - with an income elasticity above one. The shape of the Engel curve thus indicates that the income elasticity of demand for transport fuel in Sweden is indeed heterogeneous across income groups, with gasoline being a relative luxury among low-income households compared to high-income households. Furthermore, in Figure 5(b) we see that every decile has experienced an increase in real income over the sample period, but the growth rate is considerably higher for richer households, resulting in an increase in inequality.

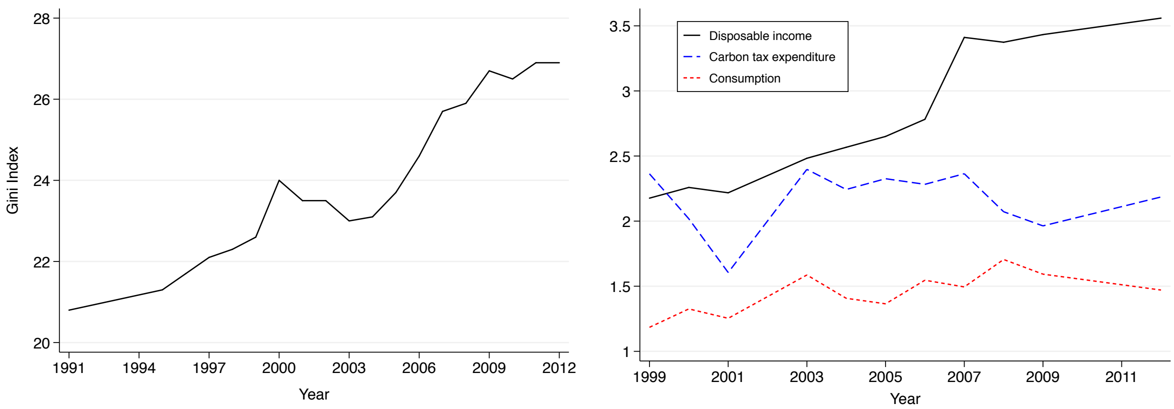
[13]Even if we assume that the income elasticity for transport fuel in Sweden is as low as 0.2, we only get an increase in regressivity of -0.048 and -0.037, respectively.



(a) Engel Curve for Gasoline (b) Growth in Real Disposable Income

Figure 5: Engel Curve for Gasoline and Growth in Real Disposable Income 1999-2012

Note: Figure (a) depicts the average Engel curve for gasoline over the years 1999-2012; real annual income per household is measured in 2005 SEK. The reference line is a straight line through the origin and depicts the Engel curve for a good with an income elasticity equal to one. Source for the data in figure (b) is the same that Statistics Sweden use to compute the Gini index.



(a) Gini coefficient 1991-2012 (b) 90/10 ratio 1999-2012

Figure 6: Income and Consumption Inequality in Sweden

Source: The Gini coefficient is calculated using data on disposable income, excluding capital gains. There are missing values for the years 1992-1994. Figure (b) depicts the ratio of high-income to low-income respondents' disposable income, carbon tax expenditure, and total consumption expenditures. High income refers to the average of households with disposable income in the ninth and tenth deciles. Low income refers to the average of households with disposable income in the first and second deciles. Source: (a): Statistics Sweden; (b): own calculations using HUT data from Statistics Sweden.

3.2 Income Inequality in Sweden

Having derived a formula for the relationship between changes in income inequality and distributional outcome, and simulated the observed changes in regressivity over time using a numerical exercise, we now analyse further the correlation between changes to inequality in Sweden and the distributional effects of its carbon tax.

Except for a few years in the beginning of the 2000s, income inequality in Sweden

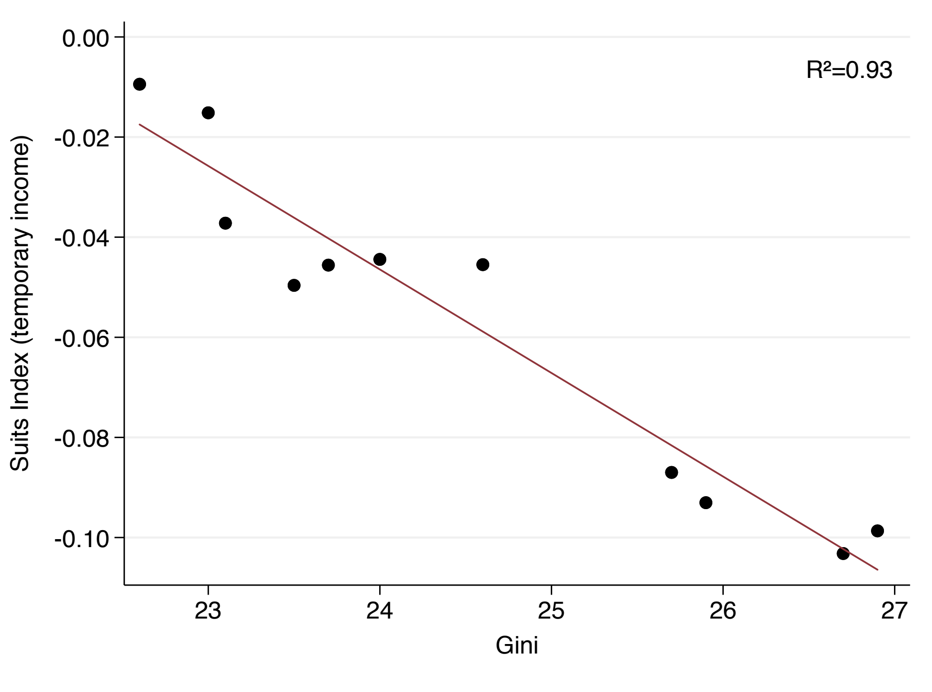


Figure 7: Carbon Tax Incidence and Income Inequality: Annual Income

Note: The red line is a fitted trend line with corresponding R^2 in upper-right corner. The equation for the trend line is $Suits = 0.45 - 0.0207 * Gini$. Source: Gini coefficients are provided by Statistics Sweden.

has steadily increased from the time of the carbon tax implementation. In 1991, Sweden had a Gini of 20.8, which then increased to 22.6 in 1999 and 26.9 in 2012, see Figure 6(a).[14] Looking at the very top of the income distribution, the top-5 and top-1 percent earned 10.5 and 3.0 percent respectively of all disposable income in 1991 (excluding capital gains). These numbers increased to 11.5 and 3.5 percent in 1999 and 13.5 and 4.9 percent in 2012 (Statistics Sweden, 2019b).

Figure 6(b) further illustrates how inequality has grown over the sample period. The figure depicts the 90/10-ratio of high-income to low-income respondents' disposable income, carbon tax expenditure, and total consumption expenditures from 1999-2012. High income refers to the average of households with disposable income in the ninth and tenth deciles. Low income refers to the average of households with disposable income in the first and second deciles. Income inequality has grown from a 90/10 ratio of 2.2 to over 3.5, a 64 percent increase. Consumption inequality has also increased, albeit at a slower rate, a 24 percent increase in the ratio. Contrary to income and consumption, the 90/10 ratio of carbon tax expenditure is rather flat. Taken together, this evolution of inequality in income, consumption, and carbon tax expenditure, shows how the Swedish carbon tax has become more regressive over time.

When regressing the estimated Suits index numbers on the Gini coefficients for each

[14]The level of income inequality at the start of the 1990s was historically low. The preceding decade, the 1980s, was the time period with the lowest level of income inequality in Sweden since at least the early 1900s (Roine, 2014).

