FUEL TAX INCIDENCE AND THE ROLE OF HETEROGENEOUS PASS-THROUGH: EVIDENCE FROM FINLAND

Jyväskylä University School
of Business and Economics

Master's thesis

2018

Author: Kimmo Palanne
Discipline: Economics
Supervisor: Ari Hyytinen

JYVÄSKYLÄN YLIOPISTO

ABSTRACT

Author Kimmo Palanne	
Title Fuel Tax Incidence and the Role of Heterogeneous Pass-Through: Evidence from Finland	
Discipline Economics	Type of work Master’s thesis
Time (date) 15.7.2018	Number of pages 76+5

Abstract

Despite being potentially highly effective in curbing carbon dioxide emissions arising from motoring, taxes on transportation fuels often face public discontent for their perceived regressivity. While this concern originates from the presumption that fuel expenditure constitutes a larger share of total consumption among poorer households, most studies suggest that fuel taxes are nearly proportional in this sense in developed countries. However, the studies assume that the fuel price increases caused by tax raises exhibit no regional variation. According to the theory of tax incidence and the limited number of empirical studies delving into the matter, differences in the price elasticities of income and supply and the degree of competition might translate into heterogeneity in regional pass-through rates. Asymmetric price changes are thus plausible and may play a significant role in determining the distributional consequences of fuel taxation.

This thesis studies the degree of heterogeneity in pass-through of the Finnish diesel tax raise implemented on January 1, 2012. The substantial raise of 10.55 euro cents per liter corresponded to a 29 percent increase in the excise tax on diesel. Using station-level fuel price data enables analyzing the asymmetricity in price responses at the postal code level. The results suggest that pass-through rates fell with regional income, wealth, proxied by house prices, population density and the degree of urbanization. Based on various difference-in-differences specifications, pass-through rates were approximately 15 percentage points lower in the richest, wealthiest, the most densely populated and the most urban areas compared to the other extremes. However, the regional price disparities were mitigated during the following two to three years. Nevertheless, considering the size of the tax raise, these regional differences likely had actual distributional implications and tilted fuel taxation to a more regressive direction.

Keywords
diesel tax, difference-in-differences, fuel taxation, pass-through, tax incidence

Location
Jyväskylä University Library

TIIVISTELMÄ

Tekijä
Kimmo Palanne

Työn nimi
Fuel Tax Incidence and the Role of Heterogeneous Pass-Through: Evidence from Finland

Oppiaine
Taloustiede

Työn laji
Pro gradu -tutkielma

Aika (pvm.)
15.7.2018

Sivumäärä
76+5

Tiivistelmä

Huolimatta siitä, että liikennepolttoaineverotus on mahdollisesti erittäin tehokas tapa vähentää autoilusta johtuvia hiilidioksidipäästöjä, verotusta usein vastustetaan, koska sitä pidetään regressiivisenä. Huoli regressiivisyydestä perustuu siihen, että polttoainekulujen oletetaan muodostavan suuremman osan köyhempien kotitalouksien kokonaiskulutuksesta. Tutkimusten mukaan polttoaineverotus on tällaisen polttoaineiden kulutusosuuksien vertailun perusteella kuitenkin lähes suhteellista kehittyneissä maissa. Tutkimuksissa toisaalta oletetaan, ettei veromuutosten seurauksena tapahtuvissa hinnanmuutoksissa esiinny alueellista vaihtelua. Verotuksen kohtaantoteorian ja aihetta käsittelevien empiiristen tutkimusten perusteella erot kysynnän ja tarjonnan hintajoustoissa sekä markkinoiden kilpailullisuudessa voivat ilmetä eroina veron läpimenossa hintoihin (pass-through). Epäsymmetriset hintamuutokset ovat siis mahdollisia, ja niillä voi olla merkittäviä tulonjaollisia vaikutuksia.

Tässä tutkielmassa tarkastellaan Suomessa 1.1.2012 tehdyn dieselveron korotuksen läpimenon alueellista vaihtelua. Korotuksen suuruus oli huomattavat 10.55 senttiä litralta ja vastasi dieselveron 29 prosentin nousua. Tutkielmassa käytetty huoltoasemakohtainen hinta-aineisto mahdollistaa hintavaikutusten analysoinnin postinumeroaluetasolla. Käyttäen erilaisia difference-in-differences-mallispesifikaatioita läpimeno oli tulosten perusteella noin 15 prosenttiyksikköä alhaisempaa rikkaimmilla, asuntojen hintojen perusteella varakkaimmilla, tiheimmin asutuilla sekä kaupunkimaisimmilla alueilla verrattuna toisiin alueellisiin ääripäihin. Kasvaneet alueelliset hintaerot toisaalta tasoittuivat veromuutosta seuranneiden kahden tai kolmen vuoden aikana. Ottaen huomioon veromuutoksen suuruuden näillä alueellisilla hintaeroilla kuitenkin todennäköisesti oli todellisia tulonjaollisia vaikutuksia, ja ne muuttivat polttoaineverotusta regressiivisempään suuntaan.

Asiasanat
dieselvero, difference-in-differences, polttoaineverotus, veron hintavaikutus, verotuksen kohtaanto

Säilytyspaikka
Jyväskylän yliopiston kirjasto

FIGURES

TABLES

CONTENTS

ABSTRACT

FIGURES AND TABLES

1 INTRODUCTION

Among the variety of laws and regulations implemented at least in part to reduce the negative impact of human activity on the environment, taxing transportation fuel is perhaps one of the most salient in everyday life. Altogether, fuel taxes compose on average approximately 60 percent of the retail prices of gasoline and the diesel in the EU15 (European Environmental Agency 2017). Despite being potentially effective in reducing both environmental and other harm caused by motoring, fuel taxes face public discontent for their perceived regressivity. This concern usually stems from the presumption that the poor spend a larger portion of their income on fuel and transportation, which are often considered necessities. Hence, the additional monetary burden arising from increased fuel taxation would be borne more heavily by low-income households. Sterner (2007) argues that fuel taxes are a vital instrument in combatting climate change and should not be abolished in the face of political pressure due to their effectiveness in curtailing oil-related carbon emissions, over half of which in the OECD are attributable to motor fuel use.

