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

Julius J. Andersson[1]*, Giles Atkinson[2]†

[1]Stockholm School of Economics
[2]London School of Economics and Political Science

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Abstract

We present a simple model that shows how the two parameters of income inequality and the income elasticity of demand determine changes in the distributional effect of a consumption tax; with rising inequality increasing the regressivity of a consumption tax on necessities. We test the model's predictions by analysing the Swedish carbon tax on transport fuel. We find that the tax is increasingly regressive over time, which is highly correlated with a rise in income inequality, and that the distributional effect moves from regressive to progressive when switching from annual income to the more evenly distributed measure of lifetime income.

JEL classification:

Keywords: Distributional effects, income inequality, carbon tax, climate change

*Contact: julius.andersson@hhs.se. Stockholm School of Economics, Box 6501, 113 83 Stockholm, Sweden.

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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 important: how is the tax burden distributed across households?

The debate around the distributive implications of carbon taxes is often focused on the concern that they may be regressive; that the tax burden increases less than in proportion to income.[1] If not proportional, taxes are either regressive or progressive, and there are degrees of each – which may change over time or be different across countries.

In this paper, we derive a simple model that demonstrates how income inequality and the income elasticity of demand determine changes in the distributional effect of a consumption tax. More specifically, the model shows that rising income inequality increases the degree of regressivity of a tax on necessities – with necessities being defined as normal goods with an income elasticity below one. If we further assume that the income elasticity of demand is heterogeneous across income groups, with decreasing elasticities as income increases, this will amplify the increase in regressivity as inequality rises.

We test our model's predictions by analysing 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. First, we find that the distributional effect changes from regressive to progressive when switching the income measure, from annual income to the more evenly distributed measure of lifetime income. Second, we find that increases in regressivity over time are highly correlated with a rise in income inequality. Lastly, with a numerical exercise, we test the importance of the assumption of heterogeneous income elasticities and find that the assumption is needed to replicate the change in the distributional effect that we observe in Sweden over time.

We end the paper by analysing previous studies of distributional effects of gasoline taxation across high-income countries. In line with the prediction of our model, we again find a strong correlation between the level of income inequality and the degree of tax progressivity[2]; the higher the level of inequality in a country, the more regressive are gasoline taxes.

There are two reasons why we chose to test our model using a case study of carbon taxation. First, to mitigate climate change, economists recommend applying a carbon tax to typical necessities – transport fuel, food, heating, and electricity – and, to increase efficiency, globally across countries with varying levels of income inequality. The predic-

[1] With a concave (inequality averse) social welfare function, a regressive distributive effect reduces the level of social welfare.

[2] The terms "tax progressivity", "distributional effects", and "redistributive effects" are used interchangeably throughout the paper.

tions of our model are thus especially relevant for analyses of the distributional effects of carbon pricing. Second, 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. For instance, 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 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 an important reason why only a few countries have adopted carbon taxes, and why we see a growing literature analysing different policy designs to reduce its regressiveness – using, for instance, revenue recycling or reduction of distortionary taxes (Cronin, Fullerton, and Sexton, 2019; Goulder et al., 2019). We believe that the theory and findings presented in this paper can contribute to our understanding of the need and scope for such tax policy designs in different settings.

The focus of this paper is on the applied question of the distributive effects of a consumption tax across households, and, more specifically, the determinants of changes to tax progressivity over time or across countries.[3] A carbon tax is a Pigouvian tax that ensures that economic actors internalise the negative externality of carbon emissions, thereby restoring efficiency. As such, the distributive effects of the tax may be seen as of second order importance, best addressed with an additional instrument or tax policy – for example, revenue recycling or reduction of income tax rates for low-income households. However, such measures may be costly and the ability to fully offset adverse distributive effects are limited by the information available to policymakers. Furthermore, due to heterogeneity of preferences, leading to horizontal inequites – large differences in tax burden within groups with similar levels of income – regressive effects are difficult to undo even with targeted reductions in income tax rates or rebates. Therefore, with regards to acceptability and the political constraints around carbon pricing, the distributive effects are of first order importance (Stiglitz, 2019), and changes to tax progressivity may explain variations over time or across countries in public opposition to commodity taxes, such as

[3]We are here analysing distributive effects from the use-side of income, and how the degree of progressivity may change over time, and not analysing distributive effects of local environmental damages from the taxed good nor tax incidence in the form of how much of the burden that falls on consumers versus firms. Depending on the pass-through to consumers, a consumption tax could have a separate incidence on the source-side of income – wages, capital income, and transfer incomes. A simulation study by Goulder et al. (2019) finds that a carbon tax in the US would likely be regressive on the use-side but progressive on the source-side. An analysis by Andersson (2019), however, finds that changes to the energy and carbon tax rates on transport fuel in Sweden are both fully passed through to consumers.

gasoline taxes.

This paper address a somewhat overlooked area of the literature: studies of the determinants of tax progressivity across time and across countries. There is much support in the economics literature that carbon and transport fuel taxes are indeed regressive.[4] However, most of this earlier literature study 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 unrepresentative of an average high-income country when it comes to variables that are arguably important for the redistributive effects of carbon and fuel taxes. For instance, in the US, relative to all OECD (high-income) countries, income per capita is high but unequally distributed, carbon dioxide 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. Results from US studies may therefore be atypical, and to better understand how distributional effects differ across countries we should identify the main determinants of the degrees of tax progressivity of consumption taxes. An analysis of determinants is only possible, however, if we explore redistributive effects across multiple countries or for one country over multiple years.

Lastly, the model presented in this paper can help explain two common findings in the literature on distributional effects from transport fuel taxation. First, a frequent result is that how we measure income matter; a switch from annual to lifetime income is typically found to reduce the regressivity of gasoline taxation (Poterba, 1989, 1991; Hassett, Mathur, and Metcalf, 2009; Sterner, 2012a). We show that it does so by switching to an income measure that reduces the measured level of inequality, and by effectively assigning a zero income elasticity of demand for gasoline across all households.[5] A second common finding is that tax progressivity vary across countries, typically between richer and poorer countries (Sterner, 2012b; Sager, 2019). Differences in income elasticities across countries – gasoline being a necessity in high-income countries but a luxury good in many developing countries – together with different levels of inequality, can explain this finding.

The main contribution from this paper is the highlighting of the importance of income inequality for distributional outcomes. It thus adds to the expanding literature in economics on the economic effects of growing inequality in high-income economies, as well as adding to the literature on the political economy of commodity taxation.

[4]See, for example, highly cited studies by Poterba (1991); Metcalf (1999); Parry (2004); West and Williams III (2004); Bento et al. (2009); and, Grainger and Kolstad (2010).

[5]This is true especially for those studies that use total expenditure on goods and services in a year as a proxy for lifetime income.

2 The role of Income Inequality

In empirical analyses of the redistributive effects of commodity taxes we are often trying to establish if they are overall progressive or regressive. However, there are also degrees of progressivity that depends on the design of the tax and the type of good. Furthermore, the degree of progressivity may change over time – if the budget share for the specific good increases or decreases, but at different rates (and directions) across income groups. In this section we derive a model that shows how such changes in tax progressivity are determined by the income elasticity of the budget share and the level of income inequality.

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 for good i 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 if $e_i < 1$ the budget share decreases. Thus, whether or not e_i is above or below unity is commonly used to define goods as either luxuries or necessities, respectively.