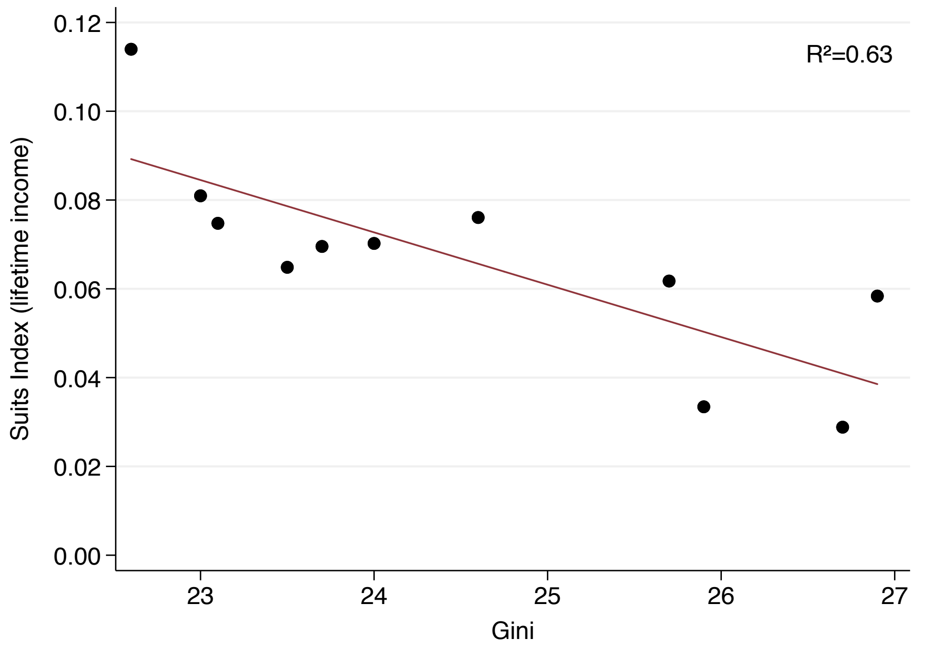


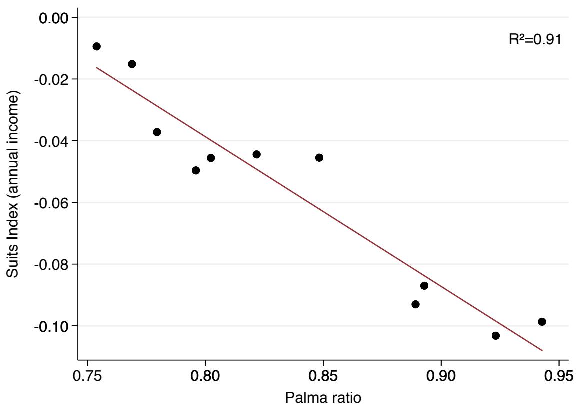
Figure 8: Carbon Tax Incidence and Income Inequality: Lifetime Income

Note: The red line is a fitted trend line with corresponding R^2 in upper-right corner. The equation for the trend line is $Suits = 0.36 - 0.0118 * Gini$. Source: Gini coefficients are provided by Statistics Sweden.

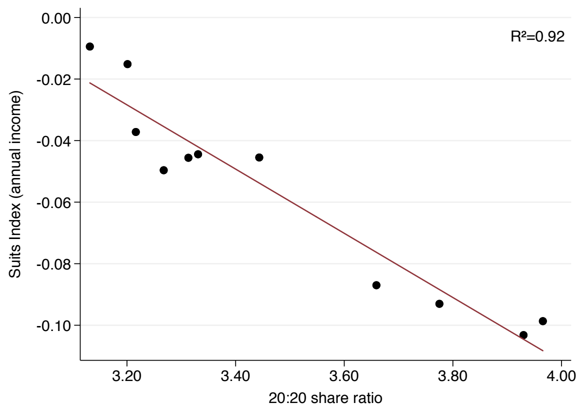
year the results show a strong negative correlation; $r = -0.96$ when using annual income, and $r = -0.79$ when using lifetime income. Extrapolating, these simple linear regressions, depicted in Figures 7 and 8, indicate that at a Gini below 22, the Swedish carbon tax on transport fuel will be progressive on both measures of the Suits index, and that at a Gini above 30, the tax will be regressive. Thus, in 1991, the carbon tax incidence was likely progressive, using either income measure, and we have further support of our earlier conclusion from reading the ECC reports that regressivity was likely not a concern among Swedish policy-makers at the time of implementation. From 1997 and onwards, the Gini is above 22, but still below 30.

The Gini index has though been criticised for being overly sensitive to changes in the middle of the income distribution, and thus not giving enough weight to changes at the very top and bottom (Cowell, 2011). As a robustness check, we therefore regress the estimated Suits index numbers (using annual income) on five additional measures of income inequality: the Palma Ratio; the 20:20 share ratio, the P90/P10 ratio, the P99/P50 ratio, and the Atkinson Inequality index.

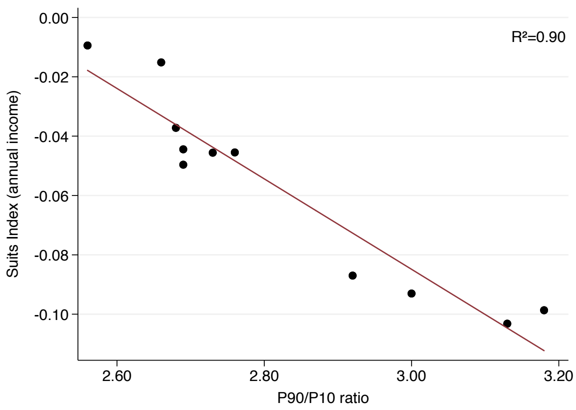
The Palma Ratio is calculated as the ratio of the richest 10 percent of the population's share of national income, divided by the share of the poorest 40 percent. As such, the Palma Ratio is responsive to changes in the top and bottom of the income distribution, and is thus a useful complement to the Gini coefficient when tracking changes to income inequality over time. The Palma Ratio was introduced as an additional inequality measure



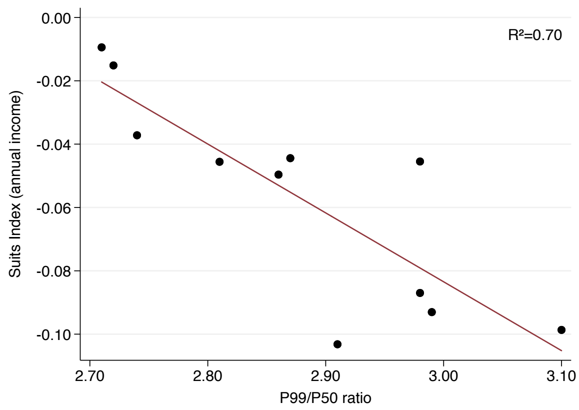
(a) Palma Ratio



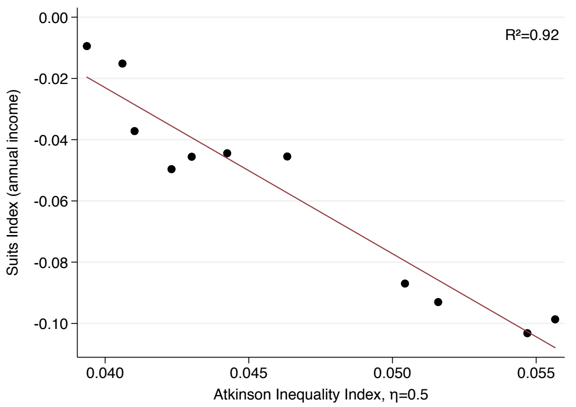
(b) 20:20 share ratio



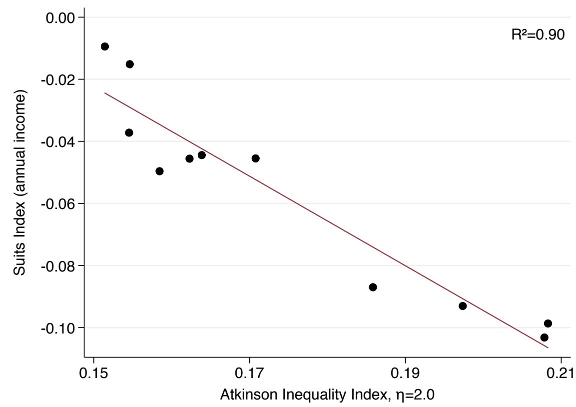
(c) P90/P10 ratio



(d) P99/P50 ratio



(e) Atkinson Index, η=0.5



(f) Atkinson Index, η=2.0

Figure 9: Carbon Tax Incidence and Income Inequality: Multiple Inequality Measures
Source: (a)-(b), (e)-(f): own calculations using data from Statistics Sweden; (c)-(d): Statistics Sweden.

based on the finding that the income going to the middle, deciles 5-9, are often around half of the total, and stable across time and countries. In Sweden, the share of income going to deciles 5-9 are remarkably stable around 54-55 percent during the time period of 1991-2012.

Similar to the Palma Ratio, the 20:20 share ratio is computed as the ratio of the top two deciles' share of national income, divided by the share of the bottom two deciles. The P90/P10 and P99/P50 ratios looks at the ratios of specific percentiles of the income distribution: the ratio of income of households at the ninetieth and tenth percentile, and the ratio of the top 1 percent to the income of the households in the middle, the fiftieth percentile. The percentile ratios use less information than the share ratios, but can on the other hand be highly responsive to changes at the very top, the top 1 percent of the income distribution – the P99/P50 ratio – or exclude the impact of the 1 percent, the P90/P10 ratio. Research by Piketty (2014) shows that a lot of the increase in income in the top decile is actually driven by large increases for the top 1 percent.