Determining whether fuel taxes are regressive, however, requires addressing the question in a more rigorous manner. Besides differences in consumption, the allocation of tax burdens – i.e. tax incidence – among households depends on various other factors, such as the chosen time horizon, behavioral responses to price changes and their heterogeneity over the income distribution, changes in the car fleet, and how the additional tax revenue is recycled. Early empirical evidence might have lent support to the regressivity hypothesis, but more recent studies utilizing richer datasets and employing more sophisticated methods suggest that fuel taxation has different distributional implications in different countries and regressivity is a problem to a smaller extent than generally thought. That said, most studies analyze data from the United States and European evidence, for instance, is relatively scarce. Both the levels of fuel taxes and transportation preferences in European countries vastly differ from those in the United States, as noted by Bureau (2011).

Considering the substantial regional variation in income, wealth and transportation use, the distributional effects of fuel and other carbon taxes often have a regional dimension as well. What all the standard approaches to studying fuel tax incidence have in common is that they assume all consumers face an equally large tax-induced price change. That is, the pass-through of fuel taxes imposed on fuel producers and suppliers to market prices is assumed to be identical across all regional markets. However, utilizing Spanish station-level fuel price data, Stolper (2016b) finds significant heterogeneity in the pass-through of diesel taxes to retail diesel prices across stations. Furthermore, the results suggest there is a positive relationship between pass-through and local wealth, as measured by house prices. These potential differences in local price changes challenge the validity of the conclusions drawn on the distributional impacts and the progressivity of fuel taxes in the existing literature.

Acknowledging the significance of asymmetric price responses to fuel taxes, this thesis aims to contribute to the tax incidence literature by estimating the degree of heterogeneity in diesel tax pass-through in Finland and evaluating its distributional consequences. Following Stolper (2016b), the emphasis is on determining the degree of heterogeneity with respect to regional characteristics such as income, wealth, which is proxied by local house prices, and the degree of urbanization. Naturally, differences in diesel price reactions between wealthier and poorer regions could give rise to direct distributional consequences. Comparing urban and rural areas is appropriate in the Finnish context as well because of the close interconnection between the two aspects. The main identification strategy is based on a difference-in-differences approach comparing station-level diesel prices to gasoline prices at the turn of the year 2012 when a considerable diesel tax raise of 10.55 euro cents per liter was implemented. The tax raise corresponded to a 29 percent increase in the excise tax on diesel.

This thesis is structured as follows. Chapter 2 reviews the key aspects of tax incidence theory, concentrating on the factors determining the pass-through of per unit excise taxes. Ad valorem taxes, such as value added taxes, are not analyzed as fuel taxes are generally levied on a per unit basis. Theoretical motivation for heterogeneous pass-through is also discussed. Moreover, the focus in the chapter is on the incidence of welfare between individuals of different income and wealth levels but also consumers and producers. Chapter 3 then presents empirical evidence on both fuel tax pass-through and the progressivity of fuel taxation, focusing on the effect of the choice of methodology. The next two chapters constitute the empirical study of the thesis. Chapter 4 first gives an overview of fuel taxation in Finland to set the institutional context, then describes the data used in the analysis, and lastly lays out the empirical strategy and methods employed. Chapter 5 provides the empirical results, addresses their robustness and validity and considers their distributional implications. Finally, chapter 6 concludes the thesis.

2 THEORETICAL FRAMEWORK

The theory of tax incidence forms the basis for analyzing the distributional effects of taxes. It describes how the allocation of welfare is altered as a result of a tax change and encompasses a wide range of different incidence analyses (Fullerton & Metcalf 2002). In this chapter, the focus is on the incidence of welfare between individuals of different income and wealth levels and consumers and producers. The scope of this thesis is further restricted to analyzing the incidence of per unit excise taxes. The effects of these taxes are often analyzed in a partial equilibrium setting, concentrating on the imminent price reaction induced by the taxes and ignoring longer-run behavioral responses. This chapters begins with an overview of the central concepts used in tax incidence analyses, after which the predictions of various partial equilibrium models of tax pass-through are discussed.

2.1 Measuring incidence

Taxes are not only an important source of revenue for the public sector but can also be effective tools in correcting market failures, such as externalities. Fuel taxes are a prime example of taxes being utilized for both purposes. Alongside technological change and the market-based cap and trade system, taxes on transportation fuels and other pollutants may prove to be vital for curbing the rapidly increasing global carbon emissions. In theory, when the social marginal cost of fuel production is higher than the private marginal cost, imposing a tax on producers raises latter and forces the producers to internalize the negative externalities associated with their production. Higher taxes could also incentivize producers to invest in more efficient technologies, further reducing emissions.

Regardless of the purpose of levying them, taxes alter market prices, affect the behavior of consumers and producers, and thus have welfare implications.[1] Tax incidence analysis builds on the insight that the allocation of these welfare effects between market participants is not determined by who physically pays

---

[1] To be more specific, lump-sum taxes do not have these effects as they only affect budget constraints but not relative prices. However, the discussion here is limited to per unit taxes unless otherwise specified.

the tax; that is, the economic incidence of the tax may differ from the its statutory incidence (Fullerton & Metcalf 2002). For example, imposing a fuel tax on producers likely raises the price of fuel, making consumers buy less of it, to which firms react by cutting production. Consequently, both consumers and producers may bear a part of the tax burden and face a reduction in welfare. The distortion in economic activity and the subsequent reduction in efficiency is called the excess burden of taxation and it contributes to the total burden of the tax. The reason it is an excess burden is that is a real cost falling on consumers and producers which is not realized as revenue for the public sector.

There are multiple ways of theoretically measuring these direct welfare effects, but the most commonly used measures of incidence on consumers include changes in consumer surplus, compensating variation and equivalent variation. They can be used as measures of tax burdens but are also applicable to analyzing welfare effects arising from other price changes. The earliest rigorous exposition of the use of consumer surplus is usually attributed to Marshall (1890), while the other two measures were formalized by Hicks (1939). Consumer surplus represents the amount of money a consumer is willing to pay to purchase good i at the market price p_i^* relative to not participating in the market (Nicholson & Snyder 2012). It is defined as the area between the Marshallian demand curve, $D(p_1, \dots p_n, I)$, and the market price:

$$CS = \int_{p_i^*}^{\infty} D(p_1, \dots p_n, I) \tag{1}$$

where I is income. When the price of good i changes from p_i^* to p_i^{**}, the change in consumer surplus is the integral in (1) from p_i^* to p_i^{**} (Nicholson & Snyder 2012). However, introducing the concept of producer surplus enables one to conduct a similar analysis on firms as well. Producer surplus is the extra profits earned by firms if they choose to produce goods at the market price relative to producing nothing. Under perfect competition, it equals the area bounded by the market price and the marginal cost curve. Thus, a change in producer surplus represents the change in profits when the price changes from p_i^* to p_i^{**}. (Nicholson & Snyder 2012).