Now, by introducing multiple households, we can develop a simple dynamic model of the changes to tax progressivity that follows from changes to the underlying distribution of income over time.

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.[6]

Furthermore, we assume that prices are fixed and p_i is normalised to unity. The budget share for 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 growth rates 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 growth rate of the budget share is smaller for the rich household B compared to A, we move toward a more regressive (less progressive) 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:

$$w(t+1) = w(t)\left(\frac{x(t+1)}{x(t)}\right)^{e_{i,w}} \tag{10}$$

where $e_{i,w}$ is the income elasticity of the budget share for good i. The left hand side of (9) is thus equivalent to

$$\frac{w_i^B(t+1) - w_i^B(t)}{w_i^B(t)} = \left(\frac{x^B(t+1)}{x^B(t)}\right)^{e_{i,w}^B} - 1 \tag{11}$$

The growth rate of the budget share is hence determined by two parameters: the growth

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

rate of income and the income elasticity of the budget share

$$g_w^B(t) = (1 + g_x^B(t))^{e_{i,w}^B} - 1 \tag{12}$$

For small growth rates, we can rearrange, take logs, and approximate this relationship as:

$$\ln(1 + g_w^B(t)) = e_{i,w}^B \ln(1 + g_x^B(t)) \approx g_w^B(t) = e_{i,w}^B g_x^B(t) \tag{13}$$

The same applies to the right hand side of (9) and we can thus write (9) as:[7]

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

Equation (13) shows that 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:

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

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

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

the tax will become more progressive (less regressive) over time.

Equation (14) provides 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[8], 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 (15) and (16), in the special case when income elasticities are equal across income groups, and the more general case where the elasticities may differ.

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 see a rise in *regressivity* if: income inequality increases, $g_x^B > g_x^A$, and the good is a necessity, $e_i < 1$, or if income inequality decreases, $g_x^B < g_x^A$, and the good is a luxury, $e_i > 1$. Similarly, we see a rise in *progressivity* if: income inequality increases and the good is a luxury, or if income inequality decreases and the good is a necessity.

[7]For ease of exposition, we hereafter drop the time script on the growth rates of income.

[8]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.

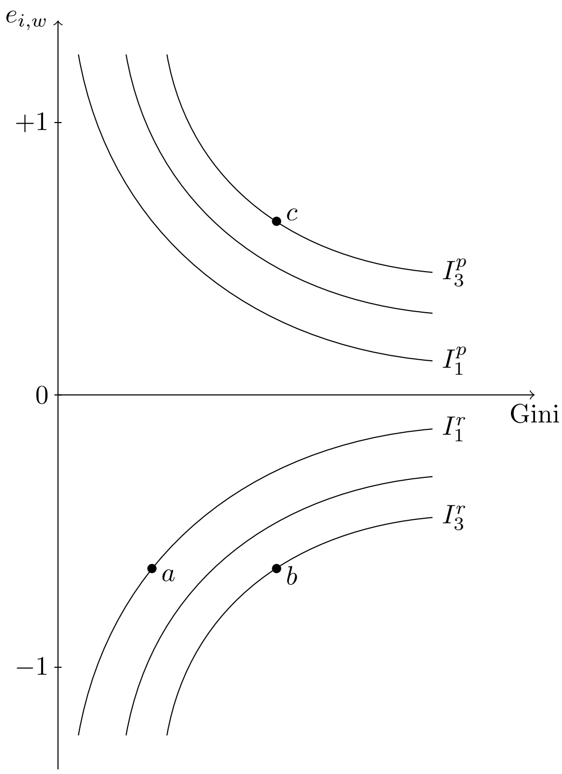


Figure 1: Isoincidence Curves

Note: Income inequality is here exemplified by the Gini coefficient. Gini is a summary statistic of inequality, taking values from 0 (complete equality) to 100 (complete inequality).

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

In the general case, when income elasticities are heterogeneous across households, we get an increase in *regressivity* 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 a rise in progressivity if the converse is true. For example, if $g_x^A = g_x^B$, giving an income growth ratio of 1, we see a rise in regressivity 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 we see an increase in progressivity.

We can illustrate with a figure the distributional effects of a consumption tax in the special case when income elasticities are equal across income groups. Figure 1 plots what we might term as isoincidence curves – along which the distributional effect is constant.[9] The isoincidence curves are a function of the income elasticity of the budget share and the level of income inequality (exemplified here by the Gini coefficient). Above the x-axis, where $e_{i,w} > 0$, the distributional effect is progressive, and below the x-axis it is regressive. Along the two axes the distributional effect is proportional; where the income elasticity of demand is unit-elastic or income is equally distributed. Furthermore,

[9]The isoincidence curves are analogous to indifference curves from consumer theory and isoquants from the theory of production.

along the isoincidence curve I_1^p the redistributive effect is progressive and along I_1^r it is regressive, and isoincidence curves further out from the origin (for example, I_3^p and I_3^r) are associated with increases in progressivity and regressivity, respectively.

We can use Figure 1 to compare distributional outcomes within a country over time or across countries at a single point in time. For example, when moving from point a to point b, the income elasticity of the budget share is unchanged but the level of inequality increases, and we obtain an increase in regressivity and reach the curve I_3^r. A movement from a to b can occur over time in a single country – as inequality rises – or across countries with different levels of inequality but similar income elasticities of demand for the taxed good. Similarly, when moving from point b to c, the distributional outcome changes from regressive to progressive – the level of inequality is unchanged but the taxed good is now a luxury good instead of a necessity. The different distributional outcomes in b and c can be exemplified by the difference in gasoline tax progressivity between a rich country where gasoline is a necessity and a developing country where gasoline is a luxury good.

Lastly, a more general result that follows from the model, and illustrated with Figure 1, is that in countries with relatively equal distributions of income, consumption taxes will be closer to proportional in their redistributive effect – no matter the income elasticities of demand – whereas in countries with high levels of income inequality, consumption taxes will be quite regressive for necessities and quite progressive for luxuries.

3 Testing the Model

To test our model and hypothesis of the role of income inequality for changes to tax progressivity we, first, analyze the distributional effects of Sweden's carbon tax on transport fuel. In turn, we look at the impact of changing the income measure, the correlation between changes to inequality and regressivity over time, and the importance of the assumption of heterogeneous income elasticities across the income distribution (the general case). Second, we test the predictions of the model by analysing previous studies of gasoline tax progressivity across high-income countries.

The Swedish Carbon Tax.—The carbon tax in Sweden was implemented in 1991 at US\$30 per ton of CO_2 and later increased quite rapidly in the early 2000s. Today, in 2021, the rate is above US\$130 per ton of CO_2, making it the world's highest carbon tax imposed on households and non-trading sectors. 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). We therefore focus our distributional analysis only on the carbon tax part of households' expenditure on gasoline and diesel, providing an estimate of the tax progressivity from the use-side of income.[10]

Data and Methodology.—The relevant data is taken from a Swedish 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 around two thousand households surveyed each year.

The HUT survey includes households with at least one person between the age of 0-79, and drawn from 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 we need to analyze distributional effects.[11]

Carbon tax burden is measured as the amount of household income that is 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. If the tax burden as a share of income decreases as we move up in the income distribution the tax will be regressive, and, conversely, the redistributive effect will be progressive if the tax burden share increases with income.

Lastly, to measure and capture changes in carbon tax progressivity over time or across countries we need a summary statistic. A useful starting point to compute such statistic is to analyse concentration curves, which plots the accumulated percentage of tax burden

[10]We are only including direct expenditure on transport fuel, and not indirect expenditure through, for instance, spending on public transport or other goods that use transport fuel as an input in production. Since the purpose of the empirical analysis is to test the predictions of the model on the determinants of changes to progressivity over time, the exclusion of indirect expenditure should not affect the overall results, assuming that the ratio of direct to indirect expenditure is rather stable. Furthermore, Ahola, Carlsson, and Sterner (2009) finds that indirect tax expenditure on transport fuel in Sweden is a very small share of the total transport fuel tax burden.

[11]To enable 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, corrects for economies of scale for large households. Different weights are, for instance, given to children and adults.

Table 1: Cumulative Income and Carbon Tax Burden

	2005		2009	
Population Decile	Annual Income	Carbon Tax	Annual Income	Carbon Tax
1	4.37	5.86	3.04	6.94
2	11.35	11.29	9.29	12.42
3	19.29	21.42	17.26	19.66
4	28.23	29.77	25.70	30.19
5	37.63	39.75	35.06	40.25
6	47.65	50.15	45.37	52.43
7	58.64	61.45	56.10	63.39
8	69.92	73.74	68.10	75.61
9	82.76	86.84	81.05	88.22
10	100	100	100	100

Note: Columns 2-5 provides the accumulated percentages of annual income and carbon tax burden.
Source: Calculated using HUT data from 2005 and 2009 (Statistics Sweden, 2019).

on the vertical axis against the accumulated percentage of income.[12]

To illustrate how concentration curves are computed and used to measure changes in tax progressivity we use household data from Sweden for the years 2005 and 2009. The first column of Table 1 lists households in order of annual income, separated into decile groups, and columns 2 to 5 contain the corresponding accumulated percentages of annual income and carbon tax burden. Now, Figure 2 shows the concentration curves for 2005 and 2009 by plotting the cumulative tax burden against cumulative income on the vertical and horizontal axes, respectively. A proportional tax is illustrated with the solid 45-degree diagonal line *0B*. Along this line, the accumulated percentage of income is equal to the accumulated percentage of tax burden. In 2005 and 2009, the lower income deciles pay a share of the total carbon tax revenue that exceeds their share of total income, and the concentration curves thus arches above the diagonal line. For instance, in 2009, the poorest decile earns around 3 percent of total income, but bear around 7 percent of the total carbon tax burden. A regressive tax thus have a concentration curve that is situated above the diagonal, and a progressive tax have a curve situated below the diagonal.[13]

The concentration curve for 2009, *0CB*, lies everywhere above the curve for 2005, and it is reasonable to describe the distributional outcome in 2009 as *more* regressive than in 2005. However, instead of plotting and comparing concentration curves for each

[12]Concentration curves are similar to the Lorenz curve, used, for instance, to compute the Gini index of inequality. With the Lorenz curve, the accumulated percentage of income is plotted against the cumulative percent of households.

[13]It is less straightforward to judge the overall progressivity when the budget shares are not monotonically increasing or decreasing – for instance, goods that are mainly consumed by the middle class, but less by the rich and poor. The concentration curve may then cross the diagonal line and we need a summary statistic to determine the overall progressivity.

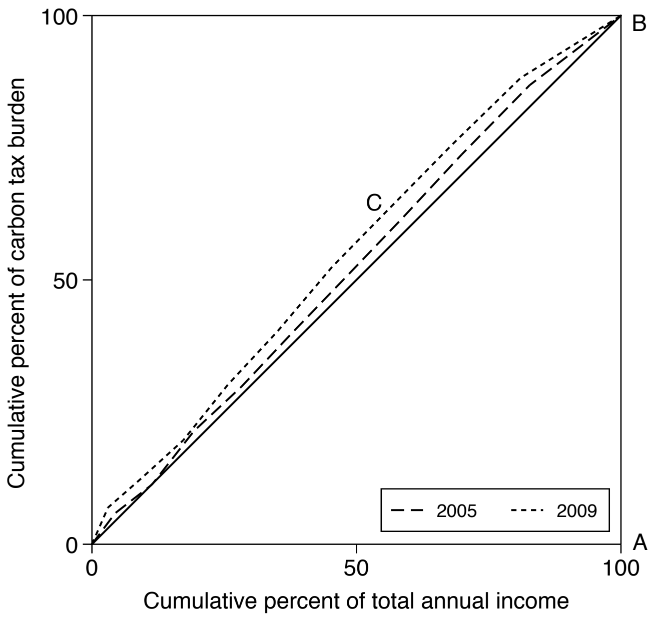


Figure 2: Concentration Curves for Carbon Tax

year it would be helpful to summarize the information given by the concentration curves with a single number. The two most common summary statistics are the Suits (1977) and Kakwani (1977) indices, and they both use concentration curves for their measure of progressivity. In the main empirical analysis we will use the Suits index, but the Kakwani index – and two more measures of progressivity – will be used for robustness tests.

The Suits index have some attractive features in that it varies from +1 to -1, with positive values indicating progressivity, negative values regressivity, and zero for a proportional tax. To compute the Suits index we first define the area of the triangle *0AB* in Figure 2 as K, and the area below a concentration curve and the horizontal axis as L. The size of the Suits index, S, is then given by the area between the diagonal line and the concentration curve, so that

$$S = \frac{K - L}{K} = 1 - \frac{L}{K} \tag{17}$$

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* gives a Suits index of -0.103.

For a progressive tax, the concentration curve is positioned below the diagonal, L is smaller than K, and the Suits index is positive: $0 < S \leq 1$. Lastly, with a proportional tax, $L = K$, so $S = 0$.

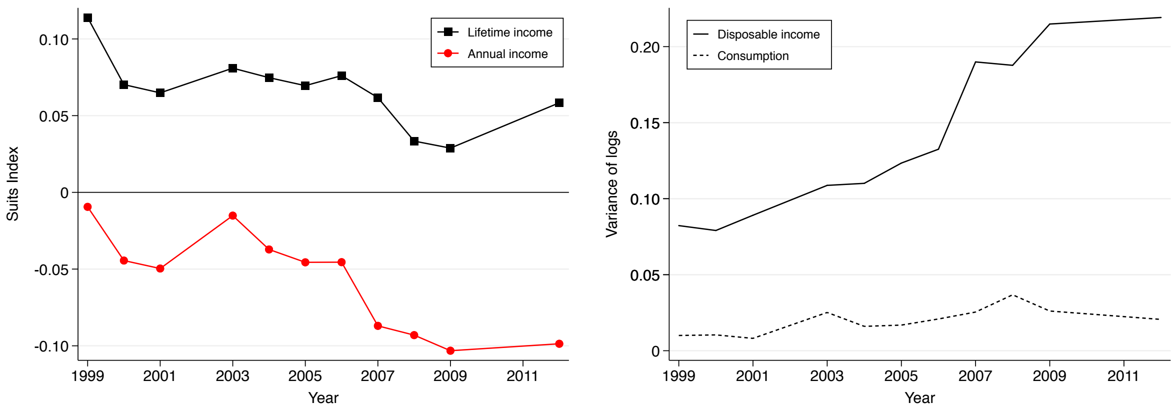
Our model shows how income inequality and the income elasticity of demand determine changes to the degree of progressivity of consumption taxes. Changes to inequality affects the cumulative shares of income and, depending on the size and heterogeneity of income elasticities, the cumulative shares of tax burden. The interaction of the two parameters thus affect the shape and position of the concentration curve, and the Suits index enables us to capture and estimate the resulting change in tax progressivity.

3.1 Annual vs Lifetime Income

Annual disposable income is most commonly used when estimating tax burden across households, but some researchers argue instead in favour of lifetime income (see, e.g., Poterba 1989, 1991). They reason that annual disposable income incorrectly estimates the income of many households in the lowest decile groups that, for instance, 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. Since we cannot measure lifetime income directly, total expenditure for each household is often used as a proxy; if consumption is always a constant fraction of lifetime income, total expenditure provides a useful substitute.

In general, studies find that carbon and gasoline taxes are less regressive, sometimes even progressive, when measured against lifetime income compared to annual income. We can use our model to explain this common finding. When we use survey data on household expenditure for analyses of tax progressivity, and change our measure of income from annual to lifetime, we change the level of income for each household but the expenditure on the good in question stays constant. Therefore, when estimating the change to progressivity that follows this change in income, the income elasticity of demand for the good is effectively treated as zero; with $e_i = 0$ a change in income has no effect on the quantity bought. With $e_i = 0$ we have $e_{i,w} = -1$, and equation (16) – the condition for when a tax becomes more progressive (less regressive) – is reduced to $g_x^B < g_x^A$. Hence, a switch to an income measure that is more equally distributed always creates a more progressive (less regressive) outcome, no matter the *actual* income elasticity of demand for the good in question.

Figure 3(a) shows the overall distributional effect of the Swedish carbon tax on transport fuel between 1999-2012. Against annual income, the tax is regressive in each year, with an average Suits index of -0.057, but against lifetime income the carbon tax is progressive, with an average Suits index of +0.067. The difference in the Suits index across the income measures in each year is large enough to flip the sign of the index. The effect on the distributional effect from changing the income measure is also robust over time. The results thus indicate that consumption is more evenly distributed than annual disposable income in Sweden during this time period. Figure 3(b) shows that this is indeed true, in each year the (logarithmic) variance in income across the decile groups is higher



(a) Carbon Tax Progressivity (b) Variance of Logs

Figure 3: Carbon Tax Progressivity and Income and Consumption Inequality in Sweden, 1999-2012

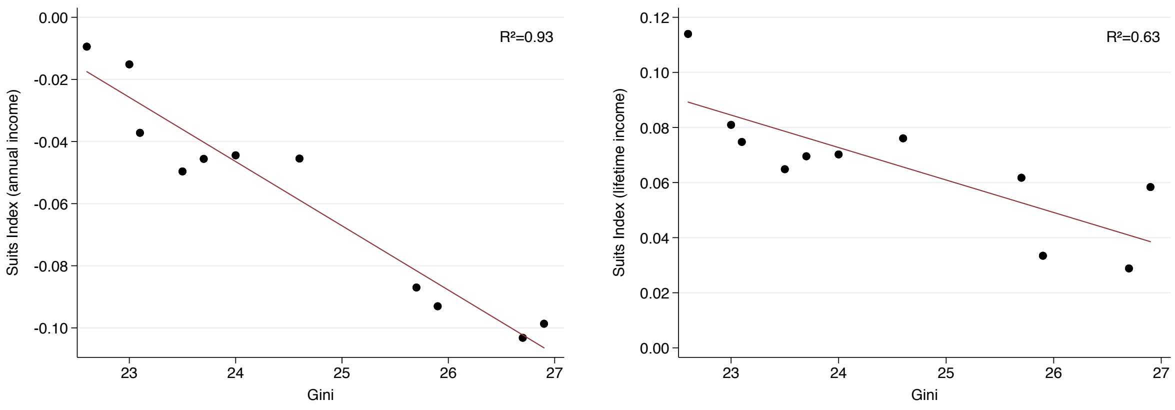
than for consumption. Household expenditure surveys in the US show a similar pattern with consumption being more equally distributed than income (Aguiar and Bils, 2015; Attanasio and Pistaferri, 2016).

3.2 Across Time

Besides the influence of the income measure on the distributional effect, another important result is apparent in Figure 3(a): the trend over time – on both measures of income – is toward an increase in regressivity (less progressivity). 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. In this section we test if rising income inequality in Sweden may account for this change in the distributional effect.

Income inequality in Sweden has increased substantially since the implementation of the carbon tax. In 1991, Sweden had a Gini of 20.8, which increased to 22.6 in 1999 and 26.9 in 2012.[14] There is a strong negative correlation between this change in inequality and carbon tax progressivity. When regressing the estimated Suits index numbers on the Gini coefficients for each year the results show a (Pearson) correlation of $r = -0.96$ when using annual income, and $r = -0.79$ when using lifetime income. Extrapolating, these simple linear regressions, depicted in Figure 4, 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, at the time of implementation, the redistributive effect was likely progressive (or, at least proportional) using either income measure. From 1997 and onwards, the Gini has been

[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).



(a) Annual Income

(b) Lifetime Income

Figure 4: Carbon Tax Progressivity and Income Inequality in Sweden

Note: The red line is a fitted trend line with corresponding R^2 in upper-right corner. Source: Gini coefficients are provided by Statistics Sweden.

above 22, but still below 30.

The distributional trends and their strong correlation with inequality are similar on both measures of income, and this indicates that the level and trend of inequality may be an important determinant of tax progressivity.

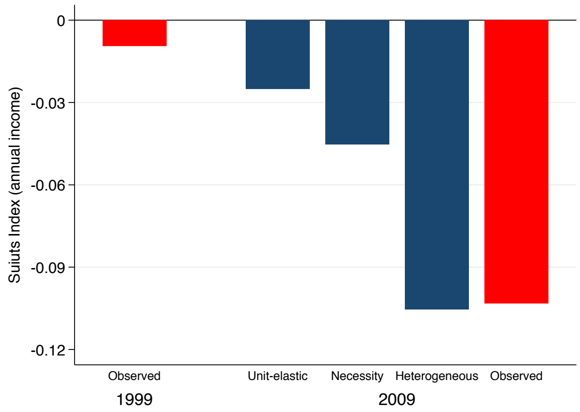
3.3 Heterogeneous Income Elasticities

The largest increase in regressivity occurred in the decade between 1999-2009; the Suits index dropped by around -0.09 on both income measures. To test our hypothesis about the effect of heterogeneous elasticities 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 ($e_i = 0.5$), or the general case of heterogeneous income elasticities – with transport fuel being a relative luxury good among low-income households compared to richer households.[15] We also include a base-case scenario with unit-elastic demand across all income groups.

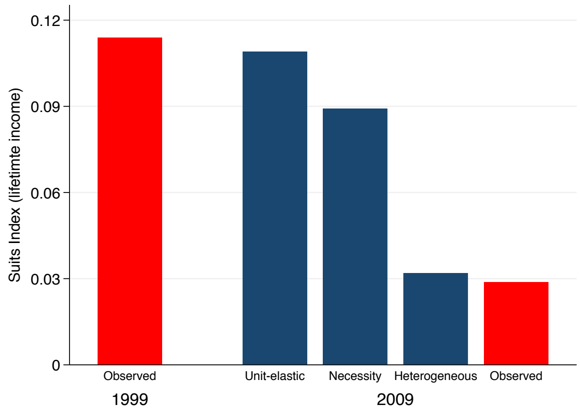
In the unit-elastic case, there is only a slight increase in regressivity, see Figure 5, and we know from the model that with unit-elastic demand for all households, a change in income inequality should not result in a change in the distributional effect. When we instead assume that transport fuel is a necessity, we get an increase in regressivity between 1999-2009 of -0.036 on the Suits index using annual income, and -0.025 using lifetime income. This increase, though, is not even half the size of the drop of -0.09 that we actually observe.[16] If we, however, assume that income elasticities are heterogeneous,

[15] We assign an income elasticity of $e_i = 1.5$ to deciles 1-2, unit-elastic demand for deciles 3-6, and the good being a necessity for high-income groups – with $e_i = 0.75$ for decile 7, $e_i = 0.50$ for decile 8, and $e_i = 0.25$ for deciles 9-10.

[16] Even if we assume that the income elasticity for transport fuel in Sweden is as low as 0.2, we only



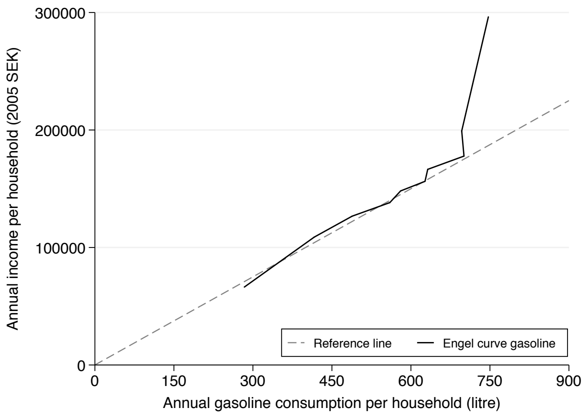
(a) Annual Income



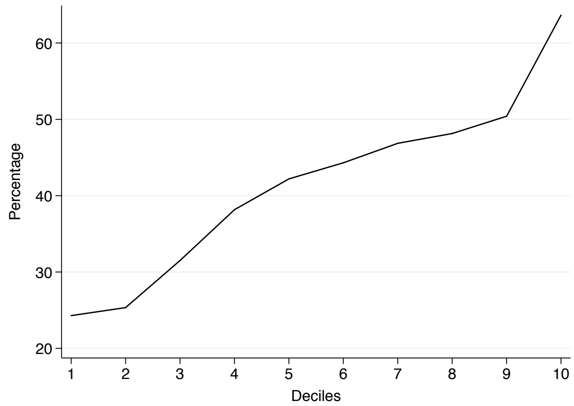
(b) Lifetime Income

Figure 5: Numerical Exercise: Suits Index in 1999 and 2009

Note: The red bars depicts the computed (observed) Suits index numbers in 1999 and 2009, and the blue bars show the simulated Suits index in 2009.



(a) Engel Curve for Gasoline



(b) Growth in Real Disposable Income

Figure 6: 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 unit-elastic good. Source: Data for (b) is provided by Statistics Sweden.

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 6(a) shows the average Engel curve for gasoline demand in Sweden between 1999-2012. The Engel curve gradient is positive, and gasoline is thus a normal good. For high-income households the curve bends upward, toward the y-axis, indicating that gasoline is a necessity – with an income elasticity below one. For low-income households, the curve instead bends slightly downward, toward the x-axis, making gasoline a luxury

get an increase in regressivity of -0.048 and -0.037, respectively.

good. The Engel curve thus indicate that the income elasticity of demand for gasoline in Sweden is indeed heterogeneous – being a relative luxury among low-income households compared to high-income households. Furthermore, in Figure 6(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.

3.4 Across High-Income Countries

To increase efficiency, carbon taxation is preferably global in scope. Therefore, we test the predictions of our model by analysing the distributional effects of current transport fuel taxation across developed countries and its correlation with levels of income inequality. If our model's predictions are valid across countries, we can make projections about the likely distributional effects of carbon taxation in high-income countries, at least for the transportation sector.

In the concluding chapter of a book that compiles studies on gasoline tax progressivity, Suits indices and Gini coefficients from the studies 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, they compare countries with drastically different levels of GDP per capita – such as, Ghana, Tanzania, India, the US, UK, and Germany – and the demand for transport fuel vary with country-level 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, gasoline and diesel are luxury goods, and we can expect a progressive tax burden. Conversely, in countries where GDP and income inequality is high, transport fuel is a necessity and we can expect a regressive tax burden. To analyse this relationship in more detail, we compiled the results of studies on the distributional effects of gasoline taxation that study a high-income (OECD) country and use a similar empirical approach: using household expenditure data and calculating Suits index numbers using either annual or lifetime income.

The result from analyzing the relationship between the Suits and Gini indices across high-income countries are presented in Figure 7. This cross-country comparison show the same strong negative correlation that we found for Sweden over time.[17] 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. It is thus 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 expected. The widespread assumption, that carbon and gasoline taxes hurt the poor

[17] The figure for lifetime income is available in Appendix F.

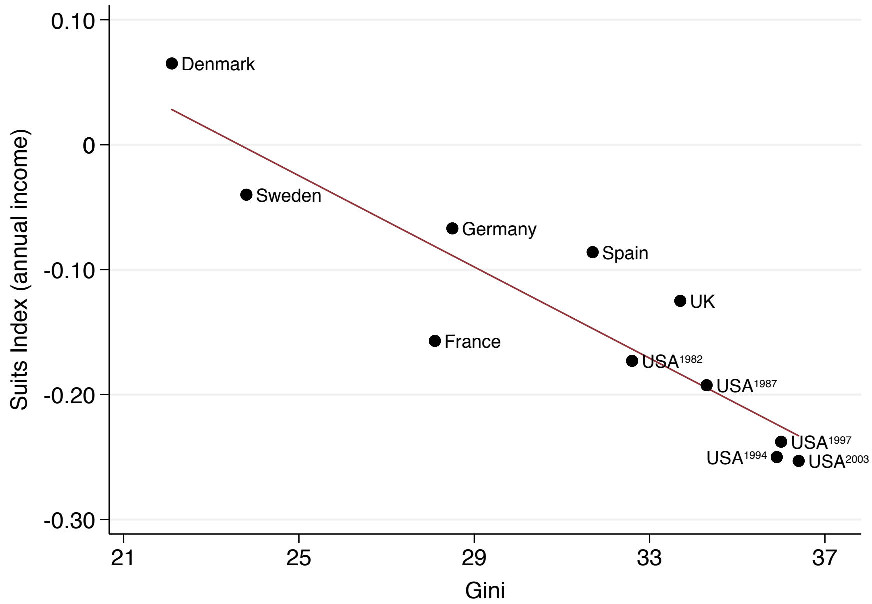


Figure 7: Gasoline Tax Progressivity and Income Inequality in OECD Countries

Note: The figure depicts the correlation between gasoline tax progressivity and income inequality across OECD countries, with $R^2 = 0.82$.
Sources: Suits index numbers in USA in 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). Gini: the SWIID database (Solt, 2019).

more, is thus based to a large part on studies of one country with a relatively unequal distribution of income.

4 Robustness Tests

4.1 Additional Inequality Metrics

The Gini index has 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) for Sweden's carbon tax 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 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:

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

with $\eta \geq 0$ due to concavity.[18]

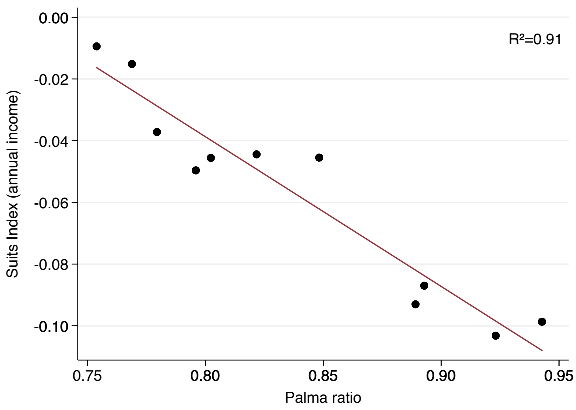
In practical terms, the index calculates the *equally distributed equivalent* level of income, i.e. the amount of (mean) income which equally distributed would provide the same amount of social wellbeing as actual mean income, $\overline{x}$. Using equation (18) as the formula for the SWF, we can define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

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

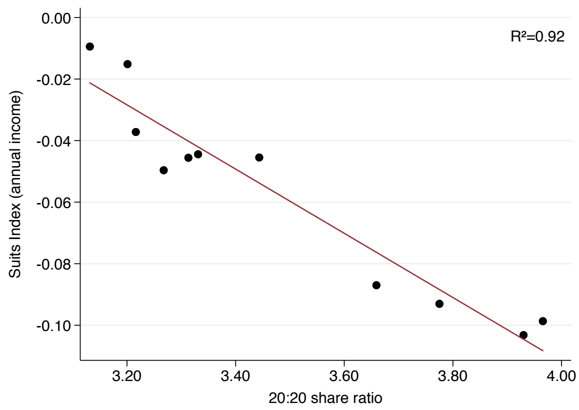
The index tells us what proportion of current average income that society would be willing to give up to achieve an income level that is equally distributed. For a given income distribution, this proportion is higher the larger the value of η. Reviews typically put the level of inequality aversion in 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 8 provides a similar overall pattern as Figure 4(a), the correlation is still very high between the progressivity 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

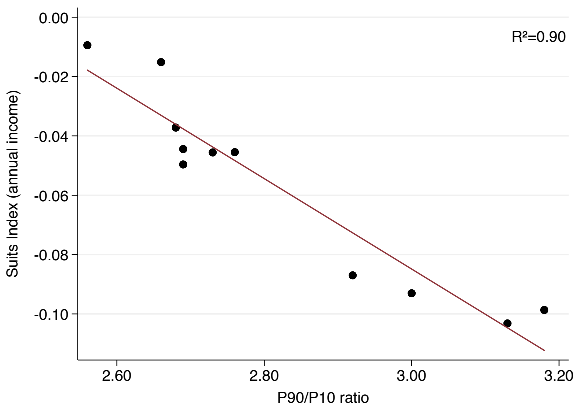
[18] When $\eta = 1$ the SWF takes a log form.



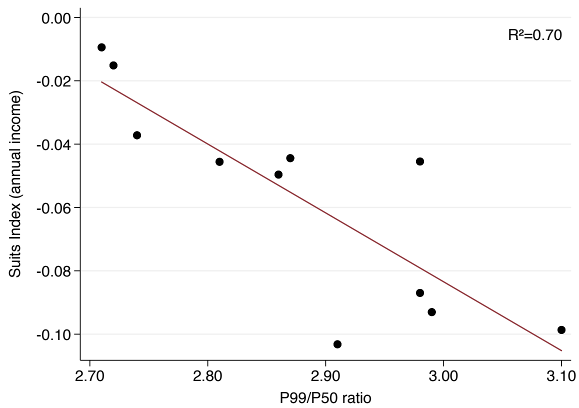
(a) Palma Ratio



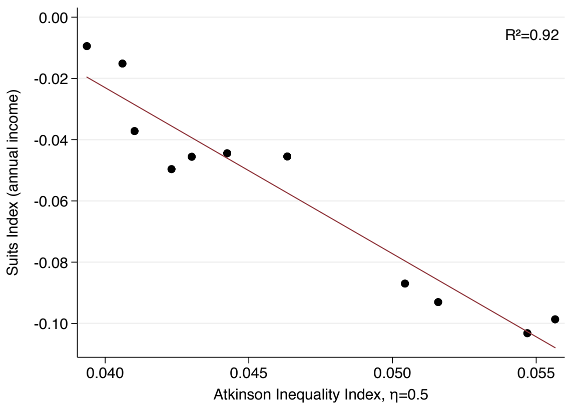
(b) 20:20 share ratio



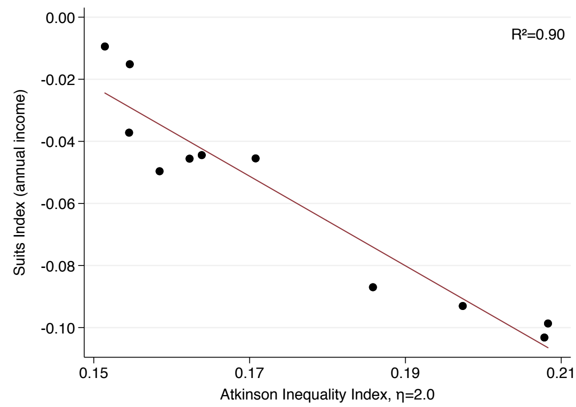
(c) P90/P10 ratio



(d) P99/P50 ratio



(e) Atkinson Index, η=0.5



(f) Atkinson Index, η=2.0

Figure 8: Carbon Tax Progressivity and Income Inequality: Multiple Inequality Measures
Source: (a)-(b), (e)-(f): own calculations using data from Statistics Sweden; (c)-(d): Statistics Sweden.

across all inequality measures indicate that the link between changes to tax progressivity and changes to the underlying distribution of income is not sensitive to the summary statistic used to measure inequality.

4.2 Additional Tax Progressivity Measures

The evidence from Sweden and other high-income countries provides empirical support for the model's predictions. There is a strong correlation between the level of income inequality and the degree of tax progressivity, with gasoline taxation being more regressive the higher the level of income inequality. However, one may be concerned that the strong correlation hinges on the particular measure of tax progressivity used, the Suits index. As a further robustness test, we therefore regress three other measures of tax progressivity on inequality: the well-established Kakwani (1977) index, the more recent Stroup (2005) index, and a simple 20:20 carbon tax budget share ratio.

The Kakwani and Stroup indices are similar to the Suits index in that they are also based on concentration curves. We thus constructed an additional, simpler measure. The measure – referred to as the 20:20 carbon tax budget share ratio – is:

$$1 - \frac{(\tau^1 + \tau^2)/2}{(\tau^9 + \tau^{10})/2} \qquad (20)$$

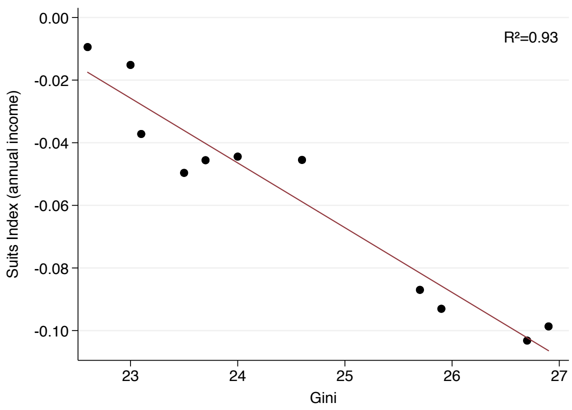
where τ^i is the carbon tax budget share per decile group $1, ..., 10$. If the average tax budget share for the 20 percent of households with the lowest income is higher than the average tax budget share of the richest 20 percent of households, this measure will be negative. Conversely, if the tax budget share is higher for the rich relative to the poor, this measure will be positive. The measure is thus bounded above at +1, but not bounded below, and positive numbers indicate overall progressivity and negative numbers regressivity. It is a simple measure of tax progressivity, but it serves the purpose of assessing if our empirical results hinge on the use of a specific form of tax progressivity measure.

Figure 9 shows that the correlation between the distributional effects of the Swedish carbon tax and income inequality is not sensitive to the measure of tax progressivity used. Overall, the Swedish carbon tax is slightly less regressive when tax progressivity is measured using the Kakwani and Stroup indices compared to the results using the Suits index. Besides that, the strong correlation with inequality is very similar across all three tax progressivity measures that are based on concentration curves. Even the simpler measure, the 20:20 carbon tax budget share ratio, shows a strong negative correlation between inequality and regressivity, with $r = -0.90$.

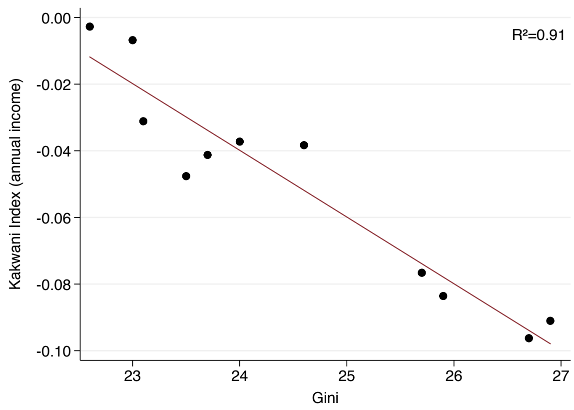
5 Discussion

The model and results presented in this paper may explain why carbon taxes were first introduced in the Nordic countries in the early 1990s.[19] Income inequality was relatively, and historically, low there at the time – with Gini coefficients in the low 20s – and policy-

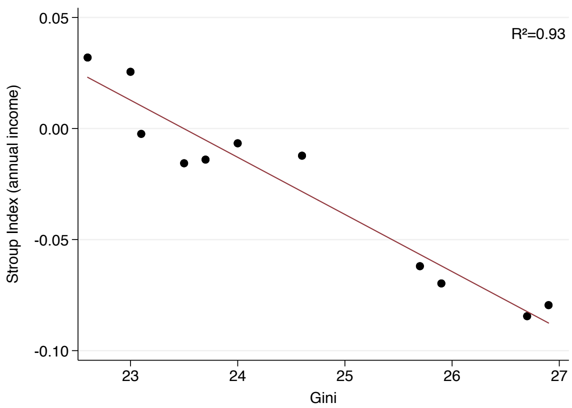
[19]Finland, Sweden, Norway, and Denmark all introduced carbon taxes between 1990-1992.



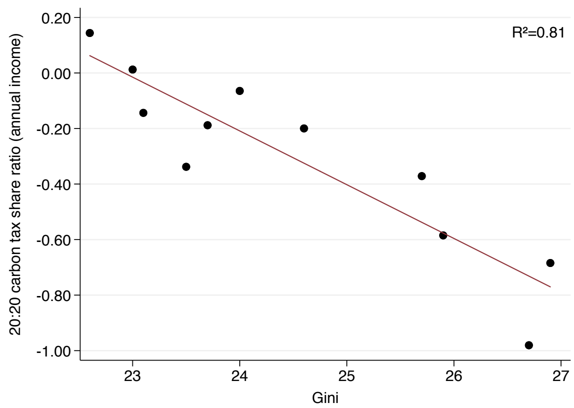
(a) Suits Index



(b) Kakwani Index



(c) Stroup Index



(d) 20:20 carbon tax budget share ratio

Figure 9: Carbon Tax Progressivity and Income Inequality: Multiple Progressivity Measures

Source: (a)-(d): own calculations using data from Statistics Sweden.

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. 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 with a carbon tax, the tax will be applied to those consumption goods that are responsible for the majority of emissions: transport fuel, food, heating, and electricity. These goods are, however, typically necessities and carbon taxation will thus likely be regressive in high-income countries, the more so the more unequal the distribution of income.

Furthermore, 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 may be harder politically to implement a carbon tax in a country with relatively high income inequality 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, and thus risk making the carbon tax policy more intricate.

You could argue, though, that an already high level of income inequality in a country can be seen as revealing a low preference for equality (Lambert, Millimet, and Slottje, 2003). Therefore, regressivity from carbon taxes may not be an issue among voters and policy-makers 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 and a carbon tax on transport fuel would there be progressive, and growing income inequality would increase this progressive effect.

6 Conclusion

This paper presents a simple model that shows how the two parameters of income inequality and the income elasticity of demand determine changes in the distributional effects of consumption taxes. The empirical analysis tests the model's predictions by analysing the Swedish carbon tax on transport fuel. We find that the income measure matter for the level of tax progressivity due to how the underlying distribution of income changes when switching from annual to lifetime income. The Swedish carbon tax moves from regressive to progressive when switching to the more evenly distributed measure of lifetime income. More importantly, however, we find that the tax is increasingly regressive (less progressive) over time on both income measures, which is highly correlated with a rise in income inequality over our sample period. We find a similar strong correlation between inequality and regressivity when analysing the earlier literature on the distributional effects of gasoline taxation across high-income countries. The level and trend in inequality in a country may thus be an important determinant for the distribution of tax burden from carbon and transport fuel taxes.

Future research should further test the model and descriptive evidence presented in this paper by, for instance, compiling a panel data set of the distributional effects of gasoline taxation across countries. A number of factors may influence tax incidence over time and across countries, and we need to test for the role of income inequality against changes in other factors, such as, gasoline tax rates, the oil price, GDP per capita, unemployment, and access to public transport.

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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: The Gini in Sweden

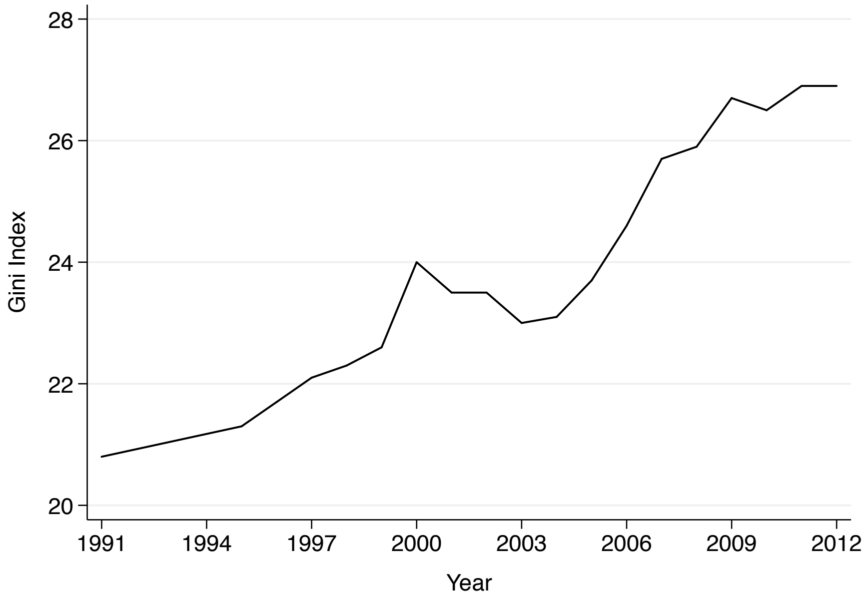


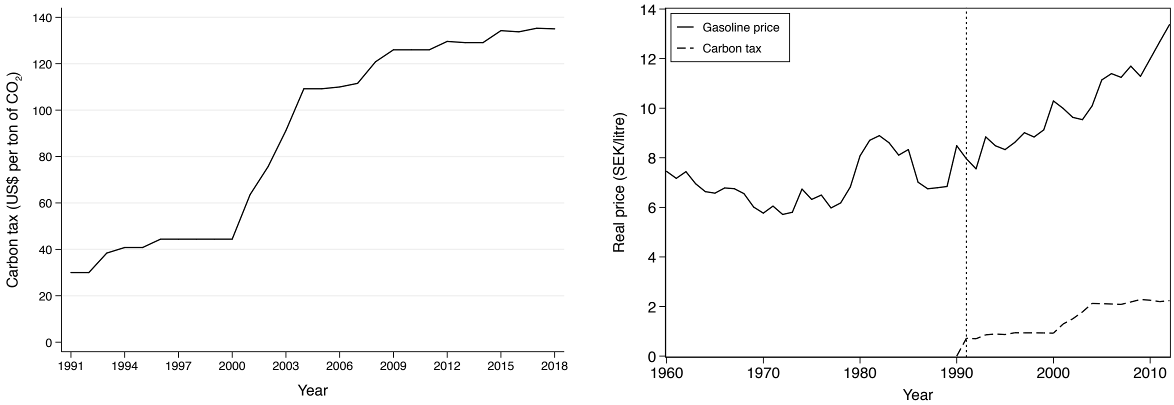
Figure 10: Gini coefficient in Sweden: 1991-2012

Note: The Gini coefficient is calculated using data on disposable income, excluding capital gains. There are missing values for the years 1992-1994. Source: Statistics Sweden.

C Appendix: The Swedish Carbon Tax

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. Today, in 2021, the rate is above US$130 per ton of CO_2, making it the world's highest carbon tax imposed on households and non-trading sectors.

Figure 10 plots the carbon tax rate from 1991-2018 and 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, 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



(a) Carbon Tax Rate 1991-2018 (b) Real Gasoline Price 1960-2012

Figure 11: Carbon Tax Rate and Gasoline Price in Sweden

and onwards.

A 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 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. This result is found in a number of highly cited studies from the last thirty years. Note, though, that the majority of these studies share the characteristic that they use US data. And most of even older studies of environmental tax incidence, from the 1970s and 1980s, also use US data, and the general result in these studies are that environmental taxes are regressive (SOU, 2003:2). The potential issue, however, is that for variables that are arguably important for tax incidence from carbon and fuel taxes, US numbers are far from the average OECD country. USA is ranked in the top-5 of countries for the variables listed in Table 2, 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 likely that carbon and gasoline taxes are less regressive, even progressive, in more "average" OECD countries.

Table 2: 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 value to lowest. For the gasoline tax rate the ranking is from the lowest to the highest.

D Appendix: Determinants of Tax Progressivity

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 progressivity if there is heterogeneity in the income elasticity of demand for transport fuel across income groups, and changes to income inequality will affect the tax burden 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 redistributive effect of the carbon tax more proportional or even progressive over time.[20]

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:

$$S_t = \alpha + X_t\beta + \epsilon_t \tag{21}$$

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 3, 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 outcome. 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), 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. 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.[21]

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

[20] 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.

[21] 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.

Table 3: 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*** (0.004)	-0.0218*** (0.004)	-0.0241*** (0.004)	-0.0210*** (0.005)	-0.0243*** (0.005)
Gasoline price	0.00163 (0.006)				-0.00026 (0.008)
GDP per capita		-0.00209 (0.003)			0.00395 (0.007)
Urbanisation			0.0309 (0.026)		0.0456 (0.040)
Unemployment				0.00423 (0.003)	0.00465 (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.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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 in the main text, 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.

E Appendix: Data for Numerical Exercise

Table 4: 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).

Table 4 lists the income elasticities used in the three simulated scenarios together with 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 4 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.

F Appendix: Gasoline Tax Progressivity and Lifetime Income

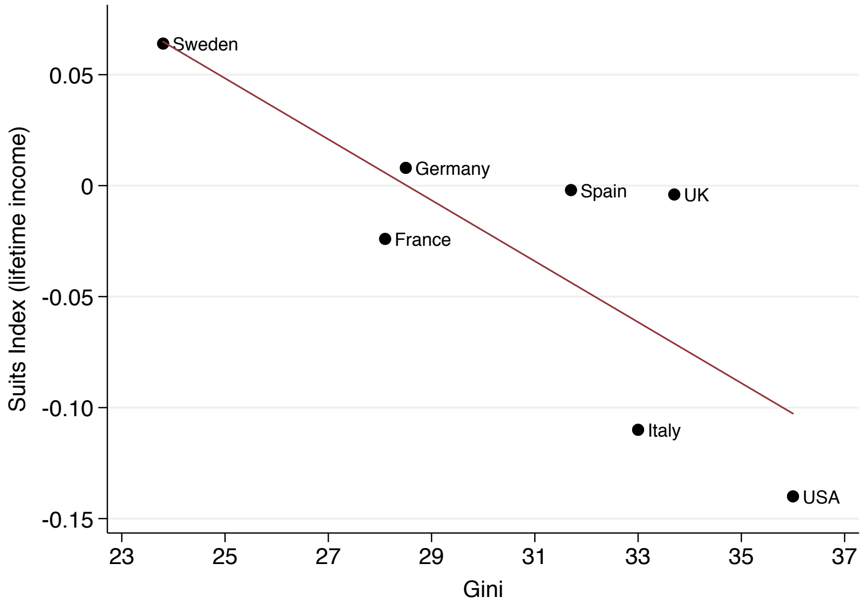


Figure 12: Gasoline Tax Progressivity and Income Inequality: OECD Countries and Lifetime Income

Note: The figure depicts the correlation between gasoline tax progressivity and income inequality across OECD countries, with $R^2 = 0.64$. Gasoline tax progressivity is measured using the Suits index and lifetime income.

Sources: The Suits index number for USA is taken from West and Williams III (2004) and the others are from Sterner (2012a). Gini coefficients: the SWIID database (Solt, 2019).