The inequality index in Atkinson (1970) is distinctive because it is explicitly derived from a social welfare function (SWF), one with constant relative inequality aversion, η:

$$W = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{y_i^{1-\eta}}{1-\eta} \right) \tag{18}$$

with $\eta \geq 0$ due to concavity.[15]

In practical terms, the index calculates the *equally distributed equivalent* level of income, i.e. the amount of (mean) income which equally distributed would provide the same amount of social wellbeing as actual mean income, $\overline{y}$. Using (18) as the formula for the SWF, we can define the Atkinson Inequality Index as:

$$AI = \begin{cases} 1 - \frac{1}{\overline{y}} \left(\frac{1}{N} \sum_{i=1}^{N} {y_i}^{1-\eta} \right)^{\frac{1}{1-\eta}} & \text{if } \eta \neq 1 \\ 1 - \frac{1}{\overline{y}} \left(\prod_{i=1}^{N} y_i \right)^{\frac{1}{N}} & \text{if } \eta = 1 \end{cases} \tag{19}$$

The index tells us what proportion of current average income that society would be willing to give up to achieve an income level that is equally distributed. For a given income distribution, this proportion is higher the larger the value of η. Reviews typically put the level of inequality aversion in the range of 0.5-2.0 (Arrow et al., 1996; Cowell and Gardiner, 1999) – but possibly as high as 4. We use the lower and upper bound of this range when computing the Atkinson index for Sweden over the sample period.

Figure 9 provides a similar overall pattern as Figure 7, the correlation is still very high between the regressivity of the Swedish carbon tax and changes in income inequality. Only the P99/P50 ratio shows a somewhat weaker correlation, $r = -0.83$, than what we found when using the Gini coefficient. The strong negative correlation across all inequality measures indicate that the link between changes to regressivity and changes to the underlying distribution of income is not sensitive to the summary statistic used to measure inequality.

[15] When $\eta = 1$ the SWF takes a log form.

3.3 Determinants of Tax Incidence

A number of factors may explain the increase in regressivity over time from the Swedish carbon tax. What we are interested in are the factors that affect the budget share for transport fuel, since if the budget share changes in a heterogeneous way across income groups, this affects regressivity.

The two most important factors are price and income. Households across the income distribution face the same price for gasoline and diesel - determined in large part by the world price on crude oil - but the price elasticity of demand may differ, resulting in a differentiated demand response to price fluctuations (West, 2004). Furthermore, average income typically increases over time, but the increase is often not equally distributed, resulting in changes in income inequality. An increase in average income will affect tax incidence if there is heterogeneity in the income elasticity of demand for transport fuel across income groups, and changes to income inequality will affect tax incidence depending on the nature of the good: luxury or necessity.

The budget share for transport fuel may, furthermore, be affected by changes in unemployment and access to public transport. An increase in unemployment may lead to reduced demand for driving and thus transport fuel. Moreover, if unemployment specifically affects, say, lower income deciles, this will lead to changes in regressivity. Regarding access to public transport, the trend in Sweden and most OECD countries is an increase in the proportion of people living in urban areas; providing households better access to public transport or other means of transportation that does not require the use of gasoline or diesel. If especially households in the bottom half of the income distribution make use of public transport, the urbanization trend will make the tax incidence of the carbon tax more proportional or even progressive over time.[16]

Using the computed Suits index numbers for annual income from 1999-2012 as the dependent variable we test the predictive power of the explanatory variables of price, income, unemployment and urbanization. The OLS regression model is static, no lags are included and all interactions between the variables of the models are thus assumed to take place within the same time period. With annual data this is a fairly reasonable assumption since the long time interval makes behavioral adjustments possible (Wooldridge, 2015).

The results show that all the explanatory variables, except unemployment, significantly affects the Suits index coefficient when included one by one.[17] An increase in any one of the independent variables increases the regressiveness of the Swedish carbon tax,

[16]An analysis of geographical differences in tax incidence finds that, on average, 22 percent of households in the three largest cities in Sweden report zero fuel expenditure, compared to only 8 percent in rural areas. This indicates that urbanization will affect tax incidence over time, especially since a larger percentage of households in the bottom half of the income distribution report zero fuel expenditure (see appendix for more information on this).

[17]See the appendix for the full results from the OLS regressions.

and changes in income inequality has the largest predictive power with an R^2 value of 0.93. However, when controlling for changes in income inequality (Gini), and running a full model, all other explanatory variables are then insignificant. The coefficient on the Gini index is however highly significant and similar in size in all model specifications where it is included. With the full model, including all explanatory variables and a time trend, we find that a one unit increase to the Gini index reduces the Suits index with -0.024 [95 percent confidence interval of: -0.038; -0.010]. Moving from a Gini of 20.8 in 1991, to a Gini of 26.9 in 2012, would thus increase the regressiveness of the Swedish carbon tax, other things equal, with almost -0.15 as measured by the Suits index using annual income.[18]

Taken together, the regression results indicate that changes to income inequality has a substantial and significant effect on the incidence of carbon taxes, and that other possible explanatory variables are of lesser importance. Thus, the result suggests that the most likely explanation for the observed trend in the distributional impact in Sweden is an increase in income inequality combined with an income elasticity of demand for transport fuel that is below unity. It is still possible that e_i is heterogeneous across income groups and decreasing as disposable income increases, which would further amplify the correlation between regressivity and income inequality. With this assumption, however, the coefficient on income (GDP per capita) should be negative and significant in the full model, which here, it is not.

There is a risk, though, that the regression estimates are biased due to omitted variables, and the small sample size limits the degrees of freedom and the accuracy of the estimated coefficients and standard errors. The results in this section lend support to the descriptive evidence presented earlier, but should be interpreted with caution and mostly serve as an indication that the relationship between carbon tax incidence and income inequality is worth analyzing in further detail. The analysis here should be followed up in the future with tests on longer time-series or, ideally, panel data sets.

4 External Validity

Carbon taxation is ideally global in scope and it is thus of interest to test the external validity of our research hypothesis on the relationship between regressivity and income inequality. If our results from the empirical analysis of Sweden are externally valid, we can make projections about the likely distributional effects of carbon taxation in other high-income countries, at least for the transportation sector. A way to test the external validity is to analyse the distributional effects of current transport fuel taxation across

[18] In the original Suits (1977) article, the author analyses 1970 data and finds that the most progressive US tax is the federal corporate income tax with an index of +0.32 and the most regressive are general sales and excise taxes with an index of -0.15.

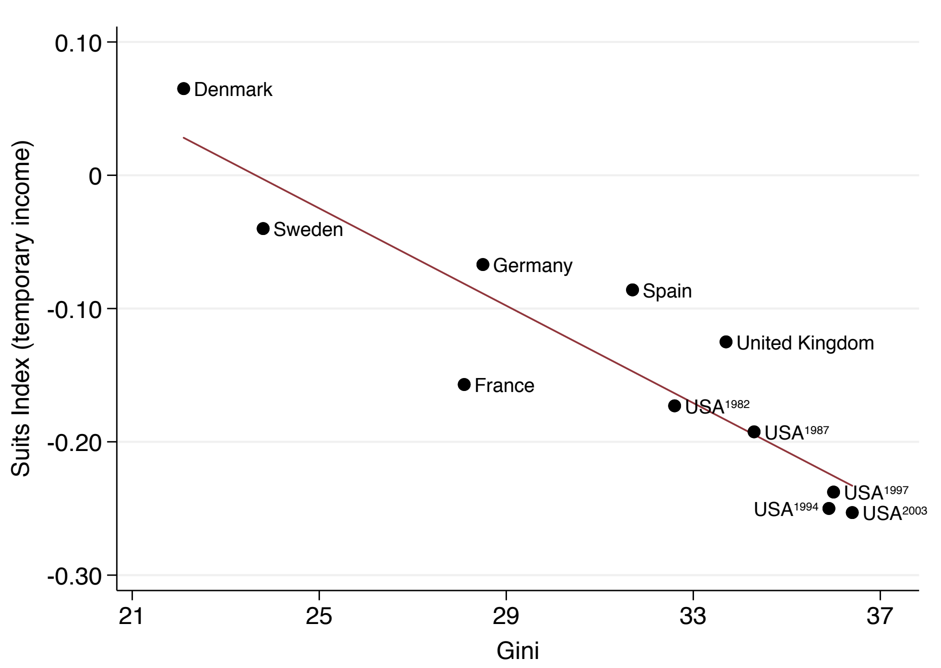


Figure 10: Gasoline Tax Incidence and Income Inequality: OECD Countries and Annual Income

Note: The figure depicts the correlation between gasoline tax incidence and income inequality across OECD countries. Gasoline tax incidence is measured using the Suits index and annual income. The equation for the trend line is $Suits = 0.43 - 0.0183 * Gini$ with a R^2 value of 0.82. The trend line crosses the x-axis at a Gini of 23.6, indicating that at a Gini below this number, excise taxes on transport fuel are progressive.
Source: Suits index numbers are taken from the following studies: USA for the years 1987, 1997, and 2003 (Hassett et al., 2009); USA in 1994 (Metcalf, 1999); USA in 1982 (Chernick and Reschovsky, 1997); Denmark in 1996 (Wier et al., 2005); rest of the European countries in 2006 (Sterner, 2012a). The studies use empirical household survey data to establish the incidence of transport fuel taxation relative to annual income. Data on Gini coefficients are taken from the SWIID database (Solt, 2019).

developed countries, and how it correlates with levels of income inequality.

The earlier literature on carbon and gasoline tax incidence has generally looked at tax incidence for only one country and one point in time – a single year, or an average over three years or so. These studies have thus not been able to analyse the determinants of tax incidence or, more specifically, the relationship between regressivity and income inequality over time, or across countries. In the concluding chapter of a book – that compiles a number of studies on gasoline tax incidence – Suits indices and Gini coefficients of the studies included are listed in a table, and the authors conclude that "there is no very obvious relation" between the two measures (Sterner, 2012b, p. 319). However, the authors compare countries with drastically different economies and level of GDP per capita, such as Ghana, Tanzania, India, the US, UK, and Germany. The income elasticity of demand for transport fuel vary a lot depending on average income, with income elasticities generally above 1 in low-income countries and below 1 in high-income countries (Dahl, 2012). Therefore, in countries where GDP is low but income inequality is high,

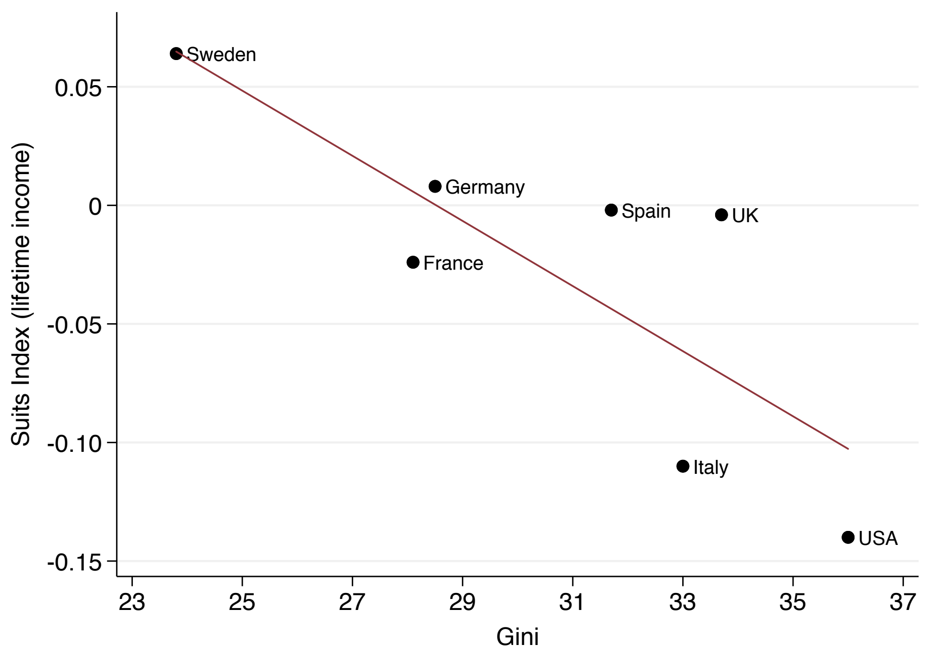


Figure 11: Gasoline Tax Incidence and Income Inequality: OECD Countries and Lifetime Income

Note: The figure depicts the correlation between gasoline tax incidence and income inequality across OECD countries. Gasoline tax incidence is measured using the Suits index and lifetime income. The equation for the trend line is $Suits = 0.39 - 0.0137 * Gini$ with a R^2 value of 0.64. The trend line crosses the x-axis at a Gini of 28.6, indicating that at a Gini above this number, excise taxes on transport fuel are regressive.

Source: The Suits index number for USA is taken from West and Williams III (2004) and the others are from Sterner (2012a). The studies use empirical household survey data to establish the incidence of transport fuel taxation in relation to total expenditure. Data on Gini coefficients are taken from the SWIID database (Solt, 2019).

gasoline and diesel are luxury goods, and we will expect a progressive tax incidence. On the opposite side of the income spectrum, in countries where GDP and income inequality is high, transport fuel is a necessity and we will expect a regressive tax incidence. Consequently, if we narrow down the list to include only OECD countries we find that there is indeed a relationship between the Suits and Gini indices: the higher the Gini coefficient, the more regressive the outcome of transport fuel taxation. To analyse this relationship in more detail, we compiled the results of studies on gasoline tax incidence that study a OECD country and use a similar empirical approach: using household expenditure data and calculating Suits index numbers using either annual or lifetime income.

The results from analyzing the relationship between the Suits and Gini indices across OECD countries are presented in Figures 10 and 11. This cross-country comparison show the same strong negative correlation that we found for Sweden over time. The results indicate that below a Gini of around 24, a carbon tax applied to transport fuel will be progressive on both measures of the Suits index, and that above a Gini of around 29, the tax will be regressive. These numbers are very similar to the ones we found when

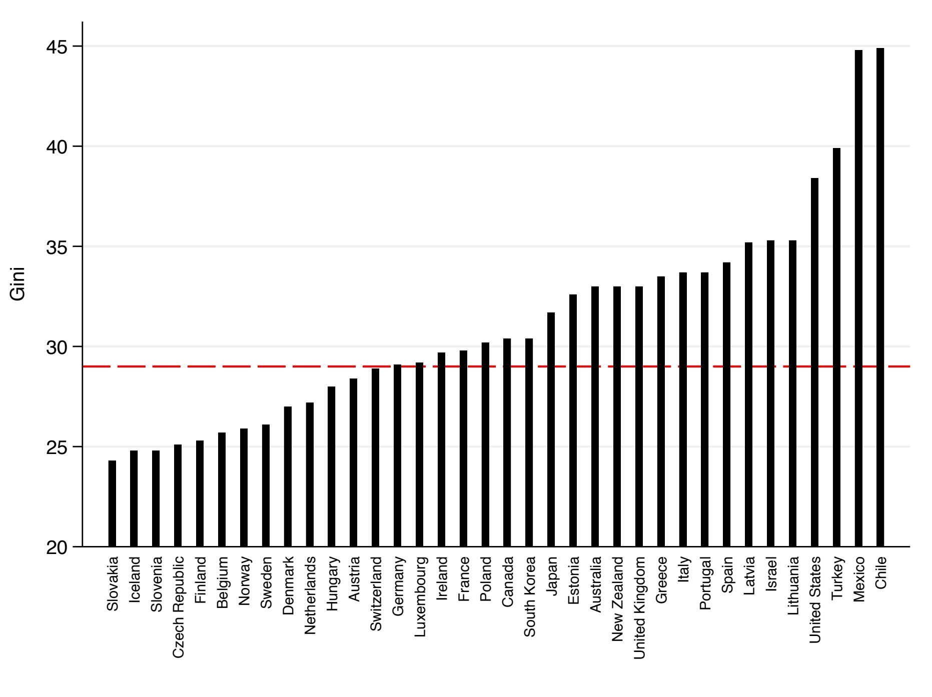


Figure 12: Income Inequality: OECD Countries

Note: Most current estimates available for the Gini coefficients of all the OECD member countries. The red dashed line crosses the y-axis at a Gini of 29. Source: SWIID database (Solt, 2019).

analyzing Swedish data over time, where the corresponding Gini numbers are (below) 22 for progressivity and (above) 30 for regressivity. (Note that, in the analysis of Sweden earlier we used Gini coefficients calculated by Statistics Sweden and here we use coefficients from the SWIID database.) With this strong negative correlation between income inequality and regressivity it is not surprising that the earlier literature on carbon and gasoline taxation that use US data finds that these taxes are, or would be, regressive. With the US Gini persistently above 30 since at least the early 1960s, this result is very much expected. The widespread assumption that carbon and gasoline taxes hurt the poor relatively more, is thus based to a large part on studies of one highly unequal country.

How many OECD countries currently have Gini coefficients *below* 24, and what percentage of total global greenhouse gas emissions is this group of countries accountable for?

Out of the 36 member countries of the OECD, currently none have a Gini coefficient below 24 (see Figure 12). Slovakia, Iceland, and Slovenia are closest with coefficients just slightly above. It is interesting to note though that the Nordic countries, that implemented carbon taxes in the early 1990s[19], had Gini coefficients well below 24 at the time - an average of 22.5. This indicates that the carbon taxes were then likely progressive - using both annual and lifetime income - making distributional effects less of a concern for the countries' policy makers. The relatively equal distribution of income

[19] All but Iceland, which waited until 2010 to implement a carbon tax.

Table 3: Carbon Tax Implementation in OECD Countries

Country	Year of implementation	Gini at implementation	Status
Finland	1990	21.0	in place
Sweden	1991	22.6	in place
Norway	1991	22.8	in place
Denmark	1992	23.4	in place
Switzerland	2008	29.5	in place
Iceland	2010	26.0	in place
Australia	2012	32.7	repealed
France	2014	29.8	in place

Source: Main source is the Carbon Pricing Dashboard from the World Bank. Gini coefficients are taken from the SWIID database (Solt, 2019).

in the Nordic countries in the early 1990s may thus explain why these countries were the first to apply carbon taxes.

Similarly, how many OECD countries currently have Gini coefficients *above* 29, and what percentage of total global greenhouse gas emissions is this group of countries accountable for?

Out of the 36 current member countries of the OECD, 23 of them have a Gini coefficient above 29. This ”above 29” group includes large emitters of greenhouse gases such as the United States, Japan, Germany, Canada, Mexico, Australia, and the United Kingdom. Taken together, the ”above 29” group is responsible for 31 percent of global greenhouse gas emissions (CAIT Climate Data Explorer, 2017).

Table 4 lists the OECD countries that currently have, or had, carbon taxes in place, and the respective Gini coefficients in the year of implementation. Of these, Switzerland, Australia, and France had Gini coefficients above 29. The Swiss carbon tax, however, only covers fossil fuels used for heating, and in 2015, 92 percent of voters rejected an initiative to replace the countries value-added tax with a general carbon tax. Australia repealed their carbon tax in 2014, only two years after it was implemented, and France is currently experiencing large public protests, the ”Gilets jaunets” (yellow vests) movement, in part due to the perceived unfair burden that the carbon tax puts on lower-income households. In response to the protests, French President Macron announced in December of 2018 that they would cancel the planned increase of the carbon tax rate in 2019.

Our results from studying regressivity over time in Sweden and across OECD countries have implications for the political economy of carbon taxation. If carbon taxes at the consumer level becomes more regressive with growing income inequality it will be politically more difficult to implement a carbon tax in a country with a relatively high Gini coefficient. Large income inequality also increases the need to offset the regressive distributional effect by other means, such as revenue recycling via lump-sum transfers and reducing the payroll tax, creating a more intricate tax policy.[20]

One could argue, though, that an already high level of income inequality can be seen as revealing a low preference for equality in the country (Lambert, Millimet, and Slottje, 2003) – the countries social welfare function is relatively straight, with little curvature. Therefore, regressivity from carbon taxes may not be an issue among voters and policymakers in highly unequal countries. Furthermore, note that it is not only the level of income inequality that matters for the distributional effect. The nature of the good that is taxed is also important. In countries with relatively low GDP per capita, transport fuel is often a luxury good – having an income elasticity of demand above unity – and a carbon tax on transport fuel would there be progressive, and growing income inequality would increase this progressive effect.[21] In high-income countries, however, a carbon tax would be added to goods that typically are necessities; transport fuel, food, heating, and electricity. Hence, a carbon tax will likely be regressive in rich countries, and more so the more unequal the distribution of income in the country.[22]

Lastly, a more general result that follows from the findings in this paper is that in countries with relatively equal distribution of income – e.g. the Nordic countries in the early 1990s – consumption taxes will be close to proportional in their tax incidence (no matter the income elasticities of demand), whereas in countries with high levels of income inequality, the incidence of consumption taxes will be quite regressive for necessities and quite progressive for luxuries.

5 Conclusion

This empirical analysis of the Swedish carbon tax shows that the tax is regressive when measured against annual income but progressive when measured against lifetime income. That moving from annual to lifetime income reduces the measured regressivity of carbon and fuel taxes is a result that matches what is found in the earlier literature. However, where the earlier literature generally have looked at tax incidence in only a single year, this study analyses distributional effects over more than a decade, allowing us to estimate changes in regressivity over time. Furthermore, evaluating the determinants of tax

[20]On January 17th 2019, an opinion article called the "Economists' Statement on Carbon Dividends" was published in the Wall Street Journal (Akerlof et al., 2019). More than 3500 US economists co-signed the statement that called for the implementation of a carbon tax in the US. One of the listed policy recommendations was to return all the revenue to US citizens through lump-sum transfers so to "maximize the fairness and political viability of a rising carbon tax". A similar statement was later released and signed by economists in Europe.

[21]Sager (2019) finds that a global carbon tax will be regressive in high-income countries such as Sweden and the US, but progressive in developing countries such as Indonesia and China.

[22]A broad carbon tax would also affect some luxury goods in rich countries, such as airline travel, and thus have a progressive effect in that section of the economy (Fouquet and O'Garra, 2020).

incidence indicate that changes in income inequality is the explanatory variable with the largest predictive power. If transport fuel is a normal good and a necessity – having an income elasticity of demand below one – this, together with growing income inequality, will lead to a carbon tax incidence where low-income households increasingly bear a larger burden of the tax relative to richer households, whether or not their income is measured using an annual or a lifetime approach. At the time of implementation, annual disposable income was rather evenly distributed in Sweden, and the carbon tax incidence was thus likely proportional, or even progressive. Since then, however, income inequality has steadily grown, making the carbon tax increasingly regressive.

After the Paris Agreement was signed in 2015, countries around the world are trying to find ways to reach their nationally determined contributions toward the common goal of limiting global warming. Economists are, in a united and unprecedented manner, recommending the implementation of carbon taxes as the most environmentally and economically efficient way to reach these emission abatement targets. At the same time, income inequality in high-income countries has steadily risen over the last forty years, in some cases to levels not seen since the late 19th century. It is in this context of growing income inequality and an urgency to tackle climate change that the results of this paper are the most relevant. If rising income inequality makes the distributional effects of carbon taxes more regressive, it will be politically more difficult to implement carbon taxes in countries with high and increasing inequality. The equity argument against taxation will be more salient, giving opportunities for opponents to attack the tax. Unfortunately, income inequality is high in precisely the OECD countries that are large emitters of greenhouse gases, such as the US, Japan, Germany, Canada and Australia. And where income inequality is relatively low, or carbon taxes already are implemented, such as the Nordic countries, emissions of greenhouse gases are small compared to the global total. To increase the political viability and perceived fairness of carbon taxes, policy-makers in the major economies of the world therefore need to design a carbon tax policy that includes revenue-recycling mechanisms, reductions of distortionary taxes, or other means to offset the regressive effect.

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A Appendix: Data Sources

- Household expenditure in Sweden 1999-2012. Source: Statistics Sweden (2019). The micro-data is only available through agreements with Statistics Sweden.
- Gini coefficients for Sweden. Measured using data on disposable income, excluding capital gains. Source: Statistics Sweden. Available at: statistikdatabasen.scb.se.
- Gini coefficients for OECD countries. Measured using data on disposable income (after tax and transfers). Source: The SWIID Database. Available at: https://fsolt.org/swiid/.
- GDP per capita in Sweden (2005 SEK). Expenditure-side real GDP, divided by population. Source: Statistics Sweden (2015). Available at: statistikdatabasen.scb.se.
- Urban Population. Measured in percentage of total. Source: The World Bank (2015) WDI Database. Available at: data.worldbank.org/indicator.
- Unemployment rate in Sweden. Percentage of total labor force. Source: Statistics Sweden (2015). Available at: statistikdatabasen.scb.se.
- Gasoline price in Sweden. Measured in 2005 Swedish Kronor. Source: SPBI (2016). Available at: spbi.se/statistik/priser.

B Appendix: Suits Index

The Suits index is inspired by, and related to, the Gini coefficient that is regularly used to measure income inequality. The Gini coefficient uses the Lorenz curve of accumulated percentage of total income against the accumulated percentage of population to measure income inequality (Deaton and Muellbauer, 1980). The Suits index, on the other hand, measure the progressivity of a tax by, similar to a Lorenz curve, plotting the accumulated percentage of tax burden against the accumulated percentage of income (Suits, 1977).

To illustrate how the Suits index and Gini coefficient are calculated we use household data from 2005 in Sweden, presented in Table 4. Column 1 lists households in order of annual income, separated into deciles. Column 2 and 3 contain the corresponding accumulated percentage of annual income and total expenditure. Lastly, the final column contains the accumulated carbon tax expenditure by the same households. In Figure 13 we plot the income data in column 2 on the vertical axis against the data in column 1 on the horizontal axis and obtain the Lorenz curve, *0CB*, of income distribution in Sweden in 2005. The 45-degree diagonal line *0B* is the Lorenz curve for an exactly equal distribution of income, and the farther the Lorenz curve bows away from this diagonal, the greater is income inequality.

Table 4: Cumulative Income, Expenditure and Carbon Tax Burden

Population Decile	Annual Income	Total Expenditure	Carbon Tax
1	4.37	9.72	5.86
2	11.35	18.07	11.29
3	19.29	26.86	21.42
4	28.23	36.18	29.77
5	37.63	45.13	39.75
6	47.65	54.54	50.15
7	58.64	64.97	61.45
8	69.92	75.34	73.74
9	82.76	86.84	86.84
10	100	100	100

Note: Columns 2-4 provides the accumulated percentages. Carbon tax burden was calculated for each decile as the percentage of total carbon tax expenditure.
Source: Calculated using HUT data from 2005 (Statistics Sweden, 2019a).

The Gini coefficient is computed as the area between the diagonal line *0B* and the Lorenz curve *0CB*, divided by the area in the triangle *0AB* in Figure 13. The coefficient ranges from 0, complete equality, to 1, complete inequality – in this article we express the coefficient as a percentage, ranging from 0 to 100.

Now, Figure 14 plots the accumulated percentage of carbon tax burden on the vertical axis – column 4 in Table 4 – against the accumulated percentage of income and total

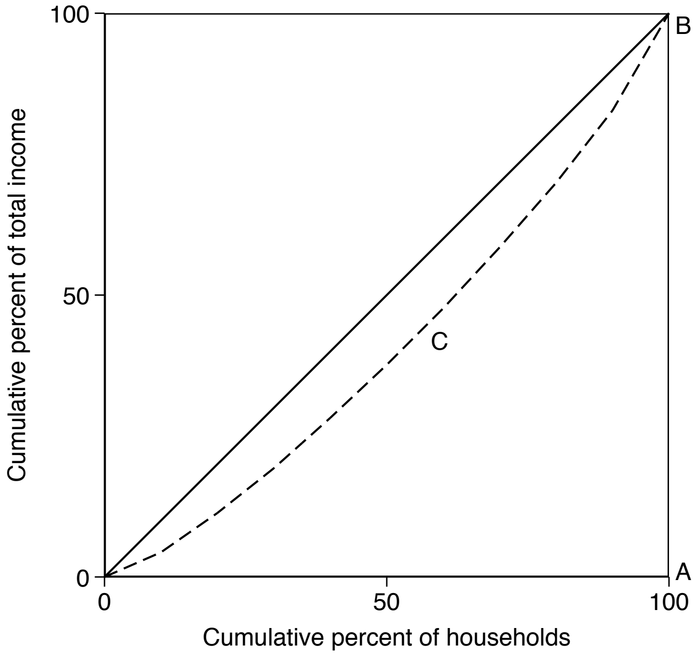
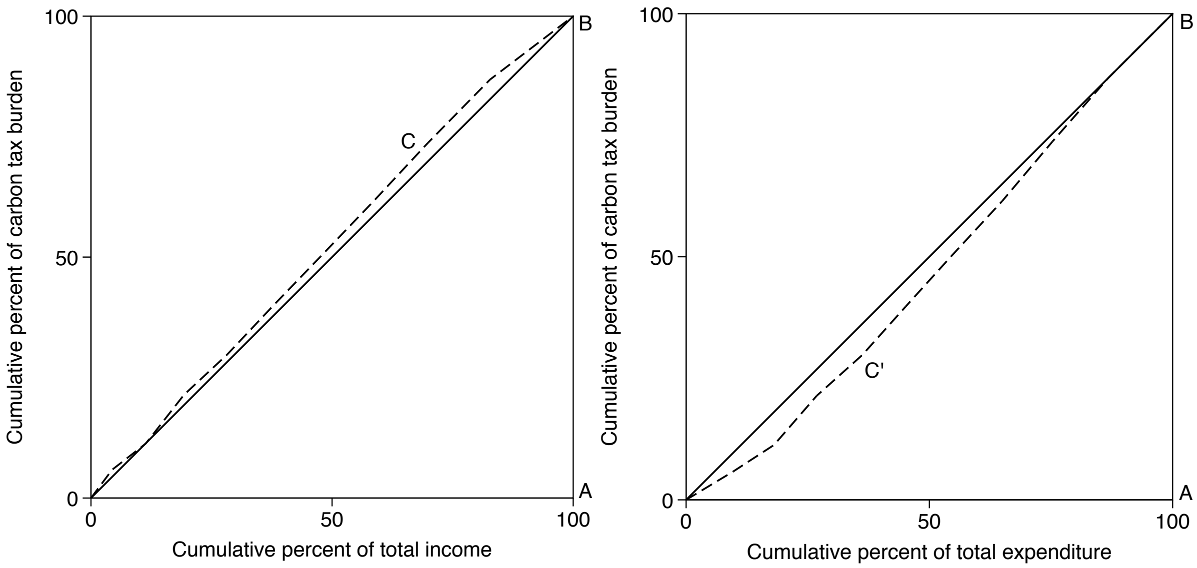


Figure 13: Lorenz Curve of Annual Income in Sweden 2005



(a) Annual Income (b) Total Expenditure

Figure 14: Concentration Curves for Carbon Tax

expenditure. Note the similarity between these concentration curves and the familiar Lorenz curve, with the difference that accumulated total income and total expenditure is now on the horizontal axis instead of the vertical.

A proportional tax incidence is illustrated with the 45-degree diagonal line *0B* in Figure 14(a). Along this line, the poorest decile, that earn 4.37 percent of total annual income, bear 4.37 percent of the carbon tax burden. Similarly, the 20 percent of poorest households, that together earn 11.35 percent of total annual income, bear 11.35 of the tax burden, and so on. With a regressive tax, the lower income deciles pay a share of the carbon tax that exceeds their percentage of total income, and the concentration curve thus arches above the diagonal line, illustrated here with the curve *0CB*. For instance, the poorest decile earns 4.37 percent of total income, but they bear 5.86 percent of the carbon tax burden.

If, instead of annual income, we use total expenditure as our income measure, we find that the carbon tax incidence is progressive, and the concentration curve is now positioned below the diagonal line; illustrated here with the curve *0C'B* in Figure 14(b). The poorest decile spends 9.72 percent of cumulative total expenditure but bear only 5.86 percent of the carbon tax burden. Similarly, the two poorest deciles spend 18.07 percent of cumulative total expenditure, but bear only 11.29 percent of the carbon tax burden, and so on.

We now have the information needed to estimate the carbon tax incidence in 2005. To compute the Suits index we first define the area of the triangle *0AB* in Figure 14 as K, and the area below the concentration curve and the horizontal axis as L. Analogous to how we computed the Gini coefficient, the size of the Suits index is given by the area between the diagonal line and the concentration curve, so that

$$S = \frac{K - L}{K} = 1 - \frac{L}{K} \tag{20}$$

For a regressive tax, the concentration curve is positioned above the diagonal line, L is thus larger than K, and the Suits index is negative: $-1 \leq S < 0$. For example, the concentration curve *0CB* above gives a Suits index of -0.046.

For a progressive tax, the concentration curve is positioned below the diagonal and the area L is smaller than K; hence, the Suits index is positive for a progressive tax: $0 < S \leq 1$. The concentration curve *0C'B* in Figure 14(b) gives a Suits index of +0.07. With a progressive tax, $L = K$, so $S = 0$.

With accumulated income, y, on the horizontal axis, ranging from 0 to 100, and tax burden, T, on the vertical axis, the area L under the concentration curve is given by the integral

$$L = \int_0^{100} T(y)dy \tag{21}$$

and the Suits index is thus computed as

$$S = 1 - \frac{L}{K} = 1 - (1/K)\int_0^{100} T(y)dy \tag{22}$$

However, our date is arranged in deciles, and with discrete data we need to use an approximation for the value of L, giving us

$$S \approx 1 - \frac{\sum_{i=1}^{10}(1/2)[T(y_i) + T(y_{i-1})](y_i - y_{i-1})}{5000} \tag{23}$$

where the area of the triangle K is the same for all taxes, and easily computed as $K = (100 * 100)/2 = 5000$.

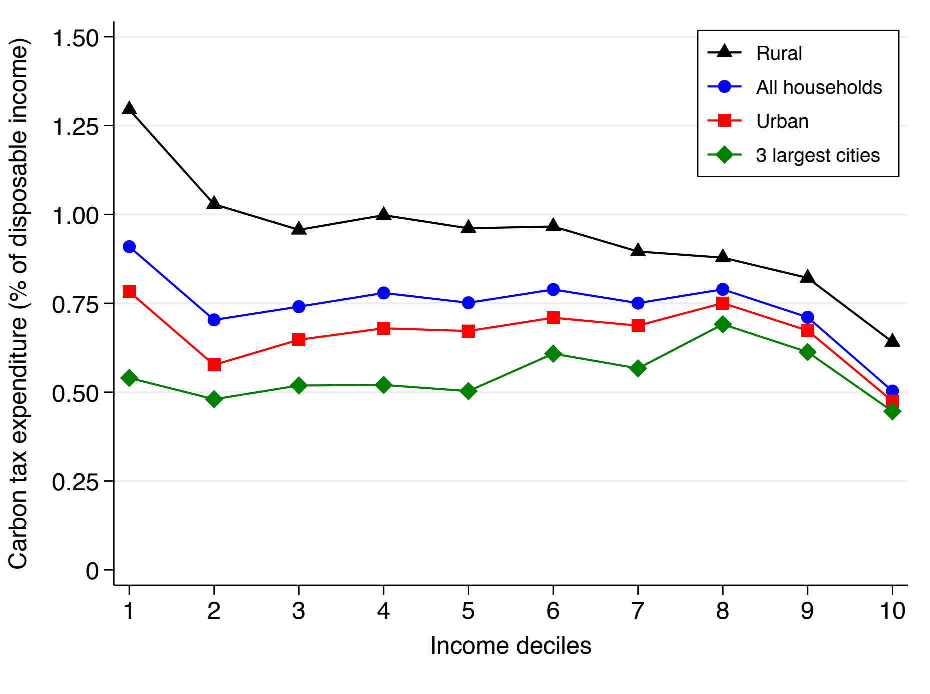


Figure 15: Average Carbon Tax Incidence Across Geographical Areas: 1999-2012

C Appendix: Further Analysis of Distributional Effects

In addition to differences in carbon tax burden across income deciles there may also be differences in tax incidence across geographical areas and age groups. Policy-makers especially may be interested in knowing if certain groups bears a relatively large tax burden, such as rural households and retirees. Furthermore, as an advantage of having household expenditure data spanning 13 years, from 1999-2012, we can analyse how households make long-rung adjustments on the extensive margin in response to the carbon tax; such as a switch to more fuel efficient vehicles and an increased use of public transport.

C.1 Urban vs. Rural

When analysing carbon tax incidence across geographical areas in Sweden there are two main findings. First, on average, rural households have higher carbon tax expenditures, both in ”dollars and cents” and as a percentage of disposable income or total expenditure – this is true across all deciles. Second, the carbon tax is more regressive in rural areas than in urban. Comparing the average Suits indeces over 1999-2012, using annual income, we find -0.079 in rural areas and -0.038 in urban. Similarly, using lifetime income, the average over 1999-2012 is +0.037 in rural areas and +0.088 in urban. The difference between rural and urban areas is even starker if we focus only on urban households in the three largest cities in Sweden: Stockholm, Gothenburg, and Malmö. The carbon tax

Table 5: Lifecycle Patterns in Carbon Tax Expenditure

	Carbon Tax Expenditure as Percentage of		Total Expenditure/ Disposable Income
Age Group	(1)	(2)	
<25	0.65	0.59	1.15
25-34	0.67	0.71	0.97
35-44	0.70	0.79	0.90
45-54	0.72	0.85	0.86
55-64	0.73	0.91	0.82
65+	0.64	0.77	0.86

Note: (1) Disposable income; (2) Total expenditure. Average carbon tax expenditure over the years 1999 to 2012.

incidence in the three largest cities is roughly proportional when using temporary income, -0.006, and highly progressive when using lifetime income, +0.130.

Note that the change in urbanisation has been small since the introduction of the carbon tax. In 1991, 83.2 percent of the total population lived in urban areas. This percentage increased slightly to 84.0 percent in 1999 and 85.6 percent in 2012.

C.2 Carbon Tax Burden across Age Groups

There is not much difference in the carbon tax expenditure share across age groups. The overall pattern, though, is that the share increases with age up until retirement, when the head of the household is 65+. Households where the head of the household is between the age of 55-64 thus have the largest share in relation to annual disposable income and total expenditure. Retirees have the smallest tax burden of all age groups in relation to annual income, and young households, where the head of the household is younger than 25, have the smallest tax burden in relation to total expenditure.

There is also evidence in the data in support of a lifecycle smoothing pattern in overall consumption. In young households, total annual expenditure is 1.15 times larger than annual income, indicating that the household is borrowing against future income. The ratio between expenditure and income then decreases with the largest savings rate for households where the head of the household is between the age of 55-64. After retirement, the savings rate decreases, again lending support to the consumption smoothing hypothesis. Overall, the consumption to income pattern lends support in favour of using "lifetime income" as our primary income measure when analysing carbon tax incidence.

C.3 Extensive Margin Analysis

Measuring changes in the expenditure on and use of public transport over time and across households in different geographical regions is difficult since the cost of public transport is not constant across time and there are large geographical differences – public transport is generally more expensive in urban areas (Trafikanalys, 2014:15). However, measuring the percentage of households that report zero fuel expenditure provides an indirect measure of use of public transport. With this measure we also capture households that make other changes on the extensive margin, such as using a bicycle, or walking back and forth from work.

Figure 16 track the percentage of households that report zero fuel expenditure over time and across geographical areas. There is an upwards trend from 2005 and onward, but before that the trend is fairly flat. Furthermore, the trend is similar across geographical areas, but there are differences in levels. On average, twice as many households in urban areas have zero fuel expenditure compared to rural households: 16 percent versus 8 percent. The difference is even larger if we compare households in rural areas with those in one of the three largest cities, where on average 22 percent of households report zero expenditure on transport fuel. These results illustrate geographical differences in the ability to "escape" the carbon tax by having access to public transport or the ability to walk or cycle back and forth from work. This ability is, unsurprisingly, higher in urban areas. Good access to public transport affects the distributional impact of the carbon tax by providing low-cost alternatives to driving a car, especially for households with relatively low disposable income. We saw this earlier when we compared the Suits indeces: the carbon tax is more regressive (less progressive) in rural areas.

There are also large differences in levels across income groups. In the bottom half of the income distribution, deciles 1 to 5, around 35 percent of households report that they don't have any fuel expenditure – average for the years 1999-2012. This can be contrasted with the upper half of the income distribution where, on average, only 7 percent of households have zero fuel expenditure. This result indicates that lower-income households make more frequent use of public transport. It also shows that there are horizontal inequities in the payments of the carbon tax, inequities that are hidden when we focus on average carbon tax expenditure across deciles (a similar point is made by Poterba

Table 6: Zero Fuel Expenditure Across Deciles 1999-2012

Income decile	1	2	3	4	5	6	7	8	9	10
Zero fuel expenditure	54.5	46.2	32.3	22.2	15.8	10.7	7.2	5.0	5.4	5.2

Note: the zero fuel expenditure variable is computed as the percentage of households in each decile that report an expenditure smaller than 1 SEK on gasoline and diesel, and averaged over the time period 1999-2012.

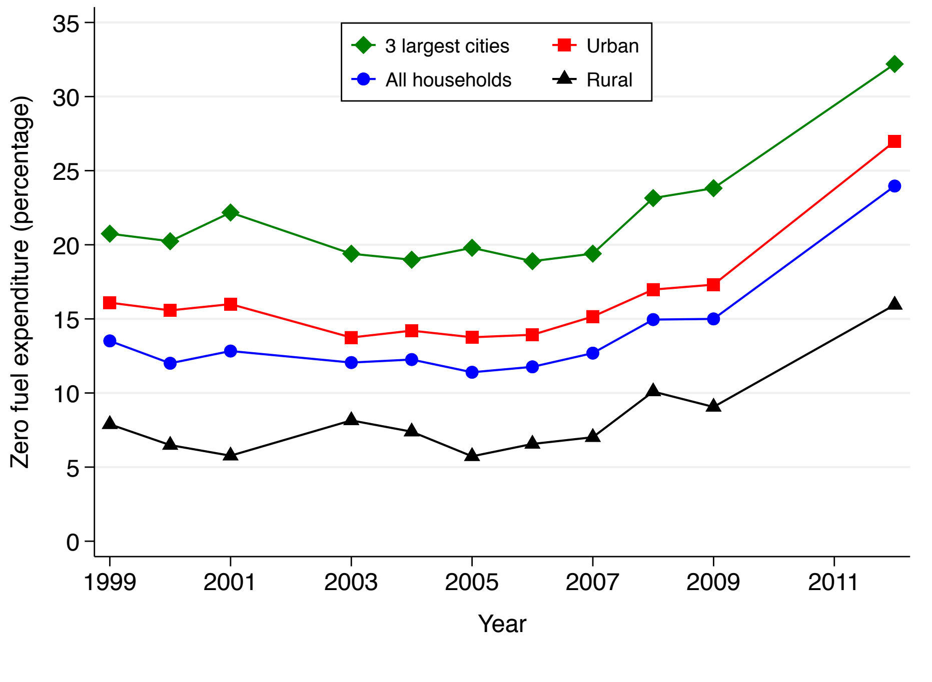


Figure 16: Households with Zero Fuel Expenditure 1999-2012

(1989); Rausch, Metcalf, and Reilly (2011), and Cronin, Fullerton, and Sexton (2019)). If we drop from our sample the households that report zero fuel expenditure, this affects the carbon tax incidence quite dramatically. For instance, in 2003, the Suits index using annual income is -0.015 for the full sample of households, indicating a slightly regressive to proportional tax incidence. However, if we drop households with no expenditure on transport fuel, the Suits index decreases to -0.122, indicating that the carbon tax is quite regressive. Using this subsample, the carbon tax is now regressive also with a lifetime income approach: the Suits index decreases from +0.081 to -0.020.

Our last measure of changes on the extensive margin is to analyse changes to the vehicle fleet. Figure 17 tracks the total percentage of passenger cars that use other engine fuels than gasoline. The large increase in the number of non-gasoline passenger cars from around 2005 and onward is due to the increasing use of diesel, but also ethanol, as transport fuel, and later on the introduction of hybrids on the market. In total, more than 43 percent of passenger cars in 2018 use other fuels than gasoline. These are all fuels used in engines that are more fuel efficient than the traditional gasoline engine. It is however hard to empirically establish how much this change on the extensive margin is attributable solely to the carbon tax and how much is possibly due to other policies that affect the transport sector.

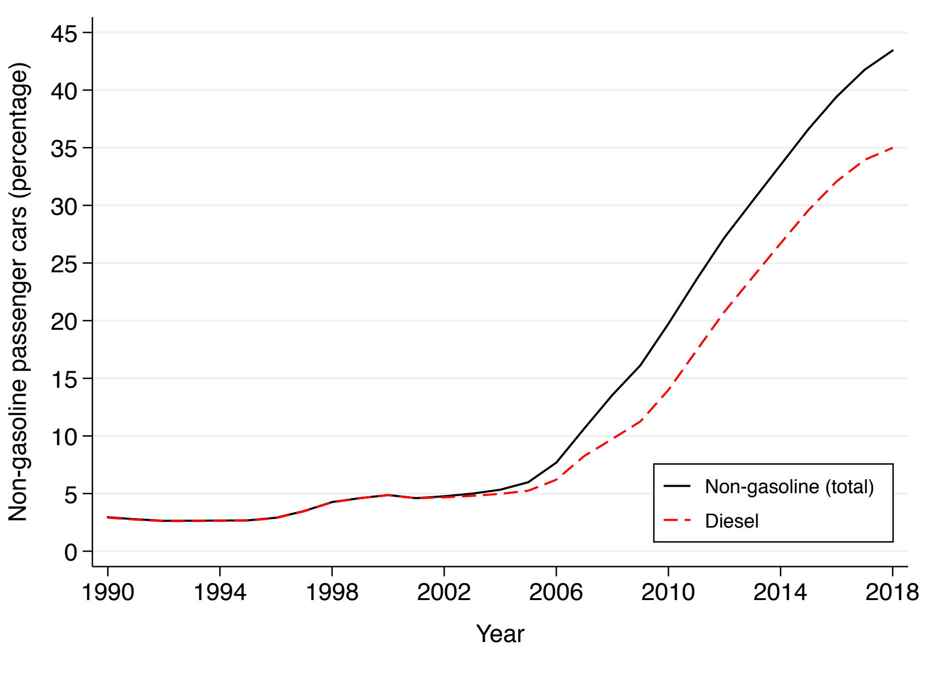


Figure 17: Percentage of Non-Gasoline Passenger Cars 1990-2018

Note: the total of non-gasoline cars includes electric cars, hybrids, and cars that use diesel, natural gas, or ethanol as fuel. Source: Transport Analysis (2018).

D Appendix: Regression Results

To test the predictive power of the explanatory variables of price, income, unemployment and access to public transport, the following OLS regression model was tested:

$$S_t = \alpha + X_t \beta + \epsilon_t \tag{24}$$

where S_t is the Suits index measured against annual income, X_t is a vector of control variables: gini coefficient, gasoline price, GDP per capita, urbanization, unemployment, and a time trend, and finally, ϵ_t is idiosyncratic shocks. We use time-series data for Sweden from 1999-2012, with N=11 and missing data for the years 2002, 2010 and 2011.

The results from the first five OLS regressions, columns (1) to (5) in the upper half of Table 7, shows that all the explanatory variables, except unemployment, significantly affects the Suits index coefficient. Changes in income inequality has the largest predictive power with an R^2 value of 0.93. An increase in any one of the independent variables increases the regressiveness of the Swedish carbon tax. The negative sign on the urbanization coefficient is somewhat surprising though, since we would expect that an increase in the proportion of people living in urban areas would lead to a more progressive tax incidence. However, when controlling for changes in income inequality, columns (8) and (10), the coefficient on the urbanization variable turns positive but is now no longer significant. In fact, when controlling for changes in income inequality, columns (6) to (9),

Table 7: Suits Index Regressions (Annual Income)

	(1)	(2)	(3)	(4)	(5)
Gini	-0.0207***				
	(0.002)				
Gasoline price		-0.0229***			
		(0.004)			
GDP per capita			-0.0103***		
			(0.002)		
Urbanisation				-0.0667***	
				(0.015)	
Unemployment					-0.00276
					(0.015)
R^2	0.927	0.676	0.628	0.728	0.005
	(6)	(7)	(8)	(9)	(10)
Gini	-0.0221***	-0.0218***	-0.0241***	-0.0210***	-0.0243***
	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
Gasoline price	0.00163				-0.00026
	(0.006)				(0.008)
GDP per capita		-0.00209			0.00395
		(0.003)			(0.007)
Urbanisation			0.0309		0.0456
			(0.026)		(0.040)
Unemployment				0.00423	0.00465
				(0.003)	(0.007)
R^2	0.928	0.931	0.935	0.938	0.943
Observations	11	11	11	11	11

Note: The dependent variable is the estimated Suits coefficients from analysing the carbon tax incidence in relation to annual disposable income. The real gasoline price and real GDP per capita are measured in 2005 Swedish kronor (tens of thousands). Urban population is measured as percentage of total population. Unemployment is measured as percentage of total labor force. The time trend is omitted from the output in specifications (6)-(10) and the constant is omitted from the output in all specifications. Standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

and running the full model, column (10), the coefficients on the other variables switches signs. Furthermore, all explanatory variables, except income inequality, are insignificant in specifications (6)-(10). The coefficient on the Gini index is however highly significant and similar in size in all model specifications where it is included.