An alternative approach is to employ measures related to the Hicksian, or compensated, demand curve, $H(p_1, \dots, p_n, U)$, in which utility is held constant instead of income. Hence, the curve illustrates only substitution effects. Compensating variation is the amount of money a consumer requires to maintain the same level of utility after the price of good i changes from p_i^* to p_i^{**} (Nicholson & Snyder 2012). Using the expenditure function, which indicates the lowest expenditure level required to attain a given utility level at the prevailing prices, it can be expressed as:

$$CV = E(p_1, \dots, p_i^{**}, \dots p_n, U_0) - E(p_1, \dots, p_i^{*}, \dots p_n, U_0) \tag{2}$$

where U_0 is the initial utility level. Equivalently, compensating variation is the area bounded by the prices p_i^* and p_i^{**} and the Hicksian demand curve associated with the initial price and utility level (Nicholson & Snyder 2012). On the other hand, equivalent variation is a measure based on the Hicksian demand curve related to the new price and the corresponding utility. It is the amount of money a consumer would be willing to pay, given the new utility level, U_1, to have the price change back to its initial level:

$$EV = E(p_1, \dots, p_i^{**}, \dots p_n, U_1) - E(p_1, \dots, p_i^{*}, \dots p_n, U_1) \tag{3}$$

Similar to compensating variation, equivalent variation also has a geometric interpretation as it is the area bounded by the old and new market prices and the Hicksian demand curve related to p_i^{**} and U_1. (Nicholson & Snyder 2012).

The compensating and equivalent variation are often regarded as more appropriate measures of incidence than the change in consumer surplus: they all essentially attempt to quantify the same concept, but the first two are more rigorous, and the latter is applicable only under strict restrictions due to the presence of income effects in the Marshallian demand curve (see, e.g., Hausman 1981). However, consumer surplus is more widely used in empirical work as data on prices and income are readily available. Using compensating or equivalent variation, on the other hand, requires an estimate of either the expenditure function or the indirect utility function. Nevertheless, the size of the change in consumer surplus is always between those of the two Hicksian measures, and the smaller the income elasticity of demand or the price change, the closer the values are to one another (Willig 1976). Alternatively, instead of directly using any of these measures, some studies only focus on the effect a tax change has on consumer and producer prices; that is, they estimate the pass-through rate of the tax. The theoretical aspects related to tax pass-through are discussed in detail in the next section.

Usually the price changes and the subsequent welfare changes are analyzed in a partial equilibrium setting, constraining the analysis to the prices of goods directly affected by the policy. In reality, however, the taxes imposed only on some goods may also affect the prices of other goods, change the relative prices of labor and capital, and have other long-term behavioral effects, such as promoting changes in production technology. These general equilibrium effects may have considerable distributional implications that are ignored in the simple partial equilibrium framework. It is also essential to consider how the additional tax revenue is spent to determine the overall distributional effects arising from the implementation of the policy. The welfare measures presented above can be applied in both partial and general equilibrium settings, but the challenge in building general equilibrium models lies in including all the relevant effects the tax might have and modeling them accurately. No specific general equilibrium models are presented in this thesis due to the sheer number of choices available, but empirical studies employing a variety of models are discussed in Section 3.2.

After choosing the appropriate tax burden measure and obtaining estimates of the average burdens in specific groups, such as income deciles or other quantiles, these burdens can be compared to determine the degree of progressivity of the tax or the tax change. A tax is progressive if the ratio of tax burden to income increases with income, regressive if it decreases with income, and proportional if it stays constant. However, because the absolute sizes of the burdens are context-dependent, the direct quantile comparison is often supplemented with or substituted for a standardized measure of progressivity. The Suits index named after Suits (1977) is a widely used measure that allows for a comparison between different taxes. It bears close resemblance to the Gini coefficient: while the latter is based on the Lorenz curve which plots the accumulated percent of income against the accumulated percent of households, the concentration curve used in calculating the Suits index plots the accumulated percent of tax burden against the accumulated percent of income. This curve is graphically presented in Figure 1 and is situated below the 45-degree line in the income-tax burden diagram.

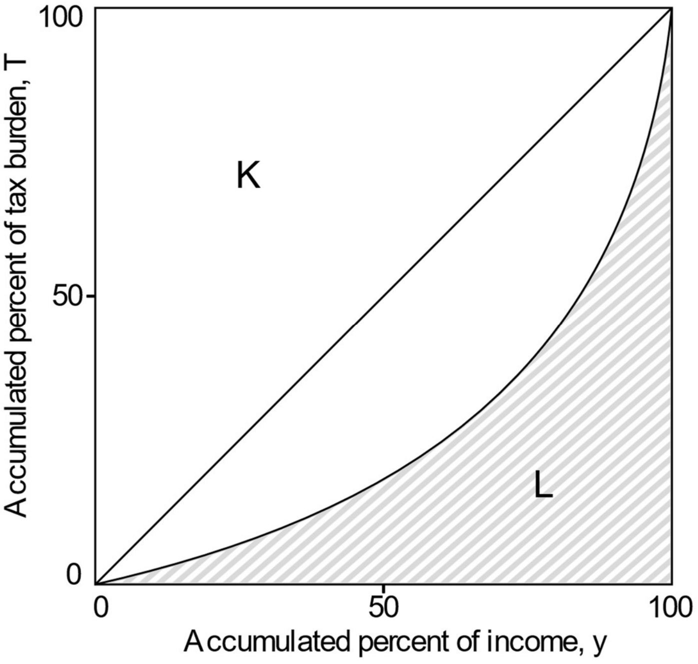

Figure 1 Graphical representation of the Suits index

The Suits index is calculated based on the areas L and K in Figure 1. Denoting the concentration curve by $T(y)$, where accumulated income, y, and the accumulated tax burden, T, range from 0 to 100 percent, the Suits index, S, is defined as

$$S = 1 - \frac{L}{K} = 1 - \frac{\int_0^{100} T(y)dy}{5000} \approx 1 - \frac{\sum_{i=1}^{n} \frac{1}{2}[T(y_i) + T(y_{i-1})](y_i - y_{i-1})}{5000} \qquad (4)$$

where the number 5000 in the denominator is the area of K in Figure 1. The last formulation is an approximation of the index from discrete data values suggested by Suits (1977), n being the number of households or quantiles in the data. The values of the index range from -1 to 1 so that negative values indicate a regressive tax, positive values a progressive tax and a value of zero a proportional tax. As the concentration curve runs below the diagonal, the tax in Figure 1 is progressive; on the other hand, a similar concentration curve situated above the diagonal would indicate regressivity. It should be noted that because the index is an average across the whole distribution, a variety of different underlying distributions can produce equal values of the index. A tax may appear proportional if, for example, it is regressive in one part of the distributional but equally progressive in another. While the tax burden in the Suits index originally represented the actual amount of money paid in taxes by households, the index can be applied to other measures of the tax burden as well.

2.2 Tax pass-through

Pass-through is a central concept in determining the incidence of a tax between consumers and producers. As producers usually bear the statutory burden of excise taxes, the term pass-through refers to what extent the tax is "passed through" to consumers. It describes the immediate consumer price reaction to an imposition of a tax or an increase in it, and thus the allocation of real economic costs between the two parties: intuitively, high pass-through indicates that consumers bear most of the burden whereas low pass-through results in the costs falling mostly on producers. This section reviews the fundamental theory of pass-through and its predictions, focusing on comparing the factors that determine the pass-through rate and their significance in different underlying market structures. The approach taken here is mostly based on the comprehensive theoretical review by Weyl and Fabinger (2013) which generalizes and formally presents the results derived from several different models since the 19th century. The following analysis is limited to the pass-through of per unit taxes; ad valorem taxes, such as a value-added tax, are not discussed but it should be noted that according to theory, their price effects differ from those of per unit taxes under imperfect competition (Delipalla & Keen 1992).

2.2.1 Pass-through under perfect competition

The pass-through rate $\rho \equiv dp/dt$ is defined as the rate at which the price of a good changes in response to a marginal change in the tax. Here, $p_c \equiv p$ denotes the consumer price so that the producer price is $p_s \equiv p - t$. Assuming that consumers and producers are price takers maximizing their welfare, that there exists a unique equilibrium in which demand equals supply, $D(p) = S(p - t) = Q$, and that both demand and supply are smooth, the marginal economic incidence of imposing an infinitesimal tax can be expressed in terms of rates of change in consumer and producer surplus. Applying the envelope theorem, the marginal economic burden on consumers is

$$\frac{dCS}{dt} = \frac{d}{dt}\int_{p}^{\infty} D(x)dx = -\rho Q \tag{5}$$

where CS is consumer surplus, and the burden on producers is

$$\frac{dPS}{dt} = \frac{d}{dt}\int_{0}^{p-t} S(x)dx = -(1-\rho)Q \tag{6}$$

where PS is producer surplus (Weyl & Fabinger 2013). The incidence of the marginal tax can be defined as the burden on consumers relative to that on producers, or $I = \rho/(1-\rho)$. Thus, the allocation of the total tax burden, defined as Qdt by Weyl and Fabinger (2013), is determined solely by the pass-through rate.

If initially $t = 0$ and in equilibrium $D(p) = S(p-t)$, based on the implicit function theorem, the pass-through rate is

$$\rho \equiv \frac{dp}{dt} = \frac{-\frac{\partial S}{\partial t}}{\frac{\partial S}{\partial p} - \frac{\partial D}{\partial p}} \tag{7}$$

Further, assuming that supply reacts identically to tax increases and price decreases so that $-\partial S/\partial t = \partial S/\partial p$, the expression in (7) simplifies to

$$\rho = \frac{\frac{\partial S}{\partial p}\frac{p}{Q}}{\frac{\partial S}{\partial p}\frac{p}{Q} - \frac{\partial D}{\partial p}\frac{p}{Q}} = \frac{\epsilon_S}{\epsilon_S + \epsilon_D} = \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}} \tag{8}$$

where $\epsilon_D \equiv -\partial D/\partial p \times p/Q$ is the price elasticity of demand and $\epsilon_S \equiv \partial S/\partial p \times p/Q$ is the price elasticity of supply. Thus, under perfect competition, the pass-through rate of a marginal tax depends only on the price elasticities of demand and supply. Moreover, it holds that $0 \leq \rho \leq 1$ and both a lower price elasticity of demand and a higher price elasticity of supply result in a higher pass-through rate. Full pass-through, $\rho = 1$, requires $\epsilon_D = 0$ or $\epsilon_S \to \infty$ whereas the burden falls entirely on producers, $\rho = 0$, only if $\epsilon_D \to \infty$ or $\epsilon_S \to 0$ and $\epsilon_D \neq 0$.

The notation above implies that the statutory burden is on producers. However, a basic result arising from tax incidence analysis is that the allocation of economic burdens is independent of the statutory incidence of the tax. This result on the neutrality of incidence can be extended to various models of imperfect competition (Weyl & Fabinger 2013). The independence can be demonstrated in this framework by denoting $D(p_s + t) = S(p_s)$ so that the tax is levied on consumers. Following the steps above and assuming that $\partial D/\partial t = \partial D/\partial p = \partial D/\partial p_s$

and $\partial S/\partial p = \partial S/\partial p_s$ results in the same expression for pass-through as in equation (7):

$$\frac{dp}{dt} = \frac{dp_s}{dt} + 1 = \frac{-\frac{\partial D}{\partial t}}{\frac{\partial D}{\partial p_s} - \frac{\partial S}{\partial p_s}} + 1 = \frac{-\frac{\partial D}{\partial p}}{\frac{\partial D}{\partial p} - \frac{\partial S}{\partial p}} + 1 = \frac{\frac{\partial S}{\partial p}}{\frac{\partial S}{\partial p} - \frac{\partial D}{\partial p}} = \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}} \tag{9}$$

Hence, the economic incidence on consumers and producers is described by equations (5) and (6). More recent empirical evidence, however, has challenged the validity of this well-established theoretical result: neutrality may not hold under real-life circumstances if consumers underreact to taxes with low salience. Based on a field experiment in a grocery store in the United States, Chetty, Looney and Kroft (2009) show that including a sales tax of 7.375 percent to prices posted on the shelf, as opposed to adding it at the register, as is customary in the country, reduced demand by 8 percent. Furthermore, their analysis suggests that increases in excise taxes on alcohol, which are included in posted prices, induce an evidently higher reduction in alcohol consumption than identical increases in sales taxes, which are added at the register. Similarly, both Li, Linn and Muehlegger (2014) and Tiezzi and Verde (2016) find that gasoline consumption reacts more strongly to changes in gasoline taxes than to gasoline price changes of the same size, a result potentially explained by the salience and persistence of excise tax raises.

Following the model presented by Chetty et al. (2009), low salience translates to a disparity between $\partial D/\partial t$ and $\partial D/\partial p$ and a violation of the neutrality result: if consumers underreact to low-salience taxes so that $\gamma \equiv (\partial D/\partial t)/(\partial D/\partial p) < 1$, the expression in (9) changes to

$$\frac{dp}{dt} = \frac{dp_s}{dt} + 1 = \frac{\frac{\partial S}{\partial p} - (1-\gamma)\frac{\partial D}{\partial p}}{\frac{\partial S}{\partial p} - \frac{\partial D}{\partial p}} = \frac{\epsilon_S + (1-\gamma)\epsilon_D}{\epsilon_S + \epsilon_D} \tag{10}$$

Now pass-through and the incidence on consumers rise with the degree of consumer's underreaction to taxes. Moreover, even if supply is inelastic or demand perfectly elastic, $\epsilon_D \to \infty$ or $\epsilon_S \to 0$, pass-through is bounded from below by $1 - \gamma$ and consumers nevertheless bear a part of the burden due to their underreaction. However, excise taxes on transportation fuels are usually levied on producers and included in the posted prices at filling stations, increasing their salience and more likely resulting in values of γ close to 1.

As the expression in (8) only describes the price reaction to marginal tax increases, Weyl and Fabinger (2013) extend the result to finite tax changes from t_0 to $t_1 > t_0$ by defining pass-through as a quantity-weighted average over the values of t:

$$\bar{\rho}_{t_0}^{t_1} = \frac{\int_{t_0}^{t_1} \rho(t) Q(t) dt}{\int_{t_0}^{t_1} Q(t) dt} \tag{11}$$

where $Q(t)$ is the equilibrium quantity as a function of the tax. Using the definition above, the authors further define the incidence between consumers and producers arising from a tax change from t_0 to t_1 as $\bar{I}_{t_0}^{t_1} = \bar{\rho}_{t_0}^{t_1}/(1-\bar{\rho}_{t_0}^{t_1})$. In other words, pass-through and incidence of a finite tax change depend on how the pass-through rate varies with the level of the tax. Both definitions are applicable to the pass-through and incidence of finite tax changes under imperfect competition by replacing $\rho(t)$ in (11) with the appropriate formula in each model.

2.2.2 Pass-through under monopoly

Providing expressions for pass-through and incidence under monopoly follows the same logic as in the model of perfect competition. An obvious difference is that the monopolist faces a downward-sloping inverse demand curve, $p(q)$, which is assumed to be smooth as is the monopolist's cost function, $c(q)$. The monopolist's revenues are $p(q)q$ and the monopolist is assumed to maximize its profits by setting marginal revenue, $mr(q) = p(q) + p'(q)q$, equal to marginal cost, $mc(q) = c'(q)$. Imposing a per unit tax on the firm leaves the incidence on consumers defined in (5) unchanged but reduces the monopolist's welfare by lowering its profits, $[p(q) - t]q - c(q)$. The incidence on the monopolist is thus $dPS/dt = -q$ and the incidence on consumers relative to the monopolist is $I = \rho$. In contrast to the result under perfect competition, the total marginal burden $|dCS + dPS| = (1+\rho)qdt$ now exceeds qdt; while the monopolist bears the full burden of the tax, consumers bear an excess burden determined by the pass-through rate (Weyl & Fabinger 2013).

The monopolist maximizes its profits by setting $mr(q) = mc(q) + t$. As this equality must hold in equilibrium, it holds that

$$\frac{dmr}{dt} = \frac{d}{dt}(mc + t) \Rightarrow \frac{dmr}{dq}\frac{dq}{dt} = \frac{dmc}{dq}\frac{dq}{dt} + 1 \Rightarrow \frac{dq}{dt} = \frac{1}{\frac{dmr}{dq} - \frac{dmc}{dq}} \tag{12}$$

Utilizing the expression above, pass-through is

$$\rho = \frac{dp}{dt} = \frac{dp}{dq}\frac{dq}{dt} = \frac{\frac{dp}{dq}}{\frac{dmr}{dq} - \frac{dmc}{dq}} \equiv \frac{p'}{mr' - mc'} \tag{13}$$

Using this notation, the price elasticities of demand and supply are defined as $\epsilon_D \equiv -dq/dp \times p/q = -p/p'q$ and $\epsilon_S \equiv dq/dmc \times mc/q = mc/mc'q$. Additionally, Weyl and Fabinger (2013) denote $mr = p - ms$, where $ms \equiv -p'q$ is the marginal consumer surplus, and modify the expression in (13) as follows:

$$\begin{aligned}\rho &= \frac{p'}{p' - ms' - mc'} = \frac{1}{1 - \frac{ms'}{p'} - \frac{mc'}{p'}} \\ &= \frac{1}{1 - \frac{p}{p'q}\frac{ms'q}{ms}\frac{ms}{p} - \frac{p}{p'q}\frac{mc'q}{mc}\frac{mc}{p}} = \frac{1}{1 + \frac{\epsilon_D}{\epsilon_{ms}}\frac{ms}{p} + \frac{\epsilon_D}{\epsilon_S}\frac{mc}{p}}\end{aligned} \tag{14}$$

where $\epsilon_{ms} \equiv dq/dms \times ms/q = ms/ms'q$ is the elasticity of the inverse marginal consumer surplus function. Noting that $ms/p = 1/\epsilon_D$ and using Lerner's rule (Lerner 1934)

$$\frac{p - mc}{p} = \frac{1}{\epsilon_D} \Rightarrow \frac{mc}{p} = \frac{\epsilon_D - 1}{\epsilon_D} \tag{15}$$

which essentially states the monopolist's profit maximization rule in an alternative form, the expression for pass-through in (14) further simplifies to:

$$\rho = \frac{1}{1 + \frac{\epsilon_D - 1}{\epsilon_S} + \frac{1}{\epsilon_{ms}}} \tag{16}$$

Apart from the fact that the pass-through formula for monopoly has the term $\epsilon_D - 1$ instead of ϵ_D, the only difference to the corresponding formula under perfect competition is the term $1/\epsilon_{ms}$. As demonstrated by Weyl and Fabinger (2013), this term measures the curvature of the logarithm of demand. They also show that if demand is convex, then $1/\epsilon_{ms} < 1$, and if it is concave, then $1/\epsilon_{ms} > 1$. Based on this observation, it is evident that pass-through rises with the degree of positive curvature of demand. Furthermore, the dependence on convexity means that pass-through can exceed unity if demand is curved enough. Under constant marginal cost, for instance, the inverse marginal cost function is perfectly elastic and $\rho > 1$ only if $\epsilon_{ms} < 0$.

2.2.3 Pass-through under imperfect competition

The derivations of the formulae for pass-through under perfect competition and monopoly date back to the 19th century when the models were originally formulated. By contrast, the expression for pass-through under other forms of imperfect competition depends on the details of the various models developed over the decades since. Notable developments in the analysis of pass-through under oligopoly include Seade (1985), Stern (1987), Delipalla and Keen (1992) and Anderson, de Palma and Kreider (2001), each introducing a slightly different framework. Weyl and Fabinger (2013) omit the details of the underlying firm interactions and instead devise a model that generalizes the behavior of symmetric firms under imperfect competition and complete information. The number of firms i is n and each produces a single product. The firms are symmetric in the sense that they have identical cost functions, $c(q_i)$, and the quantities produced in equilibrium are the same across all the firms so that $q_j = q$ for all $j \in \{1,2, \dots n\}$; however, the products may not be identical as the model permits product differentiation. Price is $p(q)$ and $p'(q)$ measures the price response of any of the goods to an infinitesimal symmetric increase in the quantities of all the n products.

The model devised by Weyl and Fabinger (2013) is based on a modified version of the monopolist's first order condition with the addition of a conduct parameter θ:

$$p(q) + \theta p'(q)q = c'(q) + t \tag{17}$$

An alternative expression for (17) is $[(p - mc - t)/p]\epsilon_D = \theta$, where $\epsilon_D \equiv -p/p'q$ is the price elasticity of market demand. It states that the elasticity-adjusted Lerner index is set equal to θ. Thus, the conduct parameter measures the degree of competitive conduct in the market. Given the appropriate number of firms, θ equals zero under perfect competition and one under monopoly. However, Weyl and Fabinger (2013) note that this formulation encompasses all the most frequently used models of symmetric imperfect competition. They demonstrate that under Bertrand price competition with homogeneous products it holds that $\theta = 0$ while under homogeneous products Cournot competition the parameter is $\theta = 1/n$, where n is the number of firms. Additionally, in a model of differentiated products with Nash-in-prices proposed by Anderson et al. (2001), the expression is $\theta = 1 - A$, where $A \equiv -\sum_{j \neq i}(\partial q_j/\partial p_i)/(\partial q_i/\partial p_i)$ is the aggregate diversion ratio. It represents the fraction of sales lost by one firm to the other firms after changing its price. If the goods produced by the firms are substitutes, $A > 0$ and thus $\theta < 1$, whereas if the goods are complements, $A < 0$ and $\theta > 1$ (Weyl & Fabinger 2013).

In line with the models in the previous sections, the marginal burden on consumers is once again $dCS/dt = -\rho Q$, where Q is the total quantity supplied. Weyl and Fabinger (2013) remark that calculating the burden on producers requires taking an alternative approach as the usual envelope theorem is not directly applicable in this model specification. The surpluses, or the profits $[p(q) - t]q - c(q)$ of each firm are identical across firms. Noting that $dq/dt = (dp/dt)/(dp/dq) = \rho/p'$ and $dc/dt = dc/dq \times dq/dt = mc \times \rho/p'$, the marginal burden on firm i is

$$\begin{aligned}\frac{dPS_i}{dt} &= \left(\frac{dp}{dt} - 1\right)q + (p - t)\frac{dq}{dt} - \frac{dc}{dt} \\ &= \left(\rho - 1 - \rho\frac{p - mc - t}{p}\frac{p}{-p'q}\right)q = -[1 - \rho(1 - \theta)]q\end{aligned} \tag{18}$$

Thus, the aggregate marginal burden on producers is $-[1 - \rho(1 - \theta)]Q$ (Weyl & Fabinger 2013). This formula is a linear combination of the corresponding formulae for monopoly and perfect competition with weights θ and $1 - \theta$ for monopoly and perfect competition respectively. The value of the conduct parameter determines whether the tax imposes an excess burden: the total burden, $|dCS + dPS| = (1 + \rho\theta)Qdt$, always exceeds Qdt if firms have market power and $\theta > 0$. At the same time, $I = \rho/[1 - \rho(1 - \theta)]$ and $\partial I/\partial\theta < 0$ with positive values of I, and hence for a given ρ the incidence on firms relative to consumers increases as the degree of competitive conduct decreases.

Following the steps taken the case of monopoly and substituting the monopolist's first order condition with the generalized rule in (17), Weyl and Fabinger (2013) show that pass-through under symmetric imperfect competition is

$$\begin{aligned}\rho &= \frac{1}{1 - \frac{d\theta}{dq}\frac{ms}{p'} - \theta\frac{p}{p'q}\frac{ms'q}{ms}\frac{ms}{p} - \frac{p}{p'q}\frac{mc'q}{mc}\frac{mc}{p}} \\ &= \frac{1}{1 + \frac{d\theta}{dq}q + \theta\frac{\epsilon_D}{\epsilon_{ms}}\frac{ms}{p} + \frac{\epsilon_D}{\epsilon_S}\frac{mc}{p}}\end{aligned} \tag{19}$$

Again, using $ms/p = 1/\epsilon_D$ along with $mc/p = (\epsilon_D - \theta)/\epsilon_D$ and defining the elasticity of the conduct parameter as $\epsilon_\theta \equiv \theta/[(d\theta/dq)q]$ results in

$$\rho = \frac{1}{1 + \frac{\theta}{\epsilon_\theta} + \frac{\epsilon_D - \theta}{\epsilon_S} + \frac{\theta}{\epsilon_{ms}}} \tag{20}$$

Ignoring the term θ/ϵ_θ, this formula is also a linear combination of the pass-through formulas under monopoly and perfect competition with weights θ and $1 - \theta$. As briefly discussed above, in many of the most frequently used models, θ is independent of q, and thus θ/ϵ_θ equals zero. Consequently, the extent to which the convexity of demand affects the pass-through rate in these models is directly determined by the value of the conduct parameter. The precondition for pass-through exceeding unity under constant marginal cost, however, remains unchanged and is independent of θ. On the other hand, if $d\theta/dq < 0$, and thus $\epsilon_\theta < 0$, which Weyl and Fabinger (2013) argue is a more relevant case than the opposite, pass-through is higher because the tax raise and the subsequent decrease in the quantity sold lead to less competitive conduct.

As these formulae for incidence and pass-through are only applicable to markets with symmetric imperfect competition, Weyl and Fabinger (2013) develop a general model of pass-through which, in addition to generalizing all the results presented in the previous sections, allows for asymmetric imperfectly competitive firms. Instead of the quantities produced and costs being identical across firms, each firm now producers quantity q_i and profits are $p_i(\boldsymbol{q})q_i - c_i(q_i)$, where $\boldsymbol{q}$ is a vector of quantities produced by all the firms. Another crucial aspect of the general model is that each firm has its own conduct parameter:

$$\theta_i \equiv \frac{(\boldsymbol{m} - \boldsymbol{t}) \cdot \frac{d\boldsymbol{q}}{d\sigma_i}}{-\boldsymbol{q} \cdot \frac{d\boldsymbol{p}}{d\sigma_i}} \tag{21}$$

where $\boldsymbol{m} \equiv \boldsymbol{p} - \boldsymbol{mc}$ is a vector of per-firm absolute markups, $\boldsymbol{p}$, $\boldsymbol{mc}$ and $\boldsymbol{t}$ are vectors of firm prices, marginal costs and taxes, and σ_i is a firm-specific strategic variable determining each firm's actions in response to the choices of the other firms. The strategic variable may simply be price or quantity, as in most models, but σ_i may also represent a more nuanced "supply function" in which the relationship between quantities and prices is determined by decisions regarding, for instance, firm size and structure or the firm's values (see Klemperer and Meyer (1989) for a more detailed exposition). Further, $\boldsymbol{q}$ and $\boldsymbol{p}$ are assumed to be smooth functions of $\boldsymbol{\sigma}$ always satisfying $\boldsymbol{q}(\boldsymbol{\sigma}) = \boldsymbol{q}\big(\boldsymbol{p}(\boldsymbol{\sigma})\big)$.

The intuition behind the definition of the conduct parameter in the general model is that the numerator includes all the real effects arising from firm i changing its actions, whereas the denominator includes the corresponding pecuniary effects (Weyl & Fabinger 2013). The real effects consist of firm i selling a higher quantity at its absolute markup, or $m_i \times dq_i/d\sigma_i$, and affecting the quantities sold by other firms, which are the real externalities. Similarly, the pecuniary effects include both the effect on firm i itself and the externalities on other firms. However, the latter are expressed in monetary terms and only influence the allocation of profits across firms (Weyl & Fabinger 2013). Ignoring taxes, the conduct parameter under symmetric imperfect competition, $[(p - mc)/p]\epsilon_D = \theta$, is a special case of the general definition in (21): when $m_i = m, p_i = p, q_i = q$ and $\sigma_i = \sigma$ for all firms i, it holds that $\theta_i = \theta$ and

$$\theta = \frac{nm\frac{dq}{d\sigma}}{-nq\frac{dp}{d\sigma}} = -\frac{m}{q}\frac{\frac{dq}{dp}\frac{dp}{d\sigma}}{\frac{dp}{d\sigma}} = -\frac{m}{q}\frac{dq}{dp} = -\frac{m}{p}\frac{dq}{dp}\frac{p}{q} = \frac{p - mc}{p}\epsilon_D \tag{22}$$

The general model not only allows for heterogeneous firms but also firms to bear the tax $\boldsymbol{\tau}$ asymmetrically. Weyl and Fabinger (2013) define $\boldsymbol{\tau}$ so that a quantity-weighted unit of the tax has size one, or $(\boldsymbol{\tau} \cdot \boldsymbol{q})/Q = (\boldsymbol{\tau} \cdot \boldsymbol{q})/(\boldsymbol{1} \cdot \boldsymbol{q}) = 1$, and denote the size of the tax by $t_{\boldsymbol{\tau}}$, making the total tax $t_{\boldsymbol{\tau}}\boldsymbol{\tau}$. As prices may react asymmetrically across firms and taxes are heterogeneous, for each tax considered there is a pass-through vector $\boldsymbol{\rho}_{\boldsymbol{\tau}} \equiv d\boldsymbol{p}/dt_{\boldsymbol{\tau}}$. Furthermore, the authors define $\boldsymbol{\tau}_i$ in such a way that the vectors $-\boldsymbol{\rho}_{\boldsymbol{\tau}_i}$ and $-(d\boldsymbol{q}/dt_{\boldsymbol{\tau}_i})$ point in the same direction as $d\boldsymbol{p}/d\sigma_i$ and $d\boldsymbol{q}/d\sigma_i$ respectively and assume $\boldsymbol{\tau}_i$ to be linearly independent. Hence, any $\boldsymbol{\tau}$ is a linear combination of $\boldsymbol{\tau}_i$, or $\boldsymbol{\tau} = \sum_i \lambda_i^{\tau}\boldsymbol{\tau}_i$. The coefficients of the linear combination, λ_i^{τ}, reflect the extent to which the strategies, prices and quantities of each firm are affected by the tax, and thus, in a sense, how the total burden is distributed among the firms. (Weyl & Fabinger 2013).

In line with the previous models, the marginal incidence on consumers in the general model is $dCS/dt_{\tau} = -\boldsymbol{\rho_{\tau}} \cdot \boldsymbol{q} = -\rho_{\tau} Q$, where $\rho_{\tau} \equiv \boldsymbol{\rho_{\tau}}/Q$ is the quantity-weighted average pass-through across firms (Weyl & Fabinger 2013). That is, the expressions in the different models are virtually identical but an alternative definition of pass-through is necessary here due to the presence of heterogeneities. Following the approach taken in the model of symmetric imperfect competition and using the definitions above, the authors show that the marginal burden on producers is

$$\frac{dPS}{dt_{\tau}} = \sum_{i} \lambda_i^{\tau} \frac{dPS}{dt_{\tau_i}} = -\left[1 - (1-\theta)\rho_{\tau} + Cov\left(\lambda_i^{\tau} \rho_{\tau_i}, \theta_i\right)\right] Q \tag{23}$$

where $\theta \equiv (1/n) \sum_i \theta_i$. This expression is also nearly identical to the corresponding formula under symmetric imperfect competition, the covariance term being the factor distinguishing the former from the latter. The term encapsulates the significance of allowing for heterogeneity on incidence and its implications are twofold: if taxes fall more on firms with high market power or if the average pass-through is higher among these firms, the incidence on producers is higher (Weyl & Fabinger 2013). This is due to both scenarios leading to a more pronounced positive covariance between $\lambda_i^{\tau} \rho_{\tau_i}$ and θ_i. It should also be noted that the formula collapses to that under perfect competition if $\theta_i = 0$ for all i, that under monopoly if $\theta_i = 1$ for all i, and that under symmetric imperfect competition if $\theta_i = \theta$ for all i, even if firms are heterogeneous.

Weyl and Fabinger (2013) limit their analysis of the general model to discussing the incidence results presented above and only derive the formula for pass-through in the Appendix C of their paper as it requires introducing more complicated notation. Their expression describes the effects taxes imposed on each firm have on the prices of each of the firms in the model. However, as noted by the authors, introducing asymmetries does not alter the fundamental factors affecting pass-through: the price reactions are again determined by the conduct parameters, which are now firm-specific, and the heterogeneous counterparts of the elasticities in (20). If the market-wide pass-through is defined as the quantity-weighted average pass-through across firms, it is thus primarily the interplay between the production shares and conduct parameters at the firm level that distinguishes pass-through in the asymmetric model from that in the symmetric model.

2.2.4 Heterogeneous pass-through

In the real world, it is reasonable to assume that firms are asymmetric or that they operate on separate local and regional markets which may differ in terms of the degree of competition and consumer preferences. This variation translates to differences in the key parameters determining the pass-through rate: the elasticities of demand and supply, the convexity of demand, the number of firms and the market power exerted by each firm. If these differences are systematically related to household income and wealth or any distinct regional characteristics, pass-through may, in addition to influencing the allocation of burdens between consumers and producers, have more indirect distributional consequences among consumers as well.

Both the price elasticity and convexity of demand in a given local market are likely partly determined by factors such as the degree of urbanization, availability of public transportation, driving preferences, and a wide variety of household characteristics. Price elasticity might be lower and demand more curved, for instance, in rural areas due to long distances and a poor public transportation network. Alternatively, the elasticity may be related to household income, but the direction of the potential relationship cannot be inferred from theory. This aspect and relevant empirical evidence are discussed in more detail in Section 3.2. Nevertheless, inferring from the models presented in the previous sections, lower price elasticity of demand would, keeping all the other parameters in the pass-through formula constant[2] and assuming non-zero marginal costs, result in higher pass-through under perfect competition, monopoly and other forms of imperfect competition.

As noted in Section 2.2.2, more pronounced positive curvature of demand also leads to higher pass-through and enables firms to overshift taxes to prices in the models of imperfect competition. A central premise common to all these models is, however, that firms only produce a single product. Departing from this traditional strand of the pass-through literature, Hamilton (2009) analyzes pass-through by devising a model of oligopoly with multiproduct firms. Allowing for multiple products distinguishes the model from the single-product models in two important ways: firms can now both set prices and decide on the level of product variety. Assuming that consumers derive utility from greater product variety and that the marginal utility of an additional product is non-decreasing in per product consumption, Hamilton (2009) shows that the relationship between the convexity of demand and pass-through in the multiproduct model is opposite to that in the single-product models: excise taxes are always overshifted to prices unless demand is sufficiently convex.

The contrary result is due to the interplay between product variety and price competition: a firm can respond to a competitor widening its product variety by lowering prices on all its own products. Provided that the model assumptions hold, higher excise taxes narrow the range of product variety in equilibrium, mitigating price competition and promoting overshifting. However, given a sufficiently high level of demand convexity, higher excise taxes may actually lead to increases in both price-cost margins and profits, encouraging firms to widen their range of product variety, intensifying price competition and lowering the pass-through rate (Hamilton 2009). Even though seemingly complicating the analysis of the relevant factors contributing to heterogeneity in pass-through, this result is not necessarily highly relevant as far as excise taxes on transportation fuels are concerned: motorists usually fill their tanks with only one variety of fuel and do

---

[2] Achieving this requires allowing for changes in prices, quantities and the other variables determining these parameters.

not benefit from a wider selection of fuels. Hence, the single-product models are more likely to offer more valuable insights into the price effects of fuel taxes.

The relevance of the prevailing market conditions to pass-through heterogeneity is not limited to the effects of demand convexity but also has to do with firm characteristics. Again, keeping all the other parameters fixed, a higher price elasticity of supply raises the pass-through rate in all the models considered. Moreover, the degree of market power each firm has also matters under oligopoly. However, the marginal effect of increased market power, even in the model of symmetric competition, is dependent on almost all the other parameters that determine pass-through. The factors that determine the value of the conduct parameter itself also vary across the different models of firm interactions, as briefly discussed in Section 2.2.3. Even though the relationship between market power and pass-through is theoretically ambiguous, if certain market conditions tend to arise in regions with particularly high or low income, these regional differences in competitive conduct may have considerable distributional effects.

Besides being limited to single-product firms, the specific models reviewed and introduced by Weyl and Fabinger (2013) naturally rely on other assumptions that are crucial to the validity of their conclusions. First, industries outside the model are assumed to be perfectly competitive and to have no externalities. The authors note that ignoring the possibility of positive markups, $p - mc > 0$, in other industries with goods complementary or substitutable to those in the industry considered induces bias in the optimal size of markups. Second, the models of imperfect competition assume complete information on the costs, demand functions and strategies of competing firms. Including uncertainties in the model might alter the dynamics of the model and potentially broaden the set of factors determining the pass-through rate, but no such models exist in the literature. Nonetheless, the framework presented by Weyl and Fabinger (2013) is most readily applicable to analyzing the different sources of heterogeneity in fuel tax pass-through due to the richness of their analysis and the fact that the transportation fuel market is remarkably similar to the theoretical single-product market with symmetric firms.

3 EXISTING LITERATURE

Focusing on the theoretical aspects covered in the previous chapter, this chapter reviews the relevant empirical studies on the distributional effects of fuel taxes. The first section discusses the relatively small number of studies providing estimates of fuel tax pass-through in different countries. The second section expands the perspective by reviewing studies that analyze how tax burdens are allocated among individuals and provide measures the degree of progressivity of fuel taxation using different models and data from a wide variety of countries.

3.1 Empirical estimates of fuel tax pass-through

Regardless of being an established and standard approach in economics, the theory of tax incidence has not been extensively tested empirically, an issue pertaining particularly to the pass-through of taxes to consumer prices (Marion & Muehlegger 2011). However, fuel tax pass-through is usually assumed being close to 100 percent, and thus the burden of fuel taxes is usually thought of as falling almost entirely on consumers. This assumption is based on the predictions arising from the partial equilibrium models of tax pass-through and both on intuition and empirical evidence regