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The heterogeneous incidence of fuel carbon taxes: Evidence from station-level data

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ABSTRACT

We use station-level price data and a significant diesel fuel carbon tax reform to study who bears the economic burden of fuel carbon taxes. We use a difference-in-differences strategy to estimate the pass-through of the large carbon tax increase to retail prices, where we compare retail diesel prices faced by private motorists to retail gasoline prices. We find that on average fuel carbon taxes are less than fully passed through to consumer prices, which suggests that consumers and the supply chain split the burden of these taxes. Using information on station location, we match price observations with postcode-level average incomes and measures of urbanization, and show that there are significant differences in the pass-through rate across areal incomes and between rural and urban areas up to one year after the reform. The effect of fuel carbon taxes on consumer prices decreases with areal income and with the degree of urbanization.

1. Introduction

Carbon taxes on diesel and gasoline have gained momentum as a policy instrument to both mitigate transport emissions and generate revenue. The incidence of a fuel carbon tax is critical for both its environmental and distributional implications. The extent to which carbon taxes are passed on to retail prices is central to their efficacy as a climate policy tool. If consumer prices do not respond to taxes, there is no reason to expect consumer behavior to be affected by these taxes either. Any differences in price responsiveness across the rural–urban continuum or depending on socioeconomic standing can have distributional implications that feed public opposition to carbon taxes (see e.g. Carattini et al., 2018). Indeed, increases in fuel taxes have been opposed forcefully on the grounds that they disproportionately burden consumers in low-income groups and rural areas. The "yellow vests" movement in France is a prominent example of this opposition. The movement initially launched in response to a proposed increase in fuel taxes, with the backing of people in small towns and rural France who drive long distances as part of their daily lives and perceived the proposed tax increase as fiscally and socially unjust.

Previous literature on fuel excise and carbon tax pass-through has focused on average effects (see e.g. Doyle and Samphantharak, 2008; Marion and Muehlegger, 2011; Bernard and Kichian, 2019; Erutku, 2019). However, the average fuel carbon tax pass-through

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can conceal considerable heterogeneity across socioeconomic and geographic continuums, thus far unaccounted for in both reduced-form incidence analysis and distributional studies.[1] We provide the first analysis studying the heterogeneity in fuel carbon tax pass-through across the income distribution and the rural–urban continuum, utilizing a significant diesel carbon tax reform as a quasi-experimental setting. Moreover, we employ a large, nationally representative dataset on day-and-station level fuel prices faced by private motorists, which we link to areal income and rural–urban characterization. We estimate the incidence of the diesel carbon tax increase using a difference-in-differences approach with retail gasoline prices as a comparison for retail diesel prices. We leverage Finland's 2012 tax reform, which increased the carbon tax on diesel by nearly €0.11 per liter (or approximately $0.43 per gallon). The large increase in the diesel carbon tax and information on fuel prices combined with the characteristics of each station location enable us to discern even small differences in price responses across the income distribution and degrees of urbanization.

The difference in station-level retail prices of diesel and gasoline provides a comparison that should reflect the diesel carbon tax increase while controlling for other factors that affect retail fuel prices. Retail gasoline and diesel are sold by the same supply chains, and consumers cannot easily substitute gasoline for diesel or vice versa due to institutional and technological reasons which we discuss further in the analysis. Moreover, our results are robust to using an alternative comparison, namely retail diesel prices in neighboring Sweden. The analysis of incidence heterogeneity links the fuel price data to the station location's disposable income and rural–urban characterization at the postcode level. We also employ individual-level data on Finland's entire vehicle fleet and vehicle owners to provide evidence that the heterogeneity analysis also fulfills the critical identifying assumptions in that diesel and gasoline consumption do not vary systematically across the income distribution or the rural–urban continuum.

We find that diesel carbon taxes are less than fully passed through to consumer prices on average: a one euro cent increase in the carbon tax leads to a 0.80 cent increase in prices. This result indicates that the economic burden of the diesel carbon tax is somewhat split between the demand and supply sides of the market, though consumers bear most of the burden. The finding differs from the related literature on fuel excise tax pass-through, most of which has documented full or nearly full pass-through. More importantly, the average effect masks considerable heterogeneity across the income distribution and the rural–urban continuum. In the highest-income areas, a one euro cent increase in the diesel carbon tax leads to a price increase of only 0.76 cents, while the corresponding price increase in the lowest-income areas is 0.91 cents. In the most urban areas, a one euro cent increase in the tax leads to a price increase of 0.77 cents, while in the most rural areas pass-through is not statistically discernible from one. These estimates suggest notable geographic heterogeneity in how consumer prices respond to fuel carbon taxes. We discuss the underlying mechanisms explaining the heterogeneity in pass-through, but we cannot empirically pin down any one particular mechanism. Thus, the specific mechanisms driving these differences deserve attention in future research.

Using our estimates of pass-through heterogeneity, we then illustrate how the heterogeneity contributes to the welfare impacts of the diesel carbon tax across geographical areas. The distributional welfare analysis utilizes administrative data on household income and vehicles' fuel consumption and kilometers traveled in Finland. The data enable us to calculate average household diesel consumption as a share of household income at the annual level in each geographical area. By comparing these consumption shares, we show that the marginal welfare losses decrease as a function of regional income and the degree of urbanization. Furthermore, ignoring pass-through heterogeneity in the analysis leads to an underestimation of the degree of regressivity.

Our finding of large heterogeneity in the price response to fuel carbon taxes is important for assessing the distributional impacts of these taxes and is essential for designing counterbalancing measures to offset possible adverse distributional effects. There is a large literature studying the distributional impacts of carbon pricing and energy taxes that employs mainly input–output models in combination with household data, or computable general equilibrium models with a set of representative households (see Ohlendorf et al., 2021 for an extensive review of this literature). Few econometrics-based papers capture geographic and socio-economic heterogeneity (see e.g. Bento et al., 2009; Gillingham and Munk-Nielsen, 2019). Importantly, this literature proceeds from the assumption that tax pass-through is uniform across income groups and the rural–urban continuum, and thus the heterogeneity in these papers arises only from differences in consumer demand across these continuums. Our results indicate that neglecting incidence heterogeneity may bias conventional distributional analysis.

There is a small existing literature on the pass-through of carbon prices to wholesale and business fuel prices, see Bernard and Kichian (2019) and Erutku (2019). Renewable fuel standards are a complementary climate policy tool applied to road transport, and the responsiveness of prices to these standards is a question that is closely related to the pass-through of carbon prices. A significant paper in this field is Knittel et al. (2017), on a system of tradable permits through which the United States renewable fuel standard is implemented. Knittel et al. estimate the pass-through of permit prices to fuel prices using an approach that is similar to ours in that the dependent variable is the spread between the prices of fuels with different RIN obligations, with the focus mainly on wholesale prices. Relative to this literature, the contributions of the present paper are to estimate the pass-through of carbon prices to retail prices faced by private motorists, to use nationally representative microdata to analyze the heterogeneity in carbon tax incidence across the income distribution and between rural and urban areas, and to provide the first estimates of road transport carbon tax pass-through for a European country, which also has one of the highest fuel carbon taxes in the world. Moreover, most of the related literature on fuel excise tax pass-through uses data for the United States, see e.g. Chouinard and Perloff (2004), Alm et al. (2009), Marion and Muehlegger (2011), Kopczuk et al. (2016), Doyle and Samphantharak (2008), and Silvia and Taylor (2016). Only a

[1] There has been a growing interest in estimating the incidence of consumption taxes in general, exploiting exogenous variation in tax rates and microdata on consumer prices (see e.g. Carbonnier, 2007; Harju et al., 2018; Benzarti et al., 2020), but only a few of these papers study incidence heterogeneity. The economic incidence of excise taxes on cigarettes and alcohol has been shown to vary considerably across socioeconomic and geographic continuums (see Harding et al., 2012; Hindriks and Serse, 2019).

few papers have addressed fuel tax incidence in Europe: Bello and Contín-Pilart (2012), Stolper (2016) and Genakos and Pagliero (2019).[2]

Finally, recent work by Coglianese et al. (2017) shows that the large fuel demand elasticity estimates found in the literature instrumenting gasoline prices with gasoline taxes may be an artifact of not accounting for shifts in gasoline purchases in anticipation of gasoline tax changes. We complement the tax incidence analysis with further evidence of anticipatory behavior in the fuel market. Using a bunching approach reviewed by Kleven (2015), we document large increases in purchases by distributors and retailers in the months leading up to the diesel carbon tax increase. Our price data also provide suggestive evidence that consumers increased their purchases in the days preceding the tax increase, filling up their tanks at the lower tax rate one last time.

The rest of the paper is organized as follows: Section 2 briefly reviews the theory of tax incidence. Section 3 describes Finland's gasoline and diesel markets, fuel taxes and the 2012 diesel tax reform. Section 4 describes the data and empirical methodology. The main empirical results are shown in Section 5, while Section 6 provides empirical evidence of forward-looking behavior in the fuel market. The concluding remarks are in Section 7.

2. The economics of pass-through

The standard representation of tax incidence in competitive markets is given by

$$\rho \equiv \frac{dp}{dt} = \frac{\eta}{\eta - \varepsilon}$$

where η and ε are the elasticities of supply and demand, p the retail price and t the tax. The rate of pass-through goes up as supply is more elastic and demand is less elastic. If supply is perfectly elastic or demand perfectly inelastic, taxes will be passed through to retail prices fully. An intuitive rule-of-thumb is that the relatively more inelastic side of the market will bear a larger share of the tax burden. Under imperfect competition, pass-through also depends on the shape (convexity) of the demand and supply curves (Weyl and Fabinger, 2013). Imperfect competition may lead to both under-shifting and over-shifting of the tax (Katz and Rosen, 1985; Seade, 1985; Stern, 1987; Besley and Rosen, 1998; Hamilton, 1999).

The pass-through rate is a key parameter for assessing the distributional impacts of taxes. The pass-through rate combined with observed demand allows approximation of the implications of a tax change for consumer welfare, as measured by the associated change in consumer surplus (see e.g. Weyl and Fabinger, 2013). From the distributional point of view it is important to note that local and regional markets may differ in terms of consumer preferences and income, degree of competition and the cost structure. These differences will translate into differences in the demand and supply elasticities and consequently pass-through rates. Heterogeneity in pass-through across the income distribution or differences in market competition or cost structure that are systematically related to local income levels may contribute to the distributional implications of fuel taxes.

3. Institutional details

3.1. Gasoline and diesel markets in Finland

While gasoline is the most common fuel in passenger vehicles in Finland and in other European countries, diesel is also widely used: Approximately 22% of passenger vehicles in Finland and 35% of passenger vehicles in the European Union ran on diesel in 2012.[3] Many passenger vehicle models are available with both gasoline and diesel engines. Diesel vehicles accounted for approximately 31% of all passenger-vehicle fuel use in Finland in 2012.[4] We return to diesel and gasoline consumption shares in more detail in the end of Section 4.1. Gasoline cannot be used in a diesel engine and vice versa, and retail gas stations in Finland always provide both fuels.[5] Diesel and gasoline are dispensed from the same fuel pumps, but from separate nozzles that are labeled and located next to each other. Finland has no oil production of its own and only has two refineries. There are six main station chains, all of which serve the entire country. Each station chain sells the same diesel and gasoline blends throughout its network in Finland. Most gas stations belong to one of the six station chains.[6]

Our analysis focuses on retail pump prices faced by private motorists. Trucks used for goods transports run on diesel, but this market can be considered separate from the retail diesel market. Trucks fuel up at truck terminals or specific truck fuel stations that only sell diesel, have a markedly faster fuel dispense rate than retail stations and payment with fleet fuel cards or sensors mounted on the vehicle, with company-specific fuel prices. The type of the station is indicated in the station name. Diesel is not used in manufacturing, mining, construction or heating in Finland.[7]

[2] Stolper's working paper is the only one of these studies to analyze pass-through heterogeneity. Stolper assesses how fuel tax incidence varies across measures of local competition and the wealth distribution within urban areas. While Stolper's paper breaks important new ground in the fuel tax incidence literature, it does not address the rural–urban divide that is at the center of a lot of the political debate around fuel carbon taxes in Europe. Genakos and Pagliero's working paper addresses how pass-through varies in isolated oligopolistic markets, in their case those on small Greek islands.

[3] Source: Eurostat Passenger vehicle data. The data begin from 2012 and were downloaded from https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=road_eqs_carpda&lang=en

[4] Source: VTT Technical Research Centre of Finland, Lipasto Transport emission inventory, http://lipasto.vtt.fi/en/index.htm.

[5] Adding gasoline to a diesel engine or vice versa could cause expensive damage to the engine. Damage due to misfuelling is not covered by warranty. In case of accidentally fueling up with the wrong fuel, the recommended procedure is to push (rather than drive) the car away from the pump, have it towed and the fuel tank drained.

[6] Most gas stations also have a convenience store and a cafe or a restaurant.

[7] These sectors use light fuel oil, which has markedly lower excise taxes. Light fuel oil is dyed red to differentiate it from diesel, and its use in private motoring is heavily penalized, with penalties typically in thousands of euros.

Table 1

Carbon taxes, other excise taxes, value added taxes (VAT) and diesel and gasoline prices in 2011 and 2012 (euro cents/liter). The tax rates in Panel A are from Finnish tax legislation (Finlex 1399/2010 and Finlex 1443/2011). Panel B shows the excise taxes for the market blends of diesel and gasoline, calculated using the tax rates in Panel A and aggregate data from Finnish Customs on the quantities of different fuel products used in the market blends supplied to the Finnish retail market. Panel C calculates the value added tax using the average market price for each blend and the value added tax rate, 23% in both 2011 and 2012. Total taxes are the sum of overall excise taxes from panel B and the calculated value added tax.

	Diesel		Gasoline (95E10)	
	2011	2012	2011	2012
Panel A. Excise taxes on pure petroleum products				
Carbon tax	5.38	15.90	11.66	14.00
Fiscal component	31.02	31.05	51.04	51.04
Overall excise tax	36.40	46.95	62.70	65.04
Change in excise tax in 2012		10.55		2.34
Panel B. Excise taxes for the average market blend				
Carbon tax	5.32	15.13	10.86	12.98
Overall excise tax	36.06	45.65	60.14	62.30
Change in excise tax in 2012		9.59		2.16
Change in the excise tax plus VAT		11.80		2.66
Panel C. Total taxes relative to price for the average market blend				
Average market price	135.90	153.51	155.12	165.47
Value added tax	25.41	28.71	29.01	30.94
Total taxes	61.47	74.36	89.15	93.24
Price excluding taxes	74.43	79.15	65.97	72.23
Proportion of taxes in retail price (%)	45	48	57	56

3.2. Finland'S 2012 carbon tax reform

Finland collects both excise taxes and value added taxes on transport fuels. While the excise taxes are largely fiscal in nature, they have also included a carbon tax since the 1990s. In January 2012, legislators raised the climate ambition of fuel taxation substantially: the carbon tax on diesel was increased from 20 euros/tCO2 to 60 euros/tCO2. This amounted to a 10.55 euro cents per liter increase in the excise tax on diesel. The carbon tax on gasoline was already 50 euros/tCO2, and was now also increased to 60 euros/tCO2, which amounted to a 2.34 euro cents per liter increase in the excise tax on gasoline.

Table 1 shows the structure of fuel taxes in Finland and compares the excise tax rates in 2011 and 2012, before and after the tax reform.[8] Panel A shows the carbon taxes and the fiscal component of the excise taxes on pure diesel and gasoline. Diesel and gasoline sold in the retail market blend pure diesel and gasoline with biofuels and additives, which are taxed at lower rates. The excise taxes on retail blends thus differ somewhat from those on pure diesel and gasoline. Panel B displays the excise taxes for the average market blends, calculated using aggregate data from Finnish Customs on the quantities of the different market blend fuel products supplied to the Finnish retail market. Panel B shows that blending with more lightly taxed biofuels attenuated the excise tax increases on the market blends relative to the pure petroleum products: while the carbon tax reform increased the excise tax on pure diesel by 10.55 euro cents per liter, the excise tax on the average market blend of diesel only increased by 9.59 euro cents per liter. This is in part explained by the share of biofuels completely free of carbon taxes increasing from 1.65% to 4.48%. Similarly, the excise tax increase for the average market blend of gasoline was 2.16 euro cents per liter. Transport fuels are also subject to value added taxes, payable on the excise tax-inclusive price. Accounting for the value added tax, which was 23% in both 2011 and 2012, the carbon tax increases amounted to overall tax increases of 11.80 cents per liter for diesel and 2.66 cents per liter for gasoline. The gasoline blend in our analysis is 95E10, the most widely used blend in Finland, with an octane rating of 95 and a maximum ethanol concentration of 10%. Panel C shows how important the overall fuel taxes are relative to prices that consumers pay in the retail market. In 2011, before the reform, the proportion of taxes in the retail price of diesel averaged 45%, and in 2012, after the reform, 48%.

Consumers do not directly observe the different tax components, as gas stations post tax inclusive prices. But, the 2012 carbon tax increase was part of a larger environmental tax reform and received substantial media coverage, so the tax change was known by fuel buyers. The transport fuel supply chain consists of distributors, which procure fuels from one of the two refineries in Finland or from abroad and operate bulk transport, wholesale storage and delivery to commercial customers, and of retail stations, which sell fuels to individual drivers. In terms of tax collection, the value added tax is remitted to the state by retailers, while excise taxes are collected when the fuels are transferred from wholesale storage to retail operators' storage.

The legislative proposal introducing the 2012 diesel tax increase was first submitted to parliament in September 2010 and passed as a bill in December 2010. The original proposal would have brought the carbon tax on diesel into line with that on gasoline, 50 euros/tCO2. The increase from 20 euros/tCO2 to 50 euros/tCO2 would have amounted to an excise tax increase of 7.9 cents per liter of diesel. An amendment to the bill, tabled in October 2011, increased the carbon taxes on both gasoline and diesel to 60

[8] Table 8 in Appendix A shows the 2012 excise tax rates for different fuel components from the Finnish tax legislation (Finlex 1443/2011). Component 10 is pure gasoline and 50 pure diesel. Gasoline blends sold in the retail market contain components 20–40, diesel blends components 51–57.

euros/tCO2, which resulted in a diesel excise tax increase of 10.55 cents per liter and the concurrent gasoline excise tax increase of 2.34 cents per liter. The amendment was adopted by the parliament on December 22, 2011.

4. Data and estimation strategy

4.1. Data

Our primary data are station-level microdata on diesel and gasoline prices, collected by two websites (polttoaine.net and tankkaus.com) where volunteer spotters report fuel prices. The data cover January 2000 to October 2015. For January 2000–December 2006, data are available only for one of the websites. Volunteer spotters can enter prices on the websites in several ways: by filling an online form or by sending a text message or email to the website moderators. The data include the prices of diesel and two types of gasoline, octane ratings 95 and 98. The data also contain a spotter-reported location (municipality and address), name, and brand for each gas station, as well as the exact time when the price was recorded.

Some stations are listed multiple times in the data, either because volunteer spotters had reported them under slightly different names or because they were reported on both websites. We cleaned the data by removing multiple listings and added station amenities using gas station chain websites and information on station location. The gas station characteristics include information on the services provided and information on whether the station is located near a highway, in a city or in a rural area. We also checked that the gas stations are retail stations based on the station name and on the availability of price information for gasoline (recall that truck stations only dispense diesel). To keep the manual workload of complementing the price data with station characteristics manageable, we used a random sample of 50% of the stations in the raw data from the price reporting websites to construct the full data set used in our analysis. We identified their exact names and locations based on the names and addresses recorded on the price reporting websites and coordinates from Google Maps. We were able to identify altogether 1117 unique station-location pairs in the sample in years 2011 and 2012, the main period of interest in the analysis. As entry and exit are rather limited, our analysis considers an unbalanced sample, with 1081 stations in 2011 and 1066 stations in 2012. According to the industry association there were altogether about 1947 gas stations in Finland in 2011, and about 1892 in 2012.[9] Thus, for each of the years 2011 and 2012, the stations in our sample represent about 56% of all retail gas stations in operation. Thirty-seven of these stations switched gas station chain once and two stations twice during the two-year period. Because of missing information on gas station ownership, we were not able to determine whether these stations changed owner as well. Fifty-one stations have price observations only for year 2011 and thirty-six stations only for year 2012.

To allow pass-through heterogeneity across the income distribution to be assessed, we matched the gas stations with postcode-level income data, using three-digit-level postcode areas.[10] Income is measured by the postcode-level average disposable income of individual adults (18 years old or over).[11] Income data are available at the postcode level only from 2012 onward, and the 2012 values were used for both years 2011 and 2012. To allow pass-through heterogeneity across different regions to be studied, each gas station was also assigned a class along the rural–urban continuum based on the rural–urban classification provided by the Finnish Environmental Institute (2014). The ready-made classification is based on precise geographic information and comprises seven classes: sparsely populated rural area, rural heartland area, rural area close to an urban area, local center in a rural area, peri-urban area, outer urban area and inner urban area. The seven classes of the rural–urban classification are numbered from the most rural to the most urban so that 1 indicates “sparsely populated rural area” and 7 “inner urban area”. We were able to assign a rural–urban class to 1114 of the 1117 station-location pairs. As the rural–urban classification has seven classes, for clarity of exposition we divided the postcode areas into seven groups in terms of income as well. Here each income group, or septile, represents one seventh of the three-digit postcode areas.[12]

The econometric analysis uses day-and-station level prices. The price of each fuel is the average of the fuel-specific prices reported for the station on that day. On average, there are prices for about 50 days of the year for each station. Table 2 shows fuel price summary statistics. The average diesel price was below the average gasoline price in both 2011 and 2012. The distribution of the number of observations per station (not shown) is skewed to the right, an indication that more frequently visited gas stations are over-represented in the data. Thus, the analysis should be interpreted as measuring the differences in pass-through among the more popular gas stations. On the other hand, the skewedness can be seen as weighting estimates automatically by gas station-level sales volumes, which allows the results to be interpreted as being representative of the average incidence in each area.

[9] Source: Finnish Petroleum and Biofuels Association, https://www.sttinfo.fi/tiedote/huoltoasemien-maara-sopeutuu-ajan-muutoksiin?publisherId=4020&releaseId=13384492, The industry association’s figures may exclude some small non-member stations.

[10] Postcodes in Finland have altogether five digits; the first two indicate the municipality or municipalities that the postcode area belongs to while the other digits describe the location in more detail. Defining areal incomes at the full five-digit level is not possible, as income data are not reported for some five-digit postcode areas due to a small population and data protection constraints. Pricing decisions made by gas stations could also be influenced by the income and wealth of individuals living in their vicinity even where the total customer base covers a larger area. If this is the case, using a small area definition could obscure the true distributional effects. As a robustness check, the analysis was also repeated using the more detailed five-digit postcode areas and less detailed municipalities. Using the former produced very similar results. The results acquired with the latter were largely similar as well, although the pass-through rate did not change as linearly with income as when using the postcode areas.

[11] Household income would have been a more accurate measure: the true financial situation of individual adults depends not only on their own income, but also the incomes of other household members, the number of people to provide for, and economies of scale in the household. Statistics Finland data on total household income do not specify the size and composition of the household, which prevents using these data as a sensible measure of variation between households.

[12] We also studied the heterogeneity in pass-through rates with respect to housing prices and population density. The results are very similar to those obtained using income and the rural–urban classification, respectively. These results are available upon request.

Table 2
Descriptive statistics of fuel prices.

	Diesel price		Gasoline (95E10) price	
	2011	2012	2011	2012
Number of day-and-station obs.	56,503	54,259	55,759	52,513
Number of stations	1056	1041	1060	1027
Average price obs. per station	54	52	53	51
Mean price (€/l)	1.36	1.54	1.55	1.66
Median price (€/l)	1.36	1.54	1.56	1.65
Standard deviation	0.05	0.05	0.05	0.06

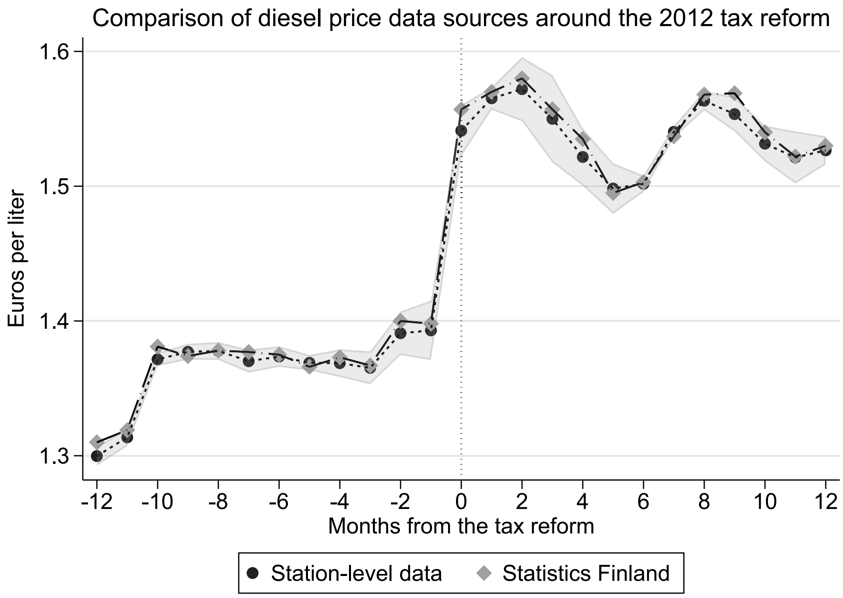


Fig. 1. Comparison of Statistics Finland data and volunteer-reported microdata with the 95% confidence intervals for the microdata (shaded area).

A concern pertaining to the data is the possibility that volunteer spotters systematically report fuel prices incorrectly, either intentionally or unintentionally. To remove obvious outliers and mistakes in the data, we excluded station-day observations with prices below 0.5 euros per liter or above 3.0 euros per liter. This trimming removes 0.07% of observations. To evaluate whether misreporting is likely to be notable, we compared the average monthly prices calculated from the volunteer-reported microdata to average gasoline and diesel fuel prices recorded by the Finnish statistics authority Statistics Finland, which collects fuel price data from the largest municipalities to compute the consumer price index. Fig. 1 compares diesel prices in the microdata and Statistics Finland data sets. The volunteer-reported microdata and Statistics Finland data on diesel prices develop very similarly over time. The difference in the monthly diesel prices in the two data sets is less than 1 euro cent on average by months close to the tax reform. The 95% confidence bands indicate that the Statistics Finland prices are statistically equal to the station-level figures. The station-day microdata and Statistics Finland data on gasoline prices exhibit similar trends as well (Fig. 16 in Appendix A). Given the virtually identical trends in the microdata and the Statistics Finland sample, we conclude that misreporting is not likely to invalidate analysis using the microdata. A caveat is that the price series in Figs. 1 and 16 only represent six municipalities that are among the largest in Finland, as Statistics Finland fuel data are only available for these locations.

Gas stations are most abundant in the urban areas of relatively large municipalities whereas rural areas have a sparser station network. Table 3 shows that even though each income septile contains the same number of postcode areas, there are more station-and-day price observations in the higher income septiles. The number of station-and-day price observations also increases across the rural–urban continuum and the increase is somewhat disproportionate to the increase in the number of stations. The skewedness of this distribution in the case of the rural–urban classification is natural. That income septiles exhibit similar skewedness is at least partially explained by significant overlap in urban and relatively high-income areas.[13] The differences in the numbers of gas stations for which price observations are available are not as notable, and we conclude that overall the data are sufficiently representative of regional price levels and trends. Table 9 in Appendix A shows that the six main station brands' stations in our data are quite equally distributed across the income groups and rural–urban classes.

[13] Spearman's rank correlation is 0.50 between the rural–urban classification and the areal income grouping.

Table 3
Numbers of day-and-station price observations and gas stations, years 2011 and 2012.

Income septile/	By income septile		By rural–urban class	
Rural–urban class	N	Stations	N	Stations
1	11,603	97	5629	83
2	19,269	143	18,050	213
3	20,501	145	8297	86
4	18,474	163	15,653	131
5	23,121	163	16,146	91
6	37,884	171	54,502	222
7	88,182	235	100,716	288
Total	219,034	1117	218,993	1114

To describe the distribution of vehicles with different engine types and the consumption shares of diesel and gasoline across the income groups and the rural–urban continuum, we draw on register data for Finland's entire vehicle fleet and vehicle owners, provided by Statistics Finland. The vehicle dataset begins in 2013 and has detailed information on vehicle characteristics, including engine type and fuel consumption at the make-and-model level, as well as odometer readings from mandatory vehicle inspections. The vehicle data include vehicle owner's postcode, so we can link the data to the income and rural–urban groups. While data are not available for 2011–2012, it is unlikely that the composition of the vehicle fleet would have changed significantly in just one year. Fig. 2 shows the shares of car-owning households that own only a gasoline vehicle, only a diesel vehicle, and both gasoline and diesel vehicles, by the income septiles and rural–urban classes used in our analysis.[14] Importantly for our empirical analysis of pass-through heterogeneity, the share of diesel vehicles does not vary much by income group. Diesel vehicles are slightly more common in rural than in urban areas, but the differences are not very large. The 10% share of households that own both diesel and gasoline vehicles implies that the possibilities for within-household gasoline–diesel substitution are rather limited.

We use the information on engine type, make-and-model fuel consumption and odometer readings in the vehicle data to assess each individual vehicle's kilometers traveled and fuel consumption in 2013. We then aggregate up to obtain the diesel and gasoline consumption shares for passenger vehicles in different areas. Fig. 3 shows the resulting consumption shares by income septiles and rural–urban classes. The diesel consumption shares do not vary much across income septiles but are somewhat larger in rural than in urban areas. The difference in consumption shares between rural and urban areas stems from diesel vehicles being somewhat more prevalent in rural than in urban areas, and diesel vehicles being driven more than gasoline vehicles on average.[15] More important for our empirical setting, the kilometers driven do not differ much across the income groups or rural–urban classes (see Fig. 15 in Appendix A).

4.2. Estimation strategy

Our econometric strategy is to compare station-and-day-level diesel and gasoline prices around the 2012 reform using a difference-in-differences (DID) approach. To estimate the average countrywide pass-through of the diesel tax increase, we estimate the following equation:

$$P_{sft} = \gamma_1 + \gamma_2 D_f + \gamma_3 A_t + \gamma_4 D_f A_t + \boldsymbol{X}'_{sft}\boldsymbol{\gamma}_5 + \varepsilon_{sft}, \tag{1}$$

where P_{sft} is the price of fuel f (diesel or gasoline) in euro cents at station s on day t, D_f an indicator variable for diesel and A_t an indicator variable for the post-reform period. Vector $\boldsymbol{X}_{sft}$ includes gas station chain or gas station fixed effects and cost, exchange rate and quality controls.

The main identifying assumption is that the prices of diesel and gasoline would have followed parallel time trends after January 2012 had the tax reform not taken place. Provided that the assumption of common trends holds, γ_4 identifies the average causal effect of the diesel tax increase on diesel prices.[16] While it is not possible to test the parallel trends assumption directly, the assumption is more plausible if diesel and gasoline prices exhibited parallel trends prior to the 2012 tax reform. Fig. 4 illustrates the average monthly changes in diesel and gasoline prices from 12 months prior to the tax reform to 12 months after, or from January 2011 to January 2013. Diesel and gasoline prices follow parallel trends until two months before the reform (time −2 on the horizontal axis). In the last months prior to the tax reform the two prices diverge somewhat. A plausible explanation for the diverging prices is normal within-year differences in diesel and gasoline prices. The months in which the trends diverge are the first winter months in Finland. In cold weather conditions, diesel fuel has to be enhanced to prevent it from gelling, and in Finland diesel fuel has to meet a specific winter diesel standard between November and March. The divergence in diesel and gasoline prices in the last months

[14] The share of engines other than diesel or gasoline was 0.1% in 2013 and has been omitted from the figure.

[15] The likely explanation for this difference is the following: Because of lower excise taxes, diesel prices are consistently below gasoline prices. Finland also has an annual vehicle tax, which is higher for diesel passenger vehicles than for gasoline vehicles. Thus, when comparing overall fuel and tax costs, a diesel vehicle is more economical than a similar gasoline vehicle for individuals who regularly drive longer distances.

[16] When interpreting the regression coefficients in this section, we ignore the challenges arising from the smaller carbon tax increase on gasoline that coincided with the larger carbon tax increase on diesel. We address these challenges in Section 4.3.

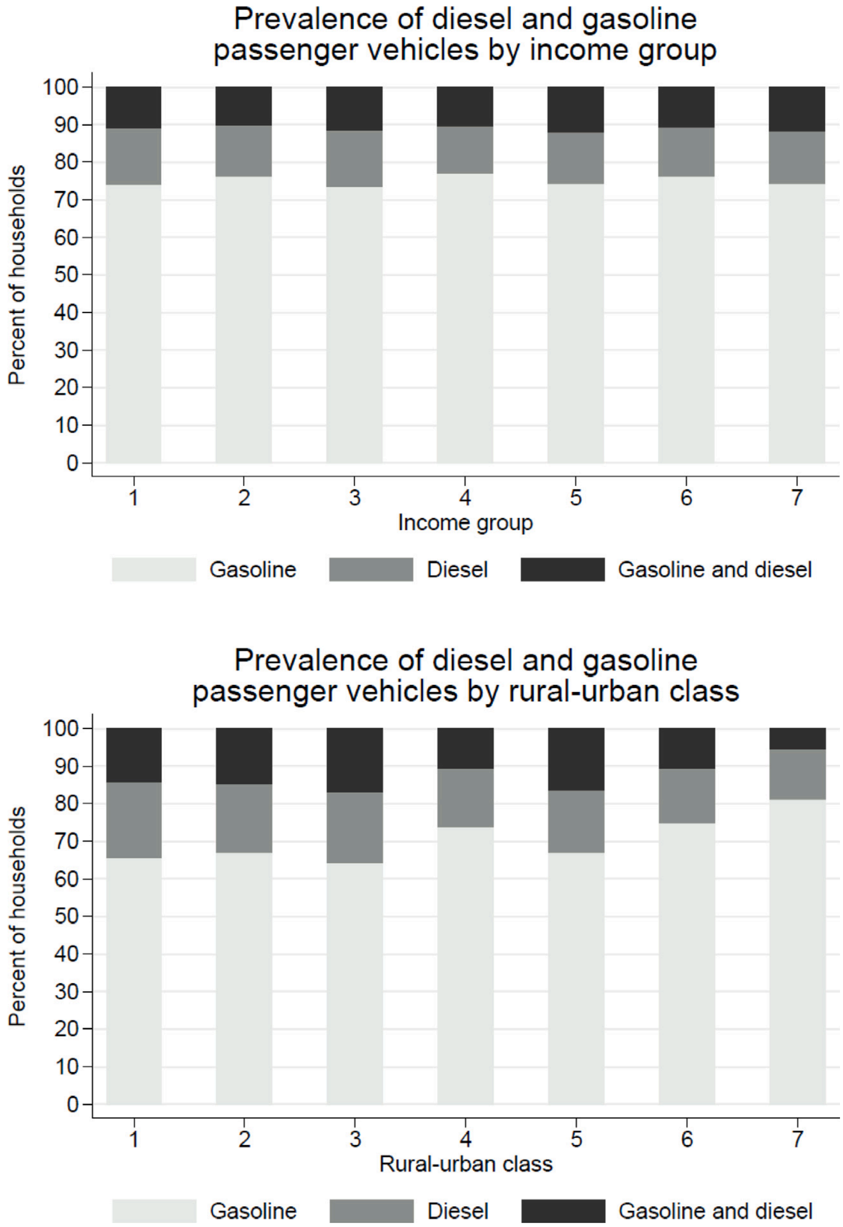
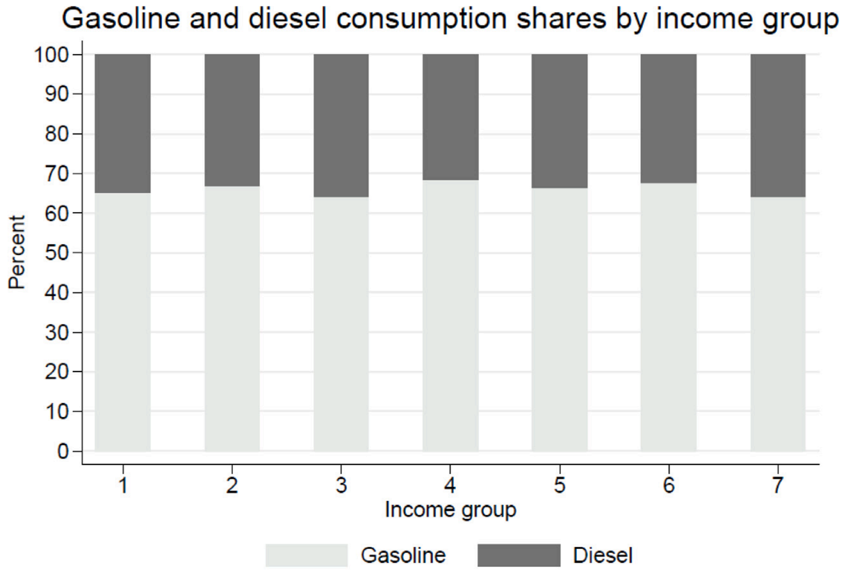


Fig. 2. The shares of car-owning households that owned only a gasoline vehicle, only a diesel vehicle, or both gasoline and diesel vehicles in 2013, by income group and rural–urban class. Source: Statistics Finland Vehicle fleet data and own calculations.

preceding the reform could reflect the transition to a blend with higher-cost components. Price data from Statistics Finland also suggest that gasoline prices exhibit a persistent seasonal pattern, with a peak in the summer and a low in the winter.[17] The price trends in November and December of the first post-reform year 2012 in Fig. 4 exhibit a similar diverging pattern, consistent with seasonal differences. Fig. 5 shows the difference in average monthly diesel and gasoline prices for a longer time period, from 2000 to 2018, in Statistics Finland fuel price data. The figure provides further evidence of persistent seasonal differences in diesel and gasoline prices.[18]

[17] Price data for the United States from the Energy Information Administration exhibit a similar pattern, see https://www.eia.gov/energyexplained/gasoline/price-fluctuations.php (Accessed March 11, 2020)

[18] Furthermore, Fig. 14 in Appendix A shows that the average annual prices of diesel and gasoline from 2000 to 2018 exhibit nearly identical trends in periods without tax changes.



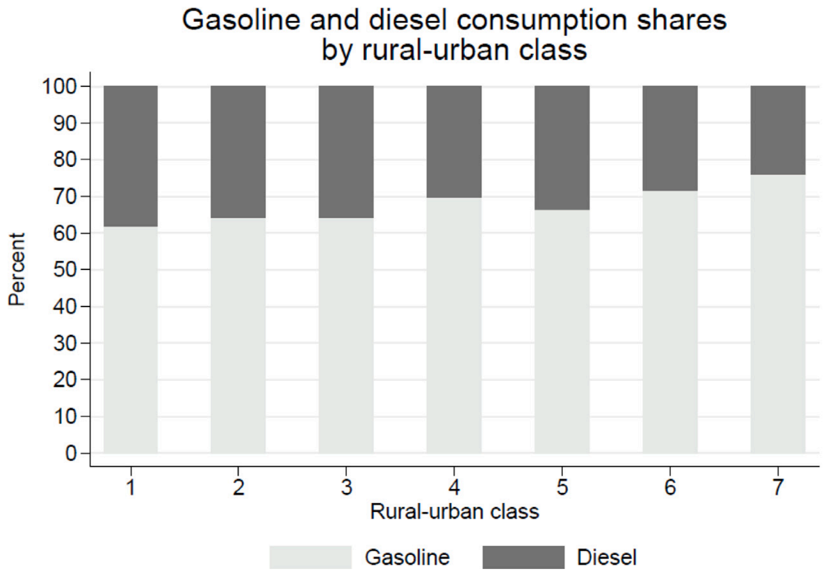


Fig. 3. Gasoline and diesel consumption shares for passenger vehicles in 2013, by income group and rural–urban class. Source: Statistics Finland Vehicle fleet data and own calculations.

Another explanation for the diverging prices is anticipatory behavior by fuel market participants, as first demonstrated in Coglianese et al. (2017). However, it is not likely that inter-temporal shifting of diesel purchases would be reflected in consumer prices already two months prior to the tax increase. While distributors and retailers have some ability to store fuel, final consumers can typically only store what their vehicle tanks hold.[19] Data reflecting consumer and distributor purchases, discussed in more detail in Section 6, indicate that consumers only started stockpiling in the last few days leading up to the reform. We conclude that the observed divergence in the price trends in the last two months preceding the reform thus plausibly reflects repeated seasonal differences in fuel prices, partially explained by the quality change in diesel in winter months.

[19] The divergence in diesel and gasoline prices also does not coincide with the time when the diesel carbon tax increase became known to the public. The diesel carbon tax increase was first introduced as a government bill on September 17, 2010 and augmented from an initial 7.9 euro cents per liter to 10.55 euro cents per liter in the government's 2012 budget proposal on August 22, 2011. The prices of diesel and gasoline started diverging in late October 2011, around the same time as the year before and the year after.

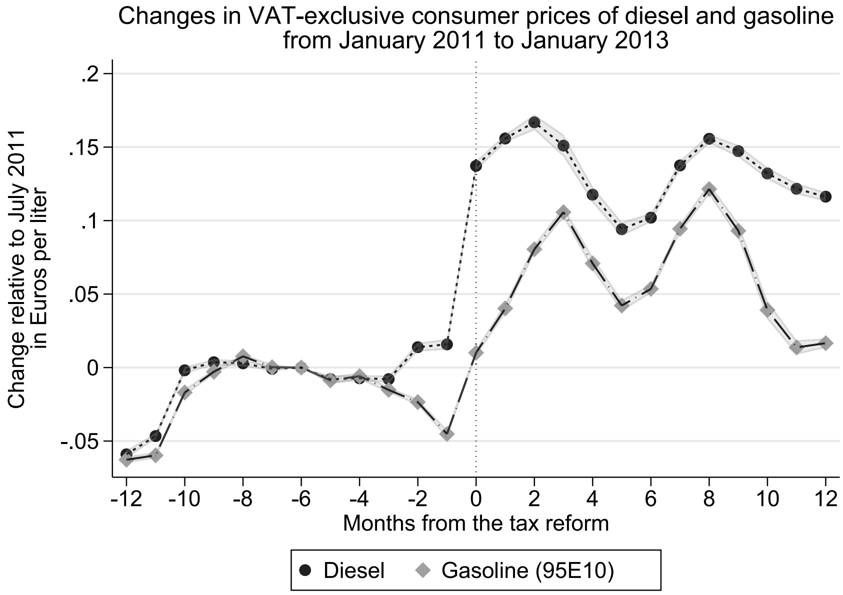


Fig. 4. Changes in tax-inclusive consumer prices of diesel and gasoline from January 2011 to January 2013.

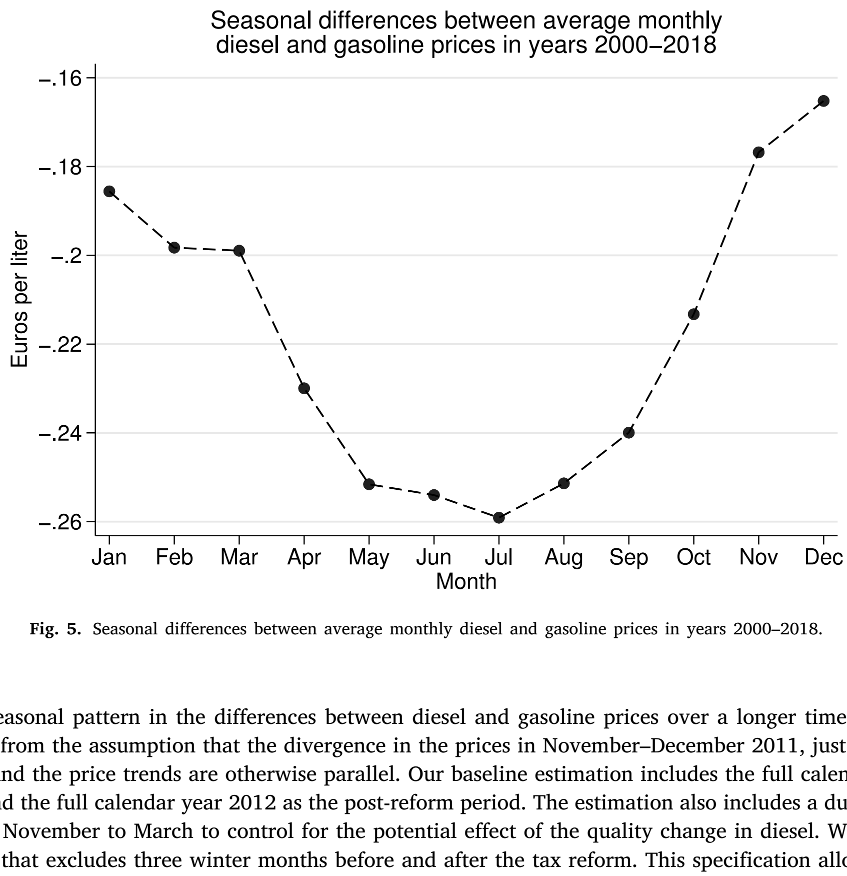


Fig. 5. Seasonal differences between average monthly diesel and gasoline prices in years 2000–2018.

Because of the seasonal pattern in the differences between diesel and gasoline prices over a longer time period, our baseline estimation proceeds from the assumption that the divergence in the prices in November–December 2011, just before the reform, is seasonal in nature, and the price trends are otherwise parallel. Our baseline estimation includes the full calendar year 2011 as the pre-reform period and the full calendar year 2012 as the post-reform period. The estimation also includes a dummy variable for the winter months from November to March to control for the potential effect of the quality change in diesel. We also present results from a specification that excludes three winter months before and after the tax reform. This specification allows us to address the potential bias due to the divergence in diesel and gasoline prices prior to the reform, whether due to a persistent seasonal divergence in diesel and gasoline prices or anticipation of the diesel carbon tax increase.

Another critical assumption underlying any difference-in-differences analysis is the Stable Unit Treatment Value Assumption (SUTVA), which requires that treatment effects do not spill over from the treated to the untreated. Our analysis focuses on diesel and gasoline prices faced by private motorists. SUTVA could be violated if diesel and gasoline buyers were able to substitute gasoline for diesel, which would make diesel and gasoline part of the same demand system. Such substitution possibilities are very limited in our context in the short run: gasoline cannot be used in a diesel-powered vehicle and vice versa, and only about 10% of households own both diesel and gasoline vehicles. In terms of the supply side, the same gas stations sell both diesel and gasoline. Station chains procure fuels from international markets where they are small buyers, so cost interdependence is limited. The assumption that gasoline prices are not affected by the diesel tax increase seems plausible in this market setting. If firms nevertheless increased gasoline prices in response to the diesel tax increase, our pass-through estimates would be biased towards zero. A robustness check described in Section 5.4 compares our baseline estimates to those from an alternative comparison that exploits retail diesel prices in neighboring Sweden. The pass-through rates obtained are very similar to those from our baseline diesel–gasoline comparison, indicating that station owners did not respond by increasing both prices in a response to the reform.

In addition to estimating the average effect of the diesel tax increase on prices, we examine heterogeneous effects across areal income levels and degree of urbanization using the following modified difference-in-differences regression:

$$P_{sft} = \beta_1 + \beta_2 D_f + \beta_3 A_t + \boldsymbol{G}_s'\boldsymbol{\beta}_4 + \beta_5 D_f A_t + D_f \boldsymbol{G}_s'\boldsymbol{\beta}_6 + A_t \boldsymbol{G}_s'\boldsymbol{\beta}_7 + D_f A_t \boldsymbol{G}_s'\boldsymbol{\beta}_8 + \boldsymbol{X}_{sft}'\boldsymbol{\beta}_9 + \eta_{sft}, \tag{2}$$

where $\boldsymbol{G}_s$ is a vector of indicators for the income level or rural–urban class of the gas station's postcode area, with the first income septile and the most rural class excluded as the baseline, and all other variables are as previously defined. If the assumption of parallel trends for diesel and gasoline prices holds in all seven groups, β_5 identifies the causal effect of the diesel tax increase on diesel prices in the baseline group, and the coefficients in vector $\boldsymbol{\beta}_8$ show how the causal effect in each group differs from that in the baseline group.

Ordinary least squares produce unbiased estimates of the standard errors only if observations are independently and identically distributed. Fuel prices at the station level are unlikely to be independently determined. This means that the error terms ε_{sft} in Eq. (1) and η_{sft} in Eq. (2), are correlated both in time and between observations. To account for error correlation, we use a sandwich estimator that allows for correlation within specific clusters of data. The estimator still assumes independence of errors across clusters. Even if this assumption is not satisfied, the cluster-robust standard errors are preferable to the standard non-robust errors.

The sandwich estimator provides consistent estimates of the standard errors only when the number of clusters approaches infinity (Cameron et al., 2008). We cluster the errors in the difference-in-differences regressions on the 257 municipalities in our data. The number of clusters could be increased by clustering on individual stations or postcode areas. But Cameron and Miller (2015) remark that while there is no rule for choosing the level of clustering, the consensus among empirical researchers is to cluster on the broadest possible level on which errors are likely to be correlated, as long as the number of clusters remains sufficiently large. Bearing this in mind, we conclude that the municipality is the most appropriate level of clustering here.[20]

4.3. Interpretation of the difference-in-differences estimates

The carbon tax increase on diesel coincided with a small carbon tax increase on gasoline, which complicates the interpretation of the coefficients in Eqs. (1) and (2). Without a simultaneous carbon tax increase on gasoline, the coefficient γ_4 in (1) and the coefficients β_5 and $\boldsymbol{\beta}_8$ in (2) would directly identify the causal effects of the diesel carbon tax increase. Countrywide average pass-through would then be calculated as $\frac{\gamma_4}{(1+\text{VAT})\Delta t_d}$, pass-through in the baseline group of the income and rural–urban spectrum as $\frac{\beta_5}{(1+\text{VAT})\Delta t_d}$, and the pass-through difference between the baseline group and the other groups as $\frac{\boldsymbol{\beta}_8}{(1+\text{VAT})\Delta t_d}$, where Δt_d is the change in the carbon tax on diesel between 2011 and 2012 and VAT is the value added tax rate, 23 percent during both 2011 and 2012. We use VAT-inclusive retail prices in the econometric analysis and therefore also divide our estimates by VAT-inclusive carbon tax increases.

With the concurrent increase in the carbon tax on gasoline, the estimated coefficients γ_4, β_5 and $\boldsymbol{\beta}_8$ measure how much of the difference in the diesel and gasoline carbon tax increases is passed through to diesel prices. We next show that if the true countrywide diesel and gasoline carbon tax pass-through rates are equal and the assumption of parallel trends holds, proportioning the coefficients to the difference in the diesel and gasoline carbon tax increases yields an unbiased estimate of the diesel carbon tax pass-through rate.

Let Δp_f denote the change in the average price of fuel $f = d, g$ between 2011 and 2012, where d is diesel and g gasoline. Similarly, let Δp_{fe} denote the change in the contrafactual average price of fuel f in the absence of any taxes, Δt_f the change in the carbon tax on fuel f, and PT_f the true countrywide carbon tax pass-through rate for fuel f. Coefficient $\hat{\gamma}_4$ in Eq. (1) can then be expressed as follows:[21]

$$\hat{\gamma}_4 = \Delta p_d - \Delta p_g = (1 + \text{VAT})(\Delta p_{de} + \Delta t_d PT_d) - (1 + \text{VAT})(\Delta p_{ge} + \Delta t_g PT_g). \tag{3}$$

If the fuel prices in the absence of any taxes follow parallel trends, then $\Delta p_{de} = \Delta p_{ge}$ and Eq. (3) simplifies to $\hat{\gamma}_4 = (1+\text{VAT})(\Delta t_d PT_d - \Delta t_g PT_g)$. Under the assumption of equal true diesel and gasoline carbon tax pass-through rates, $PT_d = PT_g$, we then have that

$$\widehat{PT}_d = \frac{\hat{\gamma}_4}{(1 + \text{VAT})(\Delta t_d - \Delta t_g)} = PT_d. \tag{4}$$

[20] As a robustness check, we considered an alternative specification that clustered the errors on station chains. Since this clustering only produced 11 clusters, which falls below the minimum number of clusters for the sandwich estimator suggested by Cameron and Miller (2015), we instead employed a wild bootstrap method of estimating cluster-robust standard errors. This method has been deemed to produce accurate rejection rates with as few as 5–10 clusters (Cameron et al., 2008). The results were found reasonably robust to the choice of the clustering variable (the full results, not reported here in the interest of saving space, are available from the authors upon request).

[21] We thank an anonymous reviewer for suggesting this formulation.

The fundamental assumption to recover Eq. (4) is that the countrywide average prices of diesel and gasoline would follow parallel trends in the absence of any taxes. To calculate pass-through from Eq. (4), we also have to assume a VAT pass-through rate. In our main analysis we assume that the VAT pass-through rate is 100%. We return to this assumption in Section 5.4, where we show that the diesel carbon tax pass-through estimates are not very sensitive to alternative assumptions about the VAT pass-through rate.

Similarly, if the true diesel and gasoline tax pass-through rates are equal within each of the areal income and rural–urban groups and the assumption of parallel trends holds within each group, proportioning the sum of coefficients $\hat{\beta}_5$ and $\hat{\beta}_{8s}$ to the difference in the diesel and gasoline carbon tax increases yields an unbiased estimate of the diesel carbon tax pass-through rate in group $s = 2, \ldots, 7$ (recall that the first group is the baseline). To show this, let Δp_{fs} denote the change in the average price of fuel $f = d, g$ in group s, Δp_{fes} the change in the contrafactual average price of fuel f in group s in the absence of taxes, and PT_{fs} the true carbon tax pass-through rate for fuel f in group s. Recall that $\hat{\beta}_5$ in Eq. (2) measures the effect of the diesel tax increase on diesel prices in the baseline group and $\hat{\beta}_{8s}$ how the effect in group s differs from that in the baseline group. We then have

$$\hat{\beta}_5 + \hat{\beta}_{8s} = \Delta p_{ds} - \Delta p_{gs} = (1 + \text{VAT})(\Delta p_{des} + \Delta t_d PT_{ds}) - (1 + \text{VAT})(\Delta p_{ges} + \Delta t_g PT_{gs}). \tag{5}$$

If the fuel prices in the absence of taxes follow parallel trends within each group s, $\Delta p_{des} = \Delta p_{ges}$ and Eq. (5) simplifies to $\hat{\beta}_5 + \hat{\beta}_{8s} = (1 + \text{VAT})(\Delta t_d PT_{ds} - \Delta t_g PT_{gs})$. With $PT_{ds} = PT_{gs}$ we have that

$$\widehat{PT}_{ds} = \frac{\hat{\beta}_5 + \hat{\beta}_{8s}}{(1 + \text{VAT})(\Delta t_d - \Delta t_g)} = PT_{ds}. \tag{6}$$

We return to the potential bias in the diesel pass-through estimates induced by a violation of the assumption of equal diesel and gasoline carbon tax pass-through rates in Section 5.4.

5. Results

5.1. Overall carbon tax pass-through

Table 4 presents results from the estimation of Eq. (1), the countrywide average pass-through. Columns (1) to (3) show the results for regressions using data for the entire period 2011–2012 and columns (4) to (6) for regressions excluding three winter months before and after the tax reform. Columns (1) and (4) show estimates from regressions of prices only on indicators for diesel and the post-reform period and their interaction. Columns (2) and (5) display estimates from regressions that add station chain fixed effects and cost, exchange rate and quality controls (the daily Brent crude oil price, the EU ETS emission allowance price, the EUR/USD exchange rate, an indicator for automated stations and an indicator for winter diesel) and columns (3) and (6) from regressions that include station fixed effects and exchange rate and quality controls. The estimated pass-through indicates the proportion of the difference in the diesel and gasoline carbon tax increases, 9.14 euro cents per liter, that was passed on to diesel prices. We find under-shifting of carbon taxes to consumer prices. In column (1), a 9.14 cent per liter increase in the carbon tax on diesel, beyond a concurrent 2.66 cent increase in the carbon tax on gasoline, resulted in a 7.3 cent per liter increase in the price of diesel. This implies a pass-through rate of about 80% for the diesel carbon tax increase. Columns (2) and (3) show that adding the control variables has virtually no effect on the pass-through estimate. Estimates from regressions with station chain fixed effects and station fixed effects are also very similar. All three estimates are statistically lower than the full pass-through rate of 100% at the 0.1% level.

As seen in Fig. 4, the prices of diesel and gasoline also diverged in the months preceding the tax reform. To address this empirical issue, we excluded the three months immediately before and after the tax reform to examine whether this divergence affects the pass-through estimates. Columns (4) to (6) of Table 4 show these results. The model in column (4) only includes indicators for diesel and the post-reform period. The estimated pass-through rate falls to approximately 73% for the model in column (4) as well as for the model with additional controls and station chain fixed effects in column (5), and to 74% for the model with additional controls and station fixed effects in column (6). For all three models, the $D \times A$ coefficients are statistically different from the corresponding coefficients in columns (1) to (3) at the 0.1% level. Excluding the six month period around the reform changes the estimates only slightly, and retains the qualitative result of lower than full pass-through. Comparison of columns (4), (5) and (6) shows that adding controls and station chain or station fixed effects again has virtually no effect on the pass-through estimate.

Our estimated average pass-through rate is somewhat lower than overall fuel pass-through rates estimated in most previous studies, which have documented rates ranging from 80% to 100% or even above. There are several explanations for the difference. First, Finland's 2012 carbon tax increase on diesel was large relative to most of the overall fuel tax increases analyzed in previous studies. It has been argued that price changes induced by tax changes may result in larger behavioral responses than other price changes because they are widely discussed in the media and thus more salient (Li et al., 2014; Rivers and Schaufele, 2015; Tiezzi and Verde, 2016). In line with this argument, one could hypothesize that large tax increases, especially ones motivated by environmental objectives, are more salient than small, fiscally motivated tax increases. Finland's diesel carbon tax increase was part of a wider environmental tax reform and received significant media coverage. Results in a range similar to ours were reported by Genakos and Pagliero (2019), who analyzed relatively large fuel tax increases in Greece. They also found under-shifting of taxes to consumer prices, with an average pass-through rate of 77%.

Second, fuel distributors may respond to carbon taxes by increasing the share of low-carbon biofuel components in their market blends, which could absorb some of the carbon tax increase. This is part of the desired policy response in that replacing pure petroleum products with cleaner fuel components is one way carbon taxes can reduce emissions from the transport sector. Aggregate

Table 4
Overall effect of diesel carbon tax increase on diesel fuel prices.

	Full calendar years 2011–2012			Three months before and after the reform excluded		
Coefficient	(1)	(2)	(3)	(4)	(5)	(6)
D×A	*7.26****	*7.30****	7.32***	*6.64****	*6.70****	6.72***
	(0.15)	*(0.17)*	(0.17)	*(0.17)*	*(0.19)*	(0.20)
D	−19.22***	−21.60***	−21.58***	−20.20***	−21.31***	−21.28***
	(0.08)	(0.12)	(0.12)	(0.09)	(0.13)	(0.12)
A	10.35***	7.88***	7.87***	10.85***	11.13***	11.23***
	(0.13)	(0.26)	(0.26)	(0.16)	(0.30)	(0.30)
Constant	155.12***	136.96***	142.63***	155.46***	125.81***	130.31***
	(0.17)	(1.02)	(3.39)	(0.16)	(1.33)	(2.78)
Controls	No	Yes	Yes	No	Yes	Yes
Station chain indicators	No	Yes	Yes	No	Yes	Yes
Station indicators	No	No	Yes	No	No	Yes
Pass-through, %	79.5	79.9	80.1	72.6	73.3	73.5
	(1.6)	(1.8)	(1.9)	(1.9)	(2.1)	(2.1)
N	219,034	219,034	219,034	163,693	163,693	163,693
R^2	0.81	0.87	0.90	0.82	0.89	0.91

The dependent variable is fuel price in euro cents per liter. The controls include the daily Brent crude oil price, the EU ETS emission allowance price, the EUR/USD exchange rate, and dummies for winter diesel and fully automated gas stations. Pass-through is calculated by dividing the estimated coefficient on D×A by the difference between the VAT-inclusive increases in diesel and gasoline taxes, 9.14 euro cents per liter. Standard errors (in parentheses) are clustered at the municipality level. The number of clusters is 257. *, ** and *** indicate significance at the 5%, 1% and 0.1% level.

data from Finnish Customs indicate that the proportion of carbon tax-exempt biofuels in the market blend of diesel increased from 1.65% in 2011 to 4.48% in 2012. Unfortunately, data on the biofuel content of diesel is only available at the aggregate level, and it is not possible to derive causal estimates on the effect of the carbon tax increase on the share of biofuels.

Third, most previous analyses of fuel tax increases based on microdata have focused on the United States. Local and regional fuel markets may differ in terms of consumer preferences, cost structure, or the degree of competition. Fuel demand may, for instance, be more elastic in Europe than in the United States because of wider availability of public transportation or markedly higher fuel taxes and prices. These differences likely lead to different pass-through estimates for different markets.

5.2. *Carbon tax pass-through by areal income and rural–urban class*

An important distributional question surrounding carbon taxes is whether and how the incidence of taxation varies across areas with different income levels and across the rural–urban continuum. Table 5 presents evidence on how diesel prices in lower versus higher income areas and rural versus urban areas were affected by the change in the carbon tax on diesel. The results in Table 5 come from estimating Eq. (2) and a specification comparable with column (2) of Table 4, with station chain fixed effects and cost, exchange rate and quality controls. As each gas station only belongs to one of the areal income or rural–urban groups, station fixed effects would be perfectly collinear with the areal income groups and rural–urban classes and thus cannot be included in these estimations. Again, the estimated pass-through is the proportion of the difference in diesel and gasoline carbon tax increases, 9.14 euro cents per liter, that was passed on to diesel prices.[22]

Panel A of Table 5 shows how carbon tax pass-through differs across areas with different income levels. Because the rural–urban classification contains seven groups, we also divided postcode areas into seven income groups. The effect of the carbon tax increase on fuel prices decreases across the income distribution. The tax increase was passed through most to prices in the lowest income areas, where individuals had a disposable income below 19,170 euros per year on average. The pass-through is still only partial, at about 91%, and statistically different from full pass-through at the 5% level of significance. In the highest income areas, where disposable income was at least 23,810 euros per year on average, the tax increase was passed through least to prices. At 76%, the pass-through rate is 15 percentage points less than in the lowest income areas. Fig. 6 illustrates the differences in pass-through between areal income groups, with the differences measured relative to the pass-through in the lowest income areas. The figure demonstrates a monotonic decrease in pass-through across the income distribution. Although the estimated coefficients for the diesel, post-reform period and income group interactions (D×A×G) are statistically significant at conventional levels only for the three highest income groups, the results suggest heterogeneity in carbon tax pass-through. F-tests for joint significance of the diesel, post-reform period and income group indicator interactions and for full pass-through in all groups also support this conclusion (Table 5). Some of these differences may be driven by consumer knowledge or consumer search sophistication, which plausibly increase with income due to positive correlation of income with education.[23]

[22] The full set of estimates from Eq. (2) by areal income level and rural–urban class can be found in Appendix B, Tables 11 and 12.

[23] Results for how the carbon tax increase affected the prices paid in areas with different housing prices, a proxy for lifetime wealth, are very similar (results available from the authors upon request).

Table 5
Estimated effect of diesel carbon tax increase on diesel prices by areal income level and rural–urban class.

	Areal income level (Panel A)/Rural–urban class (Panel B)						
	1st	2nd	3rd	4th	5th	6th	7th
Panel A. Effect by areal income level							
Pass-through, %	90.7	88.3	84.6	83.7	80.6	77.5	75.7
	(4.1)	(2.3)	(2.7)	(4.2)	(3.2)	(3.8)	(2.0)
D×A×G		−0.22	−0.55	−0.64	−0.92*	−1.20*	−1.37**
		(0.44)	(0.44)	(0.53)	(0.44)	(0.51)	(0.42)
F-test all D×A×G = 0: 4.16***							
F-test full pass-through in all groups: 39.21***							
Panel B. Effect by rural–urban class (from most rural to most urban)							
Pass-through, %	91.3	88.5	82.5	85.5	78.4	79.8	76.6
	(6.0)	(2.6)	(3.7)	(2.8)	(6.4)	(2.2)	(2.5)
D×A×G		−0.25	−0.80	−0.53	−1.18	−1.06	−1.34*
		(0.61)	(0.65)	(0.61)	(0.81)	(0.59)	(0.61)
F-test all D×A×G = 0: 2.63*							
F-test full pass-through in all groups: 32.77***							

The dependent variable is fuel price in euro cents per liter. The controls include the daily Brent crude oil price, the EU ETS emission allowance price, the EUR/USD exchange rate, station chain indicators, and dummies for winter diesel and fully automated stations. Pass-through in septile i is the sum of the coefficients on D×A and D×A×G_i divided by the difference between the VAT-inclusive diesel and gasoline tax changes, 9.14 euro cents per liter. Standard errors (in parentheses) are clustered at the municipality level and the number of clusters is 257. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

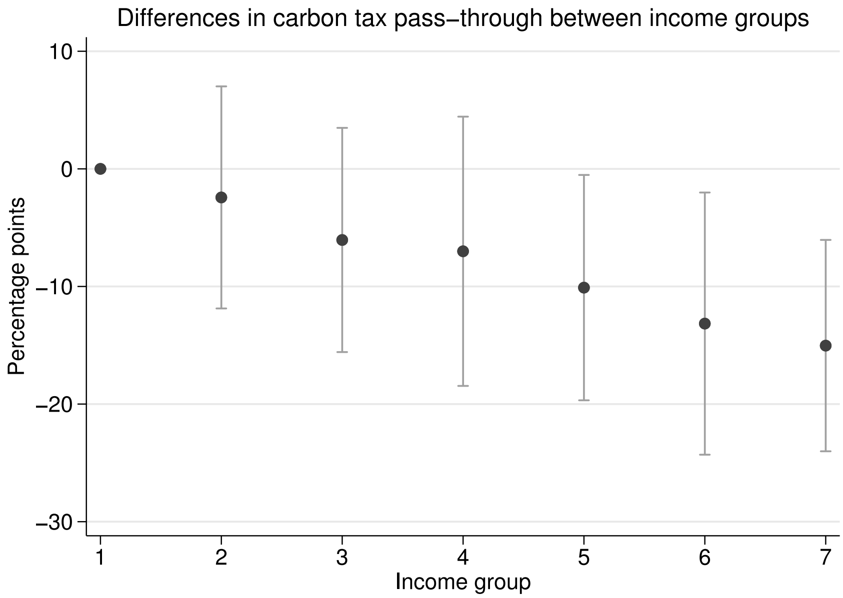


Fig. 6. Differences in carbon tax pass-through between income groups.

Table 5, Panel B and Fig. 7 suggest that carbon tax pass-through also differs across the rural–urban continuum. For the most rural areas (“sparsely populated rural areas”) the pass-through rate is 91%, which is, however, not statistically significantly different from full pass-through at conventional levels, and for the most urban areas (“inner urban areas”) 77%. The difference in pass-through relative to the most rural areas is only statistically significant for the most urban areas and at the 5% level of significance. The joint significance tests for the diesel, post-reform period and rural–urban class interactions indicate differences in pass-through rates between rural and urban areas overall and the F-test for full pass-through in all groups that some of the pass-through rates differ from 100%.

Some of the difference in pass-through between rural and urban areas may be explained by the availability of public transportation, which as a substitute for driving might affect fuel demand elasticity, and by market competition. Both are plausibly greater in urban areas than in sparsely populated rural areas. Appendix C examines local competition as a driver of heterogeneous tax incidence and suggests that the differences are at least in part due to factors other than competition. We are unable to directly test the hypothesis of public transport availability as a driver due to data limitations. Part of the difference may also be driven by the same factors as the difference across income groups, since average income levels are lower in rural areas. We also tested the

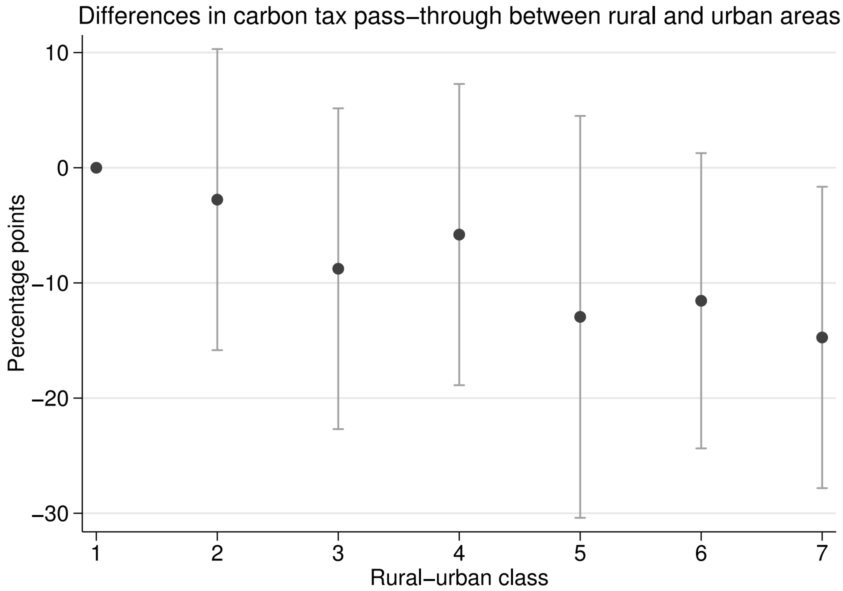


Fig. 7. Differences in carbon tax pass-through between rural and urban areas.

hypothesis that the differences in pass-through across rural and urban areas are explained by income by including all the interactions for both income groups and rural–urban classes in our model. While the pass-through rates still decrease with both income and the degree of urbanization, the differences between groups become smaller. This is the case especially for the degree of urbanization. While the magnitudes of the pass-through differences across the income groups decrease by about 20%–25%, the corresponding decrease for rural–urban classes is about 60%–70%. This suggests that income could explain a significant part of the observed heterogeneity, but we do not have enough statistical power to fully test the interdependence of these two explanatory variables.

Finally, the pass-through rates for each income group and rural–urban class are obtained through dividing estimated coefficients by the difference between the tax changes for the average market blends of diesel and gasoline. A potential concern is that the blends sold in different areas could have changed differently, which would produce bias in our groupwise pass-through estimates obtained using the tax changes for the average market blends. However, given that in the study period practically all vehicles in Finland ran on regular gasoline or diesel (with regulated biofuel content), station brands sell the same blends throughout the country, and station brands are quite evenly distributed across our income groups and rural–urban classes, we conclude that there have not been large differences in diesel blends' changes across regions that would drive our results.

5.3. Welfare implications

That the carbon tax increase is passed through more to prices in low-income areas relative to high-income areas, and in rural areas relative to urban areas, has important distributional implications. The results resonate the claims by the "yellow vests" protesters in France, and others, that fuel taxes disproportionately affect lower- to middle-income groups and rural and peri-urban areas. Assessing the distributional impacts of taxes requires information on the pass-through rate and observed demand, both necessary to accurately measure the changes in consumer surplus associated with the tax change (see e.g. Weyl and Fabinger, 2013). Yet previous literature on the distributional implications of fuel taxes proceeds from the assumption that tax pass-through is uniform across income groups and the rural–urban continuum. The results presented in Section 5.2 indicate that neglecting incidence heterogeneity may bias distributional analysis.

We next illustrate the significance of heterogeneous pass-through in assessing distributional impacts. We combine our pass-through estimates with observed fuel consumption and assess the marginal welfare losses associated with Finland's diesel carbon tax increase, using marginal decreases in consumer surplus as a measure of marginal welfare losses. The fuel consumption information comes from the Statistics Finland individual-level vehicle fleet data described in Section 4.1, which contains the population of vehicles registered in Finland. As the vehicle data begin in 2013, the fuel consumption measures are for year 2013. The data include make-and-model fuel consumption, vehicle kilometers traveled and a vehicle owner identifier.[24] The vehicle owner identifier can be combined with other Statistics Finland individual-level register data to form households and households' disposable income, and to link households with our areal income groups and rural–urban classes. Note that the data allow us to assess the monetary loss from the diesel carbon tax increase, divided by income, at the household level and for all households in Finland.

[24] The kilometers traveled by income and rural–urban classes are plotted in Fig. 15 in Appendix A.

Following the partial equilibrium tax incidence models in Weyl and Fabinger (2013), the change in consumer surplus associated with a tax change is

$$-\frac{dCS_i}{dt} = PT_i \times Q_i,$$

where dt denotes the diesel tax change, CS_i the consumer surplus in group i, PT_i the tax pass-through and Q_i the quantity consumed. The product term $PT_i \times Q_i$ has an intuitive interpretation, as $PT_i \times Q_i$ multiplied by the excise tax increase dt directly measures the monetary loss for households from the tax increase, assuming no changes in consumption. We adopt this simplifying assumption in our illustration as we do not have fuel consumption data for years 2011 and 2012, the period immediately around the tax reform. However, we believe this is a realistic assumption as previous empirical literature has found quite small short-run fuel demand elasticities (see e.g. Hughes et al., 2008; Coglianese et al., 2017). Our results should, however, be considered an illustration of the marginal welfare losses associated with the tax change rather than definitive empirical findings.

Fig. 8 shows the average marginal welfare losses relative to household income across the areal income groups and rural–urban classes used in our incidence analysis. We calculate the marginal welfare losses in two ways: First, we allow pass-through to vary between areas according to our heterogeneous pass-through estimates. Second, we assume that all households face the same pass-through rate, given by our average pass-through estimate of about 80%. Two features are evident in Fig. 8. First, welfare losses relative to income decrease with both postcode level average income and with the degree of urbanization, which implies that the carbon tax is regressive in both dimensions. Regressivity is more pronounced with respect to the degree of urbanization than with respect to areal income: the marginal welfare loss relative to income is about 1.04% in the most rural areas and about 0.24% in the most urban areas, and about 0.69% in the lowest income areas and about 0.42% in the highest income areas. Second, ignoring pass-through heterogeneity attenuates the differences in the estimated welfare impacts across the income groups and rural–urban classes. The difference between the most rural and most urban areas decreases from 0.80 percentage points to 0.66 percentage points, and the difference between the lowest and highest income areas from 0.27 percentage points to 0.17 percentage points. The results suggest that diesel carbon taxes in Finland are regressive across the areal income and rural–urban continuums. The results also demonstrate that ignoring heterogeneity in carbon tax pass-through may lead to underestimating regressivity and the associated distributional concern. A caveat is that our analysis abstracts away from changes in fuel consumption following the tax increase.

5.4. Robustness checks

The diesel pass-through estimates in Tables 4 and 5 are based on the assumptions of parallel trends in diesel and gasoline prices, also across the areal income groups and rural–urban classes; no spillovers between diesel and gasoline prices; and equal diesel and gasoline tax pass-through rates. We next perform several robustness checks and graphical analyses to confirm that these assumptions are valid in our setting.

Our first robustness check uses diesel prices in Sweden, a neighboring country of Finland, as an alternative comparison group for diesel prices in Finland. We estimate Eq. (1) using average daily diesel prices for retail gas stations in the Circle K chain in Sweden and average daily diesel prices in Finland, with the indicator variable for diesel (versus gasoline) now replaced with an indicator variable for Finland (versus Sweden). Sweden's geography, climate, economy and institutions, including fuel tax policies, are similar to those in Finland. The Circle K station data provide a representative sample of fuel prices in Sweden in that they match the overall average fuel prices recorded by the fuel trade association Svenska Petroleum & Biodrivmedel Institutet at the monthly average level. The Swedish diesel prices are not a perfect comparison, as there was a slight increase in the excise tax on diesel in Sweden in January 2012. However, the average tax increase for the market blend was negligible, at 0.17 US dollar cents (approximately 0.12 euro cents) per liter. In comparison, the VAT-exclusive diesel tax increase in Finland was almost two orders of magnitude higher, 13.36 US dollar cents (9.59 euro cents) per liter. Note that Finland uses the euro while Sweden has its own currency krona. To make the prices in the two countries comparable, we express both prices in US dollars in the Finland–Sweden comparison. We choose US dollars because it is the currency in which crude oil is traded in, and the prices of diesel largely follow changes in crude oil prices. We use the annual average exchange rates from 2011 so that the comparison is not confounded by short-term exchange rate volatility. Finally, we use VAT-exclusive prices in the comparison with prices in Sweden as the VAT rates in the two countries differ.

Fig. 9 shows the difference between the changes in retail diesel prices in Finland and Sweden from January 2011 to December 2012. The prices in the two countries followed similar trends in 2011, prior to Finland's 2012 tax reform, apart from October–November 2011 when the prices in Sweden increased somewhat more rapidly than those in Finland (Fig. 17 in Appendix A provides additional detail). Nevertheless, Finland's large 2012 diesel tax reform increased diesel prices in Finland sharply. This increase is evident immediately at the time of the reform and is much more pronounced than the small cyclical deviation around a common time trend in the fall of 2011. Table 6 presents estimates from the diesel-prices-in-Finland to diesel-prices-in-Sweden comparison. Column (1) shows the results for a regression of prices only on indicators for Finland and the post-reform period and their interaction using data for the entire period 2011–2012, and column (2) for a regression excluding the three winter months before and after the tax reform. The estimation that compares the full calendar years 2011 and 2012 yields a pass-through estimate of 84%, and the estimation that excludes the three months right before and after the tax reform in Finland yields a pass-through estimate of 76%. The pass-through estimates are both close to those from our primary specification (80% and 73% for the corresponding models), confirming our finding of under-shifting of diesel carbon taxes to consumer prices.[25] More importantly, the similar pass-through

[25] The pass-through estimates take into account the small diesel tax increase in Sweden.

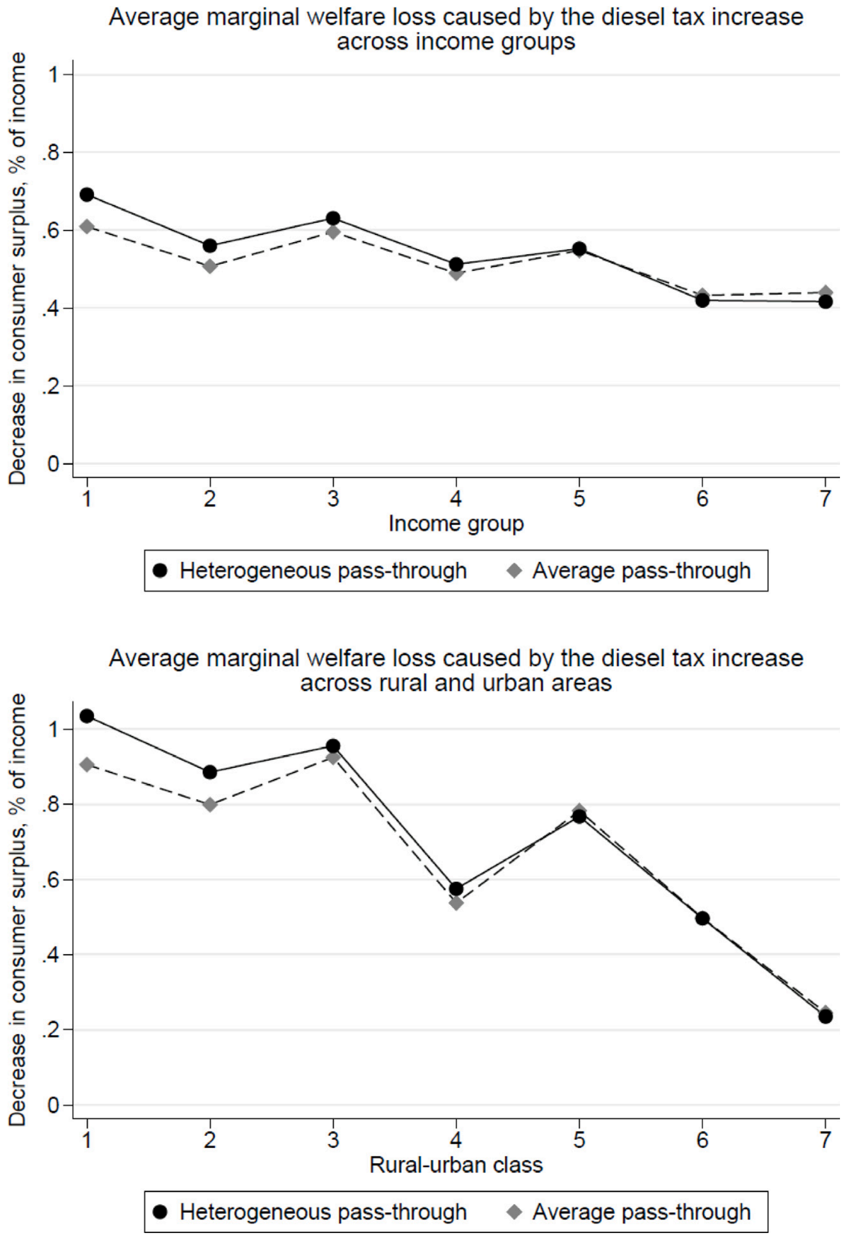


Fig. 8. Distributional effects of the diesel carbon tax increase across income groups and rural–urban classes.

estimates from this robustness check with an alternative comparison group provide support for the assumptions of no spillovers between diesel and gasoline prices in Finland and equal diesel and gasoline tax pass-through rates.

As shown in Section 4.2, the changes in diesel and gasoline prices in Finland used in our baseline analysis mostly follow parallel trends prior to January 1, 2012, but cyclicality raises some concern. Fig. 17 in Appendix A presents additional comparisons of changes in diesel and gasoline prices in Finland and Sweden over time. The figure demonstrates similar cyclicality in prices across the two fuel types and the two countries: there is a slight increase in diesel prices towards the end of 2011 in both countries, and a simultaneous decline in gasoline prices. It is evident in Fig. 17 that gasoline prices in the two countries follow each other closely over time. This comparison between two very similar countries, which are both very small relative to the size of the global petroleum markets, suggests that the cyclicality in fuel prices over time is mostly due to factors other than anticipatory changes in prices prior to the reform or other behavioral effects that would violate our identification strategy.

To assess the validity of the incidence heterogeneity analysis, it is also important to confirm the assumption that fuel prices have similar trends across different areas in the absence of fuel tax changes. To provide support for this assumption, Fig. 10 shows the differences between the average monthly diesel prices in the lowest and highest income areas, and in the most rural and urban areas, before and after the 2012 diesel tax reform. The figure also shows the 95% confidence intervals for the price differences.

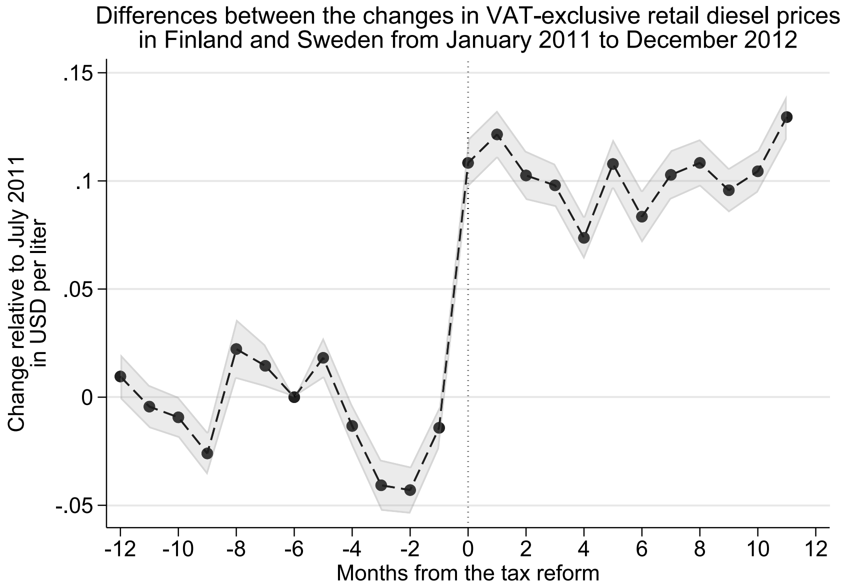


Fig. 9. Differences between the changes in retail diesel prices in Finland and Sweden from January 2011 to December 2012. Prices are VAT-exclusive.

Table 6
Overall effect of the diesel carbon tax increase on diesel prices from a comparison of Finnish and Swedish price data.

	Full calendar years 2011–2012	Three months before and after the reform excluded
Coefficient	(1)	(2)
Finland×After	*11.09****	*9.99****
	(0.30)	*(0.32)*
Finland	−19.57***	−18.74***
	(0.23)	(0.24)
After	8.85***	9.81***
	(0.30)	(0.31)
Constant	173.45***	171.89***
	(0.23)	(0.24)
Pass-through, %	84.1	75.7
	(2.2)	(2.4)
N	111,493	83,046
R^2	0.77	0.77

The dependent variable is fuel price in US dollar cents per liter excluding VAT. Pass-through is calculated by dividing the estimated coefficient on Finland×After by the difference between the VAT-exclusive increases in Finnish and Swedish diesel taxes, amounting to 13.19 US dollar cents per liter. *, ** and *** denote significance at the 5%, 1% and 0.1% level.

The monthly differences have been normalized by subtracting the 2009–2011 (pre-reform) average difference. The price differences between the lowest and highest income areas and between the most rural and urban areas are both statistically equivalent to zero before the 2012 carbon tax reform, and statistically different from zero after the reform. No other changes took place in 2012 that one could hypothesize to have disproportionately affected the lowest income or most rural areas. Fig. 10 is consistent with the finding that the pass-through rate was highest in the lowest income areas and in the most rural areas, and provides support for the validity of the identification assumptions underlying the pass-through heterogeneity analysis. Fig. 10 also provides graphical evidence that the results are robust to using a diesel price data and first differences approach. Interestingly, the figure also suggests a slightly decreasing trend in these differences over time, after the reform. This may be due to, for example, competition across fuel stations slowly eroding the excess profit margins over time. Unfortunately, we cannot test these types of mechanisms in the current setting. In addition, Fig. 18 in Appendix A shows the differences between the diesel–gasoline price differentials in the lowest and highest income areas and between the most rural and urban areas. The pattern is similar to that for presented for diesel prices below, providing further support for the robustness of our results.

Another potential concern is that effect sizes might be linked to the initial price levels, as the tax-inclusive prices of gasoline are persistently above those of diesel. Heterogeneous treatment effects or time effects of different sizes that depend on the initial price level might introduce bias to the differences-in-differences estimates and challenge our assumption of equal diesel and gasoline tax pass-through rates. Fig. 11, top panel shows the price distributions for diesel and gasoline before the reform (November 2011) and

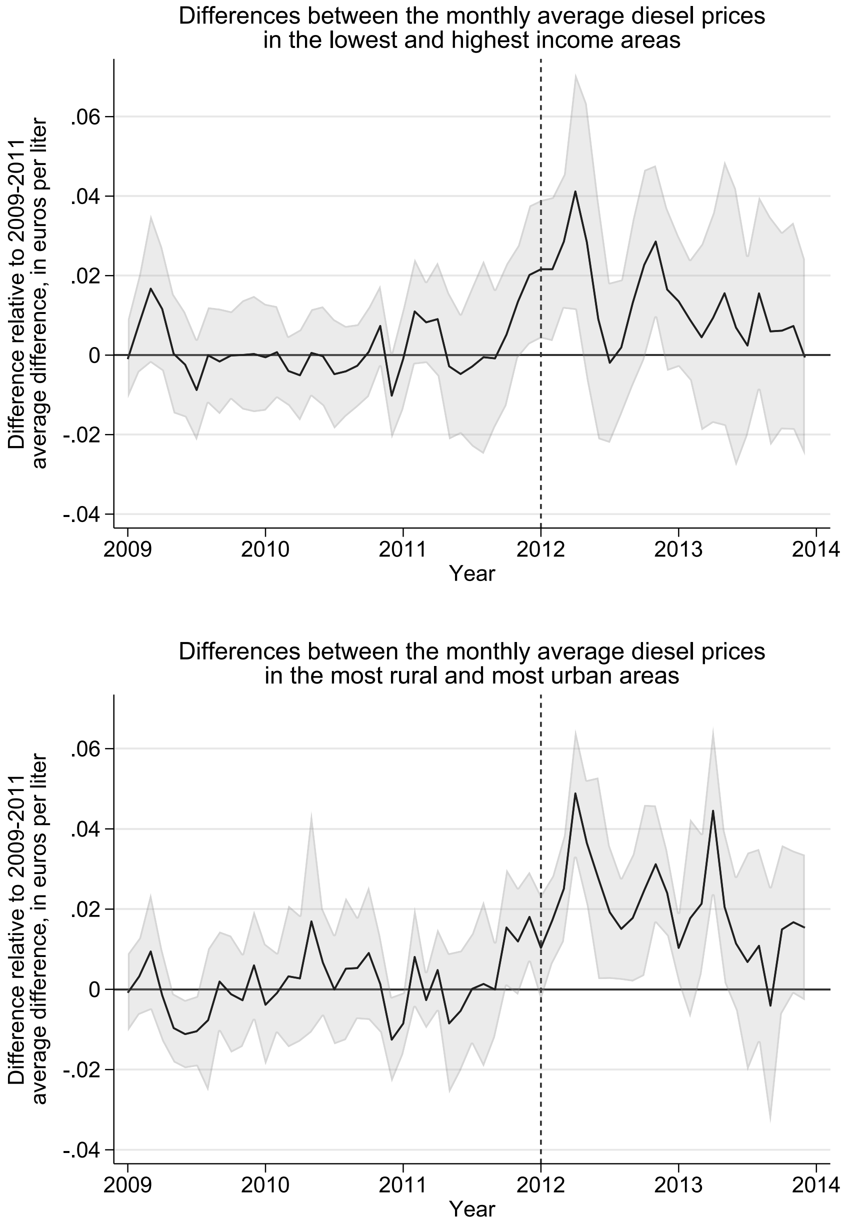


Fig. 10. Differences between the monthly average diesel prices in the lowest and highest income areas, and in the most rural and urban areas. The prices are tax-inclusive retail prices. The shaded area shows the 95% confidence interval. The monthly differences have been normalized by subtracting the 2009–2011 average difference. The dotted vertical line indicates the date of the tax reform.

after the reform (February 2012), plotted using all station and price observation pairs in our estimation sample in these months. The figure shows that the diesel price distribution shifted to the right as a response to the tax reform. The shift in the gasoline price distribution is similar in direction but much smaller in magnitude. Importantly, the shifts in the two distributions suggest uniform treatment effects that are independent of the original price levels. Fig. 11, bottom panel shows the distributions of the station-level changes in gasoline and diesel prices from November 2011 to February 2012, with station-level changes calculated as the difference between the February 2012 and November 2011 station-level average prices. These distributions further demonstrate the much more pronounced change in diesel prices throughout. In summary, the evidence in Fig. 11 provides support for the assumption underlying our difference-in-differences analysis that treatment effects are independent of the original price levels and diesel and gasoline tax pass-through rates are equal.

We also assess the credibility of our identification strategy by a placebo estimation using data for years where no excise tax changes took place. Table 7 presents results from estimating the model in Eq. (1) using two time periods where no carbon tax changes or other excise tax changes took place. In column (1), we compare year 2009 as a placebo pre-treatment period to year 2010 as a placebo post-treatment period, and in column (2) year 2012 to year 2013. As minor increases in VAT were introduced

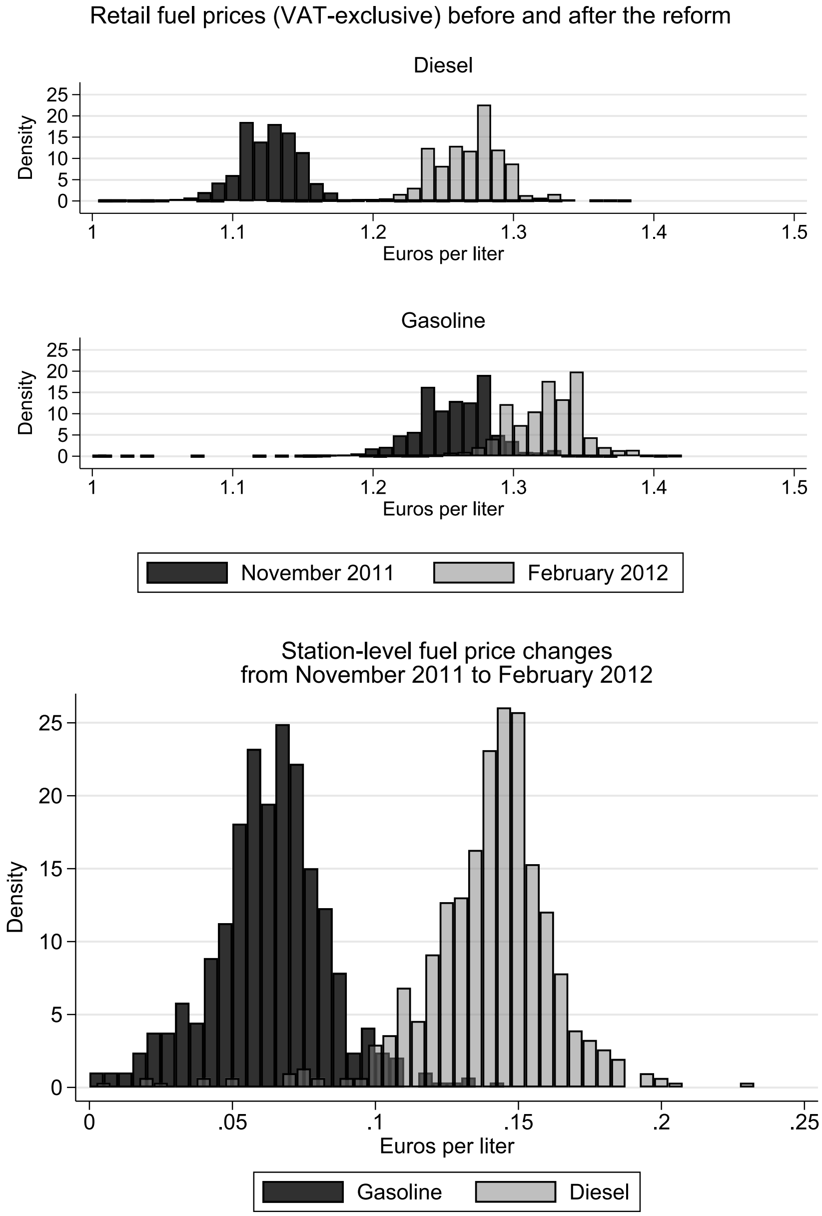


Fig. 11. Diesel and gasoline price distributions before and after the reform, as cross-sections (top) and as differences relative to the pre-reform price (bottom).

in 2010 and 2013, prices and taxes in our estimation are VAT exclusive.[26] We do not include a 2010–2011 comparison in the placebo analysis because of a notable change in the maximum ethanol content of E95 gasoline in January 2011, from 5 percent to 10 percent. Since ethanol is taxed at a lower rate than pure gasoline, the change in the quality standard and the consequent increase in the ethanol content of the retail blend translate into a decrease in the excise tax on the retail blend. A caveat pertaining to the 2012–2013 comparison is that there was also a change in biofuel legislation in July 2013 that may have resulted in some changes in the market blends and the excise taxes on the blends.

The diesel and post-treatment interaction coefficient in column (1) is statistically significant at the 1% level but small in economic magnitude at 0.66 cents and much smaller than our main estimate of 7.32 cents presented in Table 4. The interaction coefficient in column (2) is statistically insignificant and nearly zero in magnitude. Gasoline and diesel price trends diverged at the very end of 2010, which may again be a manifestation of the persistent seasonal pattern in diesel and gasoline prices discussed in Section 4.2. The market outcomes at the very end of 2010 could also reflect the change in the ethanol content of the E95 gasoline blend and

[26] The VAT rate increased from 22% to 23% in 2010 and from 23% to 24% in 2013.

Table 7
Robustness check of the effect of diesel tax changes on diesel prices in periods where no tax changes took place.

Coefficient	Years 2009 and 2010 (1)	Years 2012 and 2013 (2)
$D\times A$	*0.66**** *(0.07)*	*−0.21* *(0.13)*
D	−23.61*** (0.08)	−9.72*** (0.11)
A	11.18*** (0.09)	−3.13*** (0.11)
Constant	104.67*** (0.13)	134.53*** (0.16)
N	264,258	215,169
R^2	0.88	0.59

The dependent variable is fuel price in euro cents per liter excluding VAT. Standard errors (in parentheses) are clustered at the municipality level and the number of clusters is 257. *, ** and *** indicate significance at the 5%, 1% and 0.1% level.

the consequent decrease in the excise tax on the blend. Excluding December 2010 from the estimation decreases the interaction coefficient from 0.66 to 0.20 so the positive interaction coefficient is indeed largely due to just one month at the end of the year. Overall, these results are most compatible with no economically significant effect in time periods close to the 2012 reform but with no policy changes, and suggest that the effects we find for year 2012 are indeed caused by the carbon tax increase that came into effect in the beginning of the year.

While the robustness checks and graphical analyses above have provided support for the assumption of equal diesel and gasoline tax pass-through rates, we conclude by exploring the robustness of our pass-through estimates to violations of this assumption. Abandoning the assumption of equal countrywide diesel and gasoline pass-through rates PT_d and PT_g but maintaining the assumption of parallel trends, Eq. (3) can be rearranged as

$$PT_d = \frac{\hat{\gamma}_4 + (1+\text{VAT})\Delta t_g PT_g}{(1+\text{VAT})\Delta t_d}. \tag{7}$$

Eq. (7) shows the relationship between the true diesel carbon tax pass-through PT_d and the true gasoline carbon tax pass-through PT_g, given the estimated difference-in-differences coefficient $\hat{\gamma}_4$. We use Eq. (7) to assess how much the estimated diesel carbon tax pass-through in column (2) of Table 4 differs from the true diesel carbon tax pass-through under different assumptions about the true gasoline carbon tax pass-through. The 2012 carbon tax changes on diesel and gasoline were $\Delta t_d = 9.59$ euro cents per liter and $\Delta t_g = 2.16$ euro cents per liter. With these tax changes and the difference-in-differences coefficient $\hat{\gamma}_4$ from column (2) of Table 4, the relationship between the true diesel carbon tax pass-through PT_d and the true gasoline carbon tax pass-through PT_g, defined by Eq. (7), is a linearly increasing function. This allows us to assess bounds for the true diesel carbon tax pass-through rates that are consistent with a given range of true gasoline carbon tax pass-through rates. True gasoline carbon tax pass-through rates ranging from, say, notable under-shifting at a pass-through of 75% to full shifting at a pass-through of 100% would be consistent with true diesel carbon tax pass-through between 79% and 84%. Overall, our countrywide pass-through estimate of 80% for the carbon tax on diesel is not very sensitive to assumptions about the true gasoline carbon tax pass-through.

To calculate the pass-through rate from Eq. (4), we also have to make an assumption about the VAT pass-through rate. However, as the VAT is quite small relative to the overall difference in the diesel and gasoline carbon tax changes, the diesel carbon tax pass-through rate is not very sensitive to alternative assumptions about the VAT pass-through rate. An 80,0% countrywide pass-through of the VAT, for example, would result in a countrywide average carbon tax pass-through of 83,0%. An alternative assumption of equal diesel carbon tax and VAT pass-through rates in turn would imply a pass-through of 82,6%.

Differences between the true diesel and gasoline carbon tax pass-through rates could also be a concern when assessing heterogeneity in carbon tax incidence. To test the robustness of our diesel tax pass-through heterogeneity results to different assumptions about gasoline tax pass-through, we consider two checks that allow the diesel and gasoline carbon tax pass-through rates in areal income or rural group s to differ from each other. Rearranging Eq. (5) yields

$$PT_{ds} = \frac{\hat{\beta}_5 + \hat{\beta}_{8s} + (1+\text{VAT})\Delta t_g PT_{gs}}{(1+\text{VAT})\Delta t_d}. \tag{8}$$

Eq. (8) implies that $PT_{d1} - PT_{ds} = \frac{-\hat{\beta}_{8s} + (1+\text{VAT})\Delta t_g (PT_{g1} - PT_{gs})}{(1+\text{VAT})\Delta t_d}$ for $s = 2, \dots, 7$. Notice that the difference in the true diesel tax pass-through rates PT_{d1} and PT_{ds} that is consistent with the true gasoline pass-through rates PT_{g1} and PT_{gs} is also consistent with any other true gasoline pass-through rates PT'_{g1} and PT'_{gs} for which it holds that $PT_{g1} - PT_{gs} = PT'_{g1} - PT'_{gs}$.

Our first check assumes that there is no heterogeneity in gasoline carbon tax pass-through. This check decreases the diesel carbon tax pass-through difference between the lowest and highest income groups from our baseline estimate of 15 percentage points to 12 percentage points, and that between the most rural and urban areas from 15 percentage points to 11 percentage points. The second check assesses the gasoline carbon tax pass-through differences that would make the diesel carbon tax pass-through differences disappear. From the expression above, we obtain confidence intervals for $PT_{d1} - PT_{ds}$. At the 95 percent level, the diesel carbon

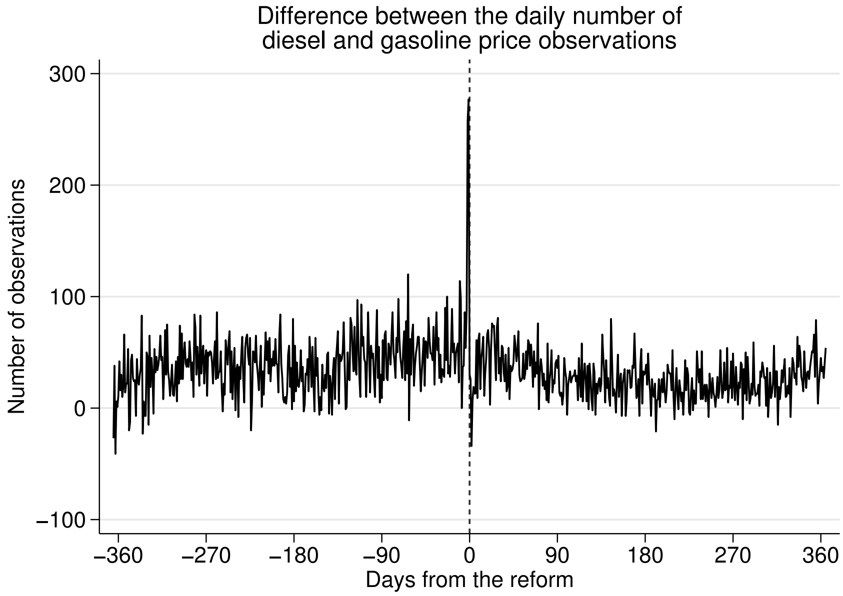


Fig. 12. Differences in the daily number of diesel and gasoline price observations from January 1, 2011 to December 31, 2012.

tax pass-through difference between the lowest and highest income areas is no longer statistically significant if the true gasoline carbon tax pass-through difference between the lowest and highest income areas is −21 percentage points or lower. Importantly, the gasoline tax pass-through difference between the lowest and highest income areas would have to of the opposite sign relative to the estimated diesel tax pass-through difference. The same holds for the gasoline pass-through difference between rural and urban areas in terms of sign, although a smaller difference in magnitude would make the diesel tax pass-through differences disappear. The diesel tax pass-through difference between the most rural and urban areas is no longer statistically significant at the 95 percent level if the true gasoline carbon tax pass-through difference between the groups is −6 percentage points or lower. In conclusion, the qualitative finding that the carbon tax increase on diesel was passed through more to prices in low-income areas than in high-income areas is not very sensitive to reasonable assumptions about the true gasoline carbon tax pass-through. The same holds for heterogeneity in pass-through across the rural–urban continuum.

We also estimated Eqs. (1) and (2) using a weighted average of the prices for the two types of gasoline sold in Finland, 95E10 and 98E5, as a comparison for diesel prices, instead of 95E10 prices alone as in the main analysis. The numbers of price observations for each type of gasoline are used as weights. The results from this analysis (not shown) are very similar to those obtained using 95E10 prices.

6. Consumer and distributor anticipation

Tax changes, like the one we are studying, are easily anticipated so that forward-looking market participants may take future tax changes into account when deciding how much fuel to buy. Coglianese et al. (2017) were the first to demonstrate such inter-temporal substitution in the US gasoline market. Both final consumers and distributors may increase purchases in the months leading up to a tax increase, making sure their tanks are filled. Such anticipatory behavior would bias conventional least-squares estimates of price elasticities towards zero.

Section 4.2 addressed whether potential anticipation was reflected in diesel prices prior to the increase in the carbon tax, but found no evidence of anticipatory effects in prices. We next address buyer behavior and examine whether diesel purchases were shifted before Finland's 2012 diesel carbon tax increase. Station-level data on diesel sales are not available, but the number of observations in the volunteer-spotted price data provides suggestive evidence of consumers' diesel purchases, as increases in gas station visits are expected to translate to increases into price records. Fig. 12 shows that the number of diesel price observations spiked in the last two days before the tax reform, which is consistent with consumers filling up their tanks one last time in the days preceding the tax increase.

Carbon taxes and other excise taxes are collected when fuels are released from refineries or importers' storage to distributors' storage. Monthly data from the tax-collecting authority Customs Finland on the quantities of taxed diesel allow us to assess more exactly whether purchases by distributors shifted in anticipation of the carbon tax increase. We quantify anticipatory purchases following a bunching approach similar to Kleven and Waseem (2013).[27] The magnitude of the bunching response is often referred

[27] Here the tax notch is at a specific point in time, the day the tax increase came into effect, rather than a level of taxable income as in Kleven and Waseem (2013). A more detailed account of the bunching method can be found in Kleven (2015).

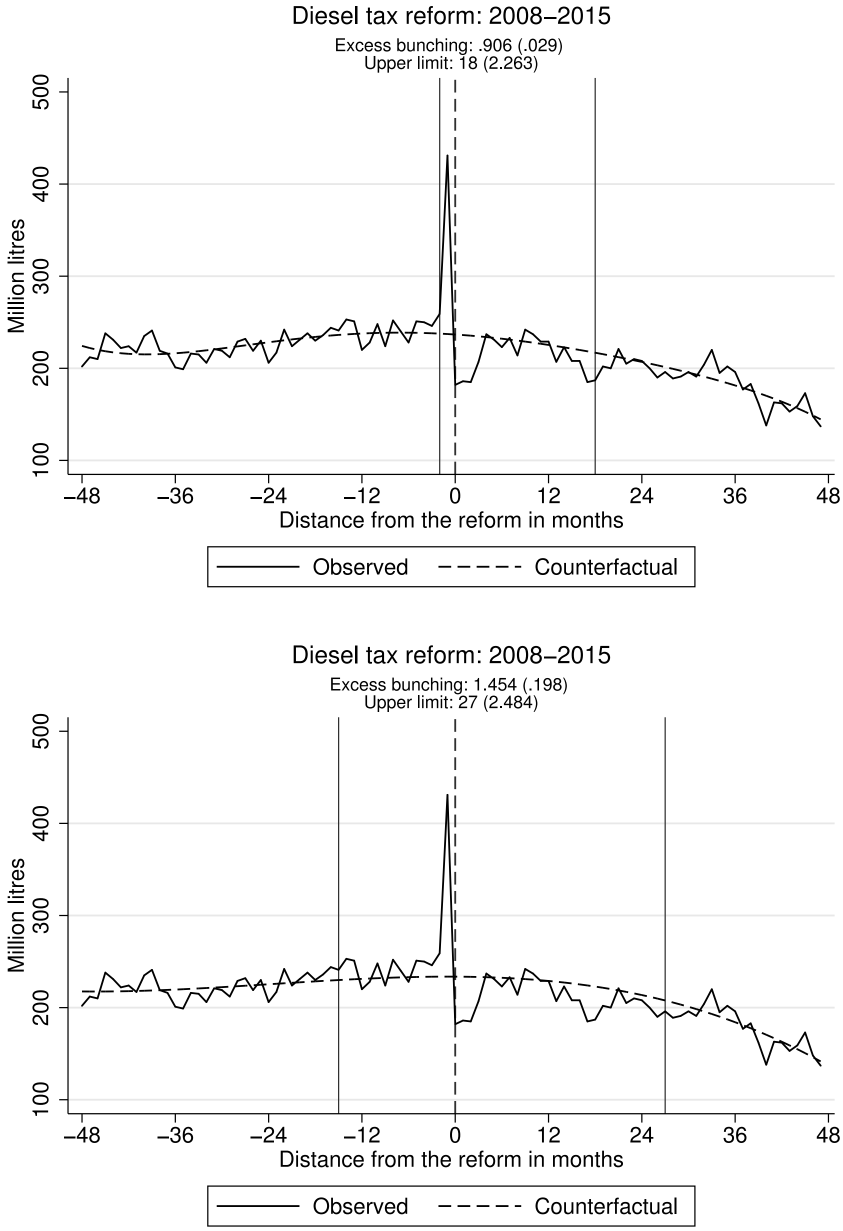


Fig. 13. Excess mass of the diesel transferred from wholesale to retail storage (million liters) in the months leading up to the 2012 reform.

to as excess mass, defined as additional mass in the observed distribution at the notch point relative to a counterfactual distribution without the notch. Measuring the excess mass requires first approximating the counterfactual distribution, in our case the empirical density of diesel released from wholesale storage to retail chains' storage in the absence of the tax reform. The counterfactual density is estimated by fitting a flexible polynomial to the empirical density such that observations in a range before and after the tax reform are excluded. The excluded observations span the range where the bunching responses occur. The lower limit of the excluded range is commonly determined by visual observation of where the behavioral response begins. The upper limit, on the other hand, cannot be determined visually. To determine the upper limit, we follow Kleven and Waseem (2013) and use the excess liters in the distribution that constitute the bunching response (appear between the lower limit and the notch point) to match the liters released to retail operators that are 'missing' after the reform. We iterate from an initial value of the upper limit which we then increase in small increments, one month at a time. The counterfactual is re-estimated for each increment until a point of convergence is achieved such that all the excess liters that were taxed before the reform have been added to the observed distribution after the reform.

Fig. 13 shows the excess bunching estimates, the observed distribution, and the estimated counterfactual distribution with two alternative lower limits for the excluded range. The lower limits are November 2011 (indicated by the vertical line at −2 months in the top panel of Fig. 13) and October 2010 (vertical line at −15 months in the bottom panel of Fig. 13), the time at which the reform was first made public. November 2011 reflects the assumption that retail operators anticipated the reform only two months in advance and October 2010 the assumption that anticipation began as soon as the reform was first made public. The top panel of Fig. 13 suggests that 90% more diesel was taxed and released to distributors' storage in the last two months leading up to the tax increase than what the estimated counterfactual would have predicted. The bottom panel of Fig. 13 suggests even more notable anticipation between the introduction of the carbon tax reform bill and the date the tax increase went into effect (October 2010 through December 2011), with approximately 145% excess liters taxed relative to the counterfactual distribution. This evidence implies that forward-looking distributors and retailers indeed anticipated the carbon tax increase and filled their terminals, tanker trucks and underground storage tanks before the tax reform.[28]

7. Conclusion

This paper uses station-level fuel price data around a diesel carbon tax reform to analyze the incidence of fuel carbon taxes. We estimate the pass-through of these taxes to consumer prices, which indicates to what extent the taxes are passed forward to consumers versus being absorbed by the supply chain. Contrary to much of the related literature on overall fuel excise tax incidence, we find that the carbon taxes are less than fully passed through to consumers on average. There are many possible explanations for the difference. Tax or price elasticities of fuel demand may differ with tax and price levels, income, and substitution possibilities provided by public transportation, and demand may be more elastic in Europe than in the US, a country on which much of the previous literature has focused. Furthermore, we examine the effect of a large diesel carbon tax increase, nearly 11 euro cents per liter, which received substantial media coverage. Large, salient tax increases may be passed on to consumers to a lesser degree than small tax increases (Chetty et al., 2009).

Using information on station location and the average income and rural–urban class of its postcode area, we estimate how the pass through of fuel carbon taxes to consumer prices differs across income levels and between rural and urban areas. We find evidence of notable geographic heterogeneity in the incidence of fuel carbon taxes. While a one cent increase in carbon taxes translates into a price increase of 0.76 cent in the highest income areas, the corresponding price increase in the lowest income areas is 0.91 cents. Similarly, a one euro cent increase in the tax leads to a price increase of 0.77 cents in the most urban areas, whereas pass-through is not statistically discernible from one in the most rural areas.

The estimates in this paper provide some of the first results on how consumer prices are affected by fuel carbon taxes, and in particular on how heterogeneous the effects are across the income distribution and the rural–urban continuum. Many voters object to fuel carbon taxes on the basis of these taxes burdening in particular lower income groups and people living in small towns and rural areas. Our results lend support to these concerns. Whether incidence heterogeneity also persists over longer time periods would be an interesting topic for a future study.

That consumers and the supply chain split the price of carbon may have implications for the effectiveness of fuel carbon taxes as a climate policy tool, as the price signal faced by individual drivers may be weaker than what has been intended by policymakers. On the other hand, the result that pass-through is higher in rural areas is consistent with the hypothesis that fuel demand is more inelastic in rural areas, where households have fewer public transportation options and are therefore more dependent on their cars. The finding is also in line with results by Lawley and Thivierge (2018), who found that households in Vancouver and other cities responded to the British Columbia carbon tax, whereas households in small towns and rural areas did not respond. The differential pass-throughs in urban and rural areas we find are not explained by local competition measures, which also points to demand-side factors as drivers of the differential effects. Finally, the finding that distributors and retailers increase their purchases in the months leading up to the diesel carbon tax reform provides further evidence of anticipatory behavior in the fuel market, and points to the need to account for inter-temporal shifts in fuel purchases when estimating fuel demand elasticities with tax changes as a source of identification.

Our results on marginal welfare losses across the income distribution and the rural–urban continuum suggest that diesel carbon taxes in Finland are regressive across the areal income and rural–urban continuums and demonstrate that ignoring heterogeneity in carbon tax pass-through may lead to underestimating regressivity and the associated distributional concern. The differential pass-throughs also point to the need to take the rural–urban dimension into account when designing compensation schemes to offset adverse distributional effects of carbon taxes.

Acknowledgments

We thank two websites displaying volunteer-reported fuel prices, tankkaus.com and polttoaine.net, for providing the data for this study. We are grateful for funding from the Strategic Research Council at the Academy of Finland, grant nos. 335559 and 335560. Tuomas Kosonen is grateful for funding from the Academy of Finland, grant no. 299373.

[28] One interesting avenue for future research would be to use the diesel price variation stemming from the tax reform and bunching analysis to estimate structural demand and supply elasticities. We thank an anonymous referee for pointing this out.

Appendix A

See Tables 8–10 and Figs. 14–18.

Table 8
Excise tax rates on liquid fuels in 2012 from Finlex 1443/2011.

Traffic fuel taxes: 2012					
Product	Pr. No.	Energy content tax	CO2 tax	Strategic stockpile fee	Total
Motor gasoline c/l	10	50.36	14	0.68	65.04
Small engine gasoline c/l	11	30.36	14	0.68	45.04
Bioethanol c/l	20	33.05	9.19	0.68	42.92
Bioethanol R c/l	21	33.05	4.59	0.68	38.32
Bioethanol T c/l	22	33.05	0.00	0.68	33.73
MTBE c/l	23	40.91	11.37	0.68	52.96
MTBE R c/l	24	40.91	10.12	0.68	51.71
MTBE T c/l	25	40.91	8.87	0.68	50.46
TAME c/l	26	44.06	12.25	0.68	56.99
TAME R c/l	27	44.06	11.14	0.68	55.88
TAME T c/l	28	44.06	10.04	0.68	54.78
ETBE c/l	29	42.49	11.81	0.68	54.98
ETBE R c/l	30	42.49	9.62	0.68	52.79
ETBE T c/l	31	42.49	7.44	0.68	50.61
TAEE c/l	32	45.64	12.68	0.68	59
TAEE R c/l	33	45.64	10.85	0.68	57.17
TAEE T c/l	34	45.64	9.01	0.68	55.33
Biogasoline c/l	38	50.36	14	0.68	65.04
Biogasoline R c/l	39	50.36	7.00	0.68	58.04
Biogasoline T c/l	40	50.36	0.00	0.68	51.04
Diesel c/l	50	30.7	15.9	0.35	46.95
Diesel para c/l	51	24	15.01	0.35	39.36
Biodiesel oil c/l	52	28.14	14.57	0.35	43.06
Biodiesel oil R c/l	53	28.14	7.29	0.35	35.78
Biodiesel oil T c/l	54	28.14	0.00	0.35	28.49
Biodiesel oil P c/l	55	24	15.01	0.35	39.36
Biodiesel oil P R c/l	56	24	7.51	0.35	31.86
Biodiesel oil P T c/l	57	24	0.00	0.35	24.35

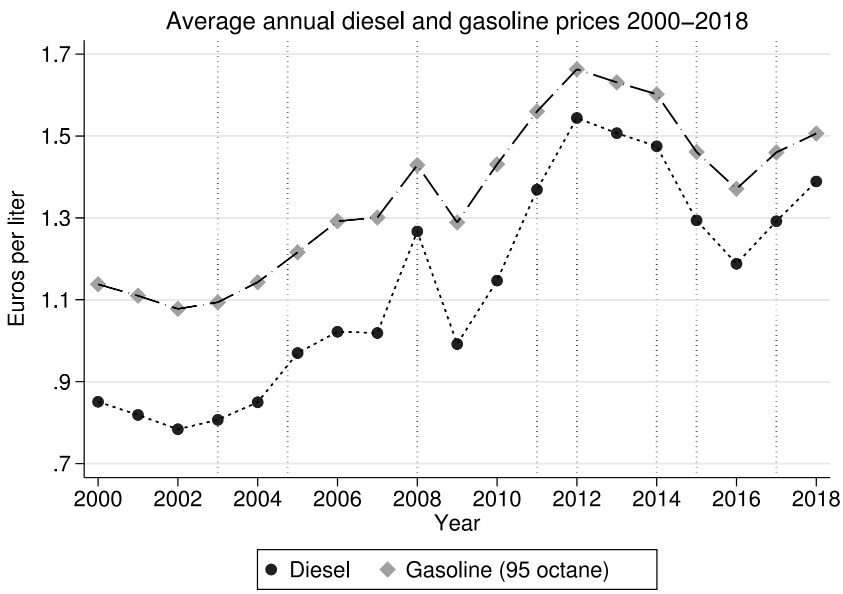


Fig. 14. Average annual prices of diesel and 95 octane gasoline (95E5 until 2010 and 95E10 from 2011 onwards) between 2000 and 2018. Vertical lines indicate tax changes.

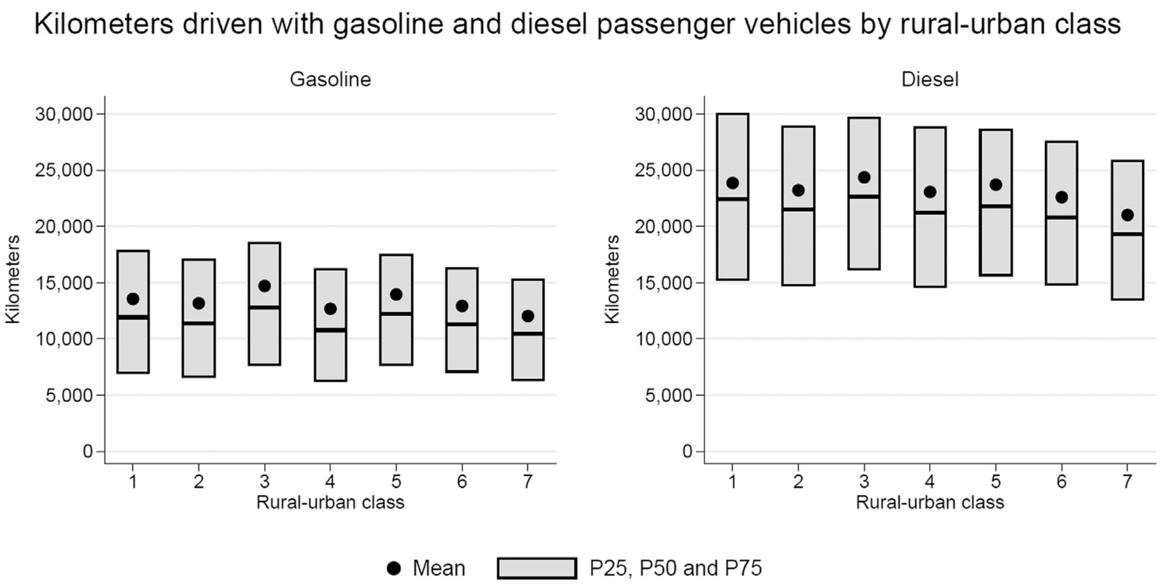


Fig. 15. Kilometers traveled by passenger vehicles, by income group and rural–urban class.

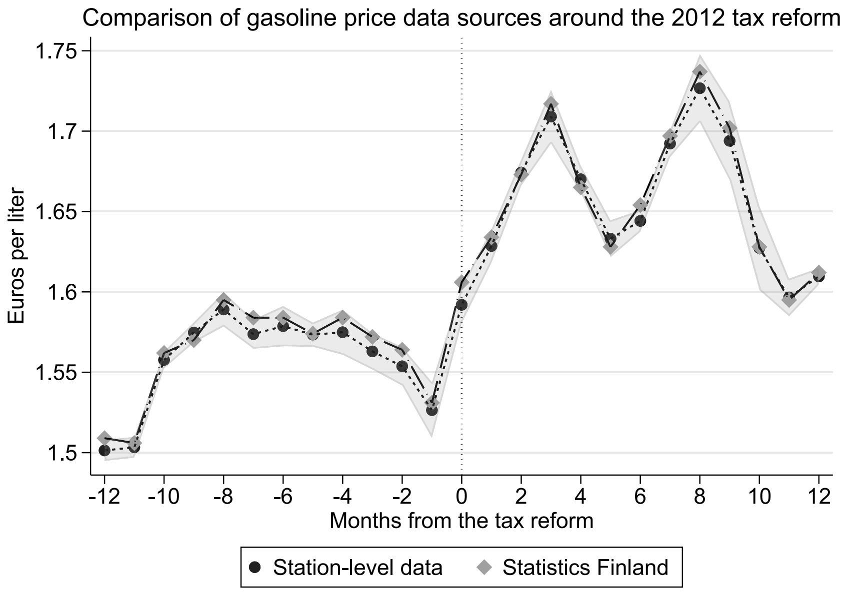


Fig. 16. Comparison of average monthly consumer prices of 95E10 gasoline (euros per liter): Consumer-reported microdata vs. data from Statistics Finland.

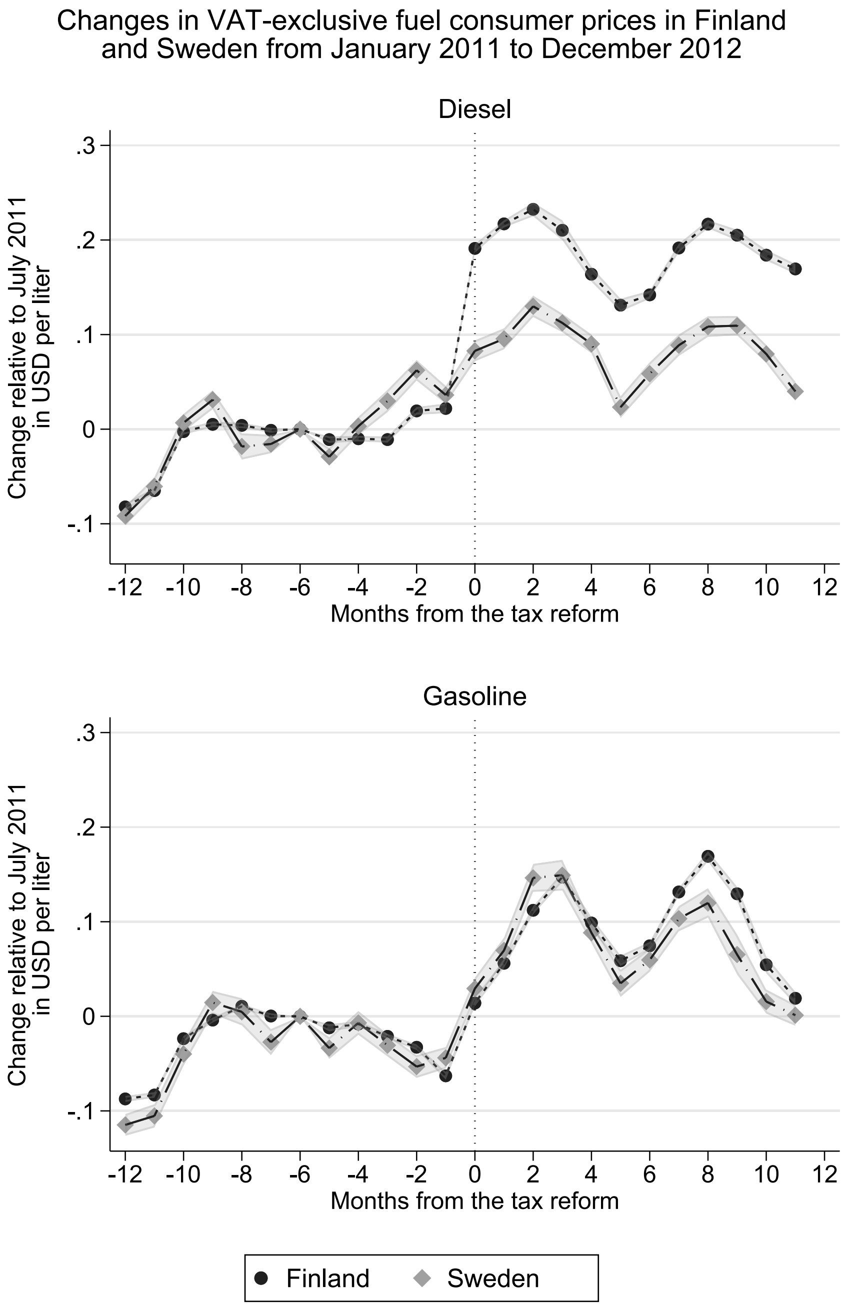


Fig. 17. Monthly average diesel prices (top panel) and gasoline prices (bottom panel) in Finland and Sweden in separate time series. The dotted vertical line indicates the date of the tax reform in Finland.

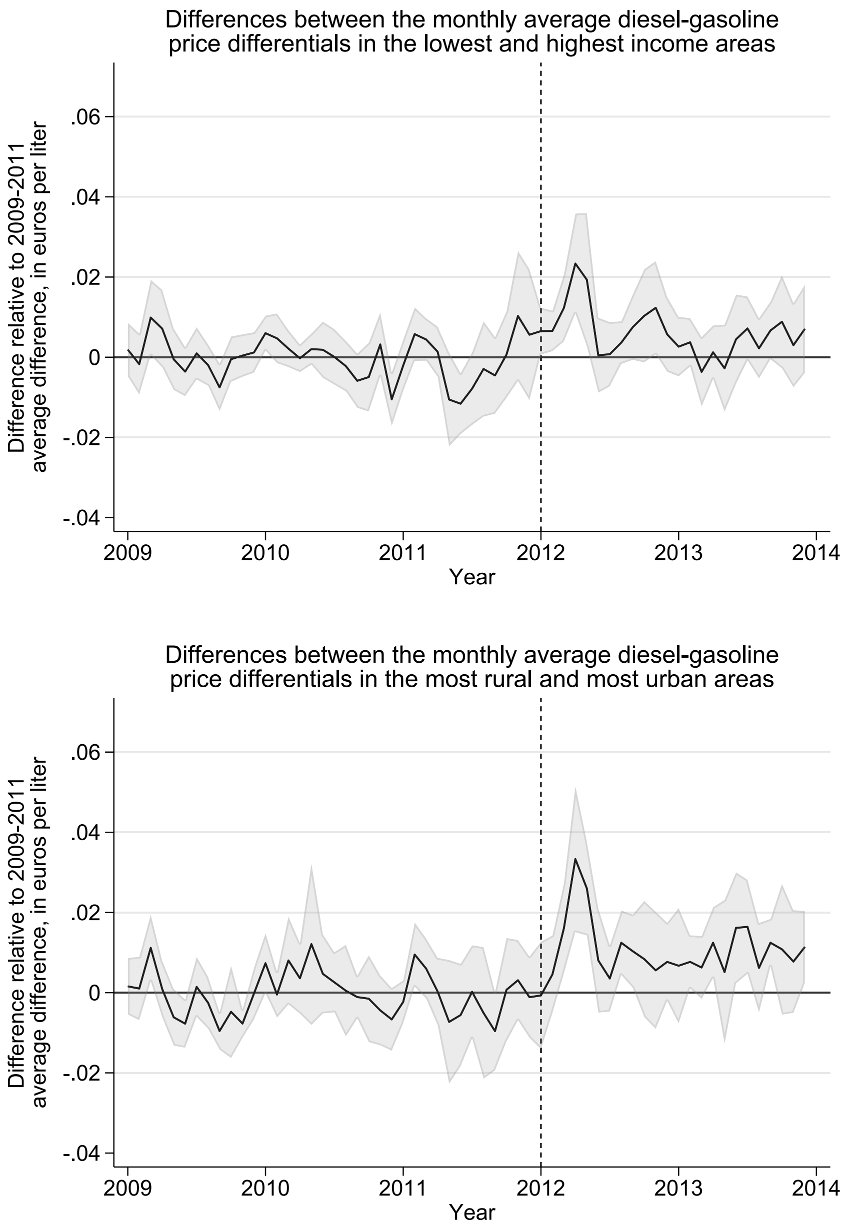


Fig. 18. Differences between the monthly average diesel–gasoline price differentials in the lowest and highest income areas, and in the most rural and urban areas. The prices are tax-inclusive retail prices. The shaded area shows the 95% confidence interval. The monthly differences have been normalized by subtracting the 2009–2011 average difference. The dotted vertical line indicates the date of the tax reform.

Table 9
Main gas station brands' shares of all gas stations, by income group and rural–urban class.

Panel A. Brand shares by income group (%)							
Station brand	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ABC	21	25	17	21	20	26	18
Neste	23	17	21	23	21	18	25
ST1	12	15	16	17	15	21	22
Seo	13	12	12	6	9	5	4
Shell	5	8	8	10	17	9	9
Teboil	23	18	23	18	17	18	20
Panel B. Brand shares by rural–urban class (%)							
Station brand	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ABC	23	26	20	18	26	22	18
Neste	14	16	21	15	23	24	27
ST1	14	15	21	22	21	18	15
Seo	16	14	16	9	8	4	1
Shell	7	6	6	12	5	11	13
Teboil	19	17	14	21	13	18	24

Note: Shares have been calculated based on the number of gas stations each station brand has in each group in our price data.

Table 10
Descriptive statistics on the number of nearby gas stations.

Variable		Mean	Median	Min	Max	SD
Number of stations within 1 km	For individual stations	0.5	0	0	5	0.8
	For stations within a postcode area (3-digit)	0.3	0	0	4.3	0.5
	For stations within a municipality	0.4	0	0	3.7	0.5
Number of stations within 5 km	For individual stations	3.9	2	0	31	4.6
	For stations within a postcode area (3-digit)	2.5	1	0	24.5	3.5
	For stations within a municipality	1.6	1	0	19.8	2.2

Appendix B

See Tables 11 and 12.

Table 11
Estimated effect of diesel carbon tax increase on diesel fuel prices, by areal income level.

	Whole period		Six months excluded	
	(1) Fuel price	(2) Fuel price	(3) Fuel price	(4) Fuel price
Panel A. Coefficient estimates				
D×A	*8.22****	*8.29****	*7.71****	*7.89****
	(0.45)	*(0.37)*	*(0.49)*	*(0.40)*
D×A×G 2nd septile	−0.26	−0.22	−0.39	−0.43
	(0.53)	(0.44)	(0.51)	(0.43)
D×A×G 3rd septile	−0.62	−0.55	−1.00	−0.90
	(0.51)	(0.44)	(0.58)	(0.50)
D×A×G 4th septile	−0.92	−0.64	−0.94	−0.80
	(0.61)	(0.53)	(0.68)	(0.56)
D×A×G 5th septile	−0.73	−0.92*	−0.72	−1.00*
	(0.54)	(0.44)	(0.57)	(0.48)
D×A×G 6th septile	−1.17*	−1.20*	−1.34*	−1.48**
	(0.55)	(0.51)	(0.61)	(0.56)
D×A×G 7th septile	−1.27**	−1.37**	−1.38**	−1.58***
	(0.48)	(0.42)	(0.53)	(0.46)
D	−19.93***	−22.39***	−21.11***	−22.31***
	(0.44)	(0.36)	(0.40)	(0.32)
A	10.77***	8.38***	11.18***	11.56***
	(0.31)	(0.31)	(0.49)	(0.43)
Constant	156.36***	138.25***	156.71***	126.95***
	(0.84)	(1.15)	(0.70)	(1.38)
Controls	No	Yes	No	Yes
Panel B. Pass-through by areal income level				
Average	79.5%	79.9%	72.6%	73.3%
1st income septile	89.9%	90.7%	84.4%	86.3%
2nd income septile	87.2%	88.3%	80.1%	81.6%
3rd income septile	83.1%	84.6%	73.4%	76.5%
4th income septile	79.9%	83.7%	74.1%	77.6%
5th income septile	82.0%	80.6%	76.5%	75.3%
6th income septile	77.1%	77.5%	69.7%	70.1%
7th income septile	76.0%	75.7%	69.3%	69.0%
F-test all D×A×G = 0	3.18**	4.16***	2.02	2.91**
	[0.005]	[0.001]	[0.063]	[0.009]
F-test all full pass-through	44.79***	39.21***	54.58***	44.64***
	[<0.001]	[<0.001]	[<0.001]	[<0.001]
N	219,034	219,034	163,693	163,693
R^2	0.81	0.88	0.82	0.89

The dependent variable is fuel price in euro cents per liter. The controls include the daily Brent crude oil price, the EU ETS CO2 price, the EUR/USD exchange rate, dummies for winter diesel, unmanned stations and station chains. Pass-through in septile i is the sum of the coefficients on D×A and D×A×G_i divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 9.14. Standard errors (in parentheses) are clustered at the municipality level and the number of clusters is 257. The p-values of the joint significance tests of all the D×A×G coefficients are in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Table 12
Estimated effect of diesel excise tax increase on diesel fuel prices, by rural–urban class.

	Whole period		Six months excluded	
	(1)	(2)	(3)	(4)
Panel A. Coefficient estimates	Fuel price	Fuel price	Fuel price	Fuel price
D×A	*8.34****	*8.34****	*7.88****	*7.98****
	(0.54)	*(0.55)*	*(0.60)*	*(0.59)*
D×A×G 2nd class	−0.38	−0.25	−0.33	−0.25
	(0.61)	(0.61)	(0.69)	(0.66)
D×A×G 3rd class	−0.61	−0.80	−0.40	−0.80
	(0.66)	(0.65)	(0.79)	(0.74)
D×A×G 4th class	−0.38	−0.53	−0.39	−0.53
	(0.62)	(0.61)	(0.69)	(0.67)
D×A×G 5th class	−1.26	−1.18	−1.33	−1.27
	(0.79)	(0.81)	(0.83)	(0.85)
D×A×G 6th class	−1.18*	−1.06	−1.39*	−1.34*
	(0.58)	(0.59)	(0.63)	(0.64)
D×A×G 7th class	−1.35*	−1.34*	−1.63*	−1.71**
	(0.58)	(0.61)	(0.65)	(0.65)
D	−19.84***	−22.13***	−20.73***	−21.85***
	(0.47)	(0.50)	(0.50)	(0.52)
A	11.05***	8.63***	11.67***	12.04***
	(0.39)	(0.51)	(0.48)	(0.56)
Constant	157.47***	138.46***	157.55***	127.13***
	(0.42)	(1.18)	(0.42)	(0.014)
Controls	No	Yes	No	Yes
Panel B. Pass-through by rural–urban classification				
Average	79.5%	79.9%	72.6%	73.3%
1st class	91.2%	91.3%	86.2%	87.3%
2nd class	87.1%	88.5%	82.7%	84.6%
3rd class	84.6%	82.5%	81.9%	78.5%
4th class	87.1%	85.5%	81.9%	81.5%
5th class	77.5%	78.4%	71.7%	73.4%
6th class	78.3%	79.8%	71.1%	72.7%
7th class	76.5%	76.6%	68.4%	68.6%
F-test all D×A×G = 0	3.13**	2.63*	3.69**	3.60**
	[0.006]	[0.017]	[0.002]	[0.002]
F-test all full pass-through	38.50***	32.77***	61.79***	52.33***
	[<0.001]	[<0.001]	[<0.001]	[<0.001]
N	218,993	218,993	163,656	163,656
R^2	0.81	0.87	0.82	0.89

The dependent variable is fuel price in euro cents per liter. The controls include the daily Brent crude oil price, the EU ETS CO2 price, the EUR/USD exchange rate, dummies for winter diesel, self-service stations and station chains. Pass-through in septile i is the sum of the coefficients on D×A and D×A×G_i divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 9.14. Standard errors (in parentheses) are clustered at the municipality level and the number of clusters is 257. The p-values of the joint significance tests of all the D×A×G coefficients are in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Appendix C. Competition analysis

Differences in the degree of competition across local markets is one potential explanation for the heterogeneity in pass-through. We next address the association of competition with pass-through differences. We measure the competition that a gas station faces by the number of gas stations within a one, two or five-kilometer driving distance, obtained using Google Maps.[29] Fig. 19 shows the average number of nearby gas stations by areal income group and by rural–urban class. There is little difference between the groups in terms of gas stations within one-kilometer or two-kilometer driving distances, whereas the average number of other gas stations within a five-kilometer driving distance increases across the income distribution and the rural–urban continuum. Furthermore, many gas stations have no other stations within a one-kilometer driving distance: the median number of other stations within a one-kilometer driving distance is zero, within five kilometers two (see Table 10 in Appendix A). Consequently, we focus on the number of gas stations within five kilometers as a measure of competition. We also construct two measures of overall local competition: the average number of other stations within five kilometers for stations in a three-digit postcode area, and the average number of other stations within five kilometers for stations in a municipality.

[29] A similar approach to measuring competitiveness is used e.g. by Li and Stock (2019) and Stolper (2016) in the fuel market and by Hindriks and Serse (2019) in the spirits retail market.

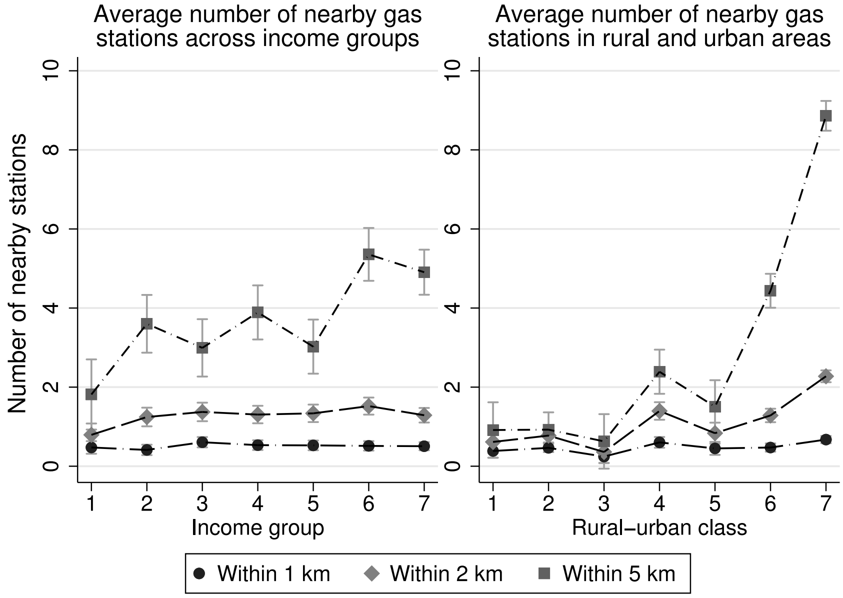


Fig. 19. Average number of other gas stations within a one- to five-kilometer driving distance by areal income group and rural–urban class.

Table 13
Estimated effect of diesel carbon tax increase on diesel fuel prices by the number of other gas stations nearby.

Competition measure	Number of gas stations within 5 km driving distance		
	Per gas station	Postcode average	Municipality average
Effect by degree of competition	(1)	(2)	(3)
D×A	*7.55****	*7.69****	*8.11****
	(0.23)	*(0.38)*	*(0.44)*
D×A×C, 2nd tercile	−0.07	0.06	−0.28
	(0.33)	(0.43)	(0.49)
D×A×C, 3rd tercile	−0.48	−0.58	−0.95*
	(0.31)	(0.41)	(0.47)
N	218,993	218,993	218,993
R^2	0.83	0.83	0.83

The dependent variable is fuel price in euro cents per liter. All estimations compare full calendar years 2011 and 2012. The controls include gas station brand, rural–urban class, population density, and indicators for automated stations and stations along highways. Standard errors (in parentheses) are clustered at the municipality level and the number of clusters is 257. *, ** and *** denote significance at the 5%, 1% and 0.1% level.

To allow for more flexibility in the estimation and avoid problems stemming from skewedness[30], we divide the sample into terciles based on each competition measure and use indicators for these terciles to describe the degree of competition. In this analysis, we use data for the entire period 2011–2012. We estimate a modified difference-in-differences model similar to Eq. (2), where the vector of indicators $\boldsymbol{G}_s$ for the income level or rural–urban class of the gas station's postcode area is now replaced with a vector of indicators $\boldsymbol{C}_s$ for the degree of competition. The first tercile is the baseline and omitted from the regressions. As before, D_f is an indicator variable for diesel and A_t an indicator variable for the post-reform period. Their interaction measures the causal effect of the tax reform on diesel price in the baseline tercile (stations with the lowest number of nearby gas stations), and the interactions with the competition indicators C_s show how the effect in the two terciles with a higher number of nearby gas stations differs from pass-through in the baseline group. The estimations also include several station characteristics that may be correlated with competition: gas station brand, rural–urban class, population density, as well as indicators for automated stations and stations along highways. Even so, the (D×A×C) coefficients cannot be interpreted as causal effects of competition on pass-through—they only show how estimated pass-through differs between station terciles with different degrees of competition. Differences in pass-through may be at least in part due to other, unobserved factors that are correlated with the competition measures. It is also important to note that because our price data have been reported by volunteer spotters, we have fewer price observations for stations in remote or rural areas with smaller customer bases.

Table 13, Column (1) shows results from a regression that measures competition by the total number of other gas stations within a five-kilometer driving distance. Columns (2) and (3) show results from regressions that measure competition by the average number

30 All three competition measures have right-skewed distributions (see Table 10 in Appendix A).

of other gas stations within a five-kilometer driving distance for gas stations within a postcode area, or within a municipality. The (D×A×C) interaction coefficients in column (3) suggest that pass-through is lower in the tercile of stations that face the most competition, as measured by the municipality-level average number of other gas stations within five kilometers. Otherwise the estimates in Table 13 suggest no statistically significant differences across stations facing different degrees of competition. If anything, these estimates are consistent with pass-through heterogeneity across areal income levels and rural and urban areas being at least in part due to factors other than competition.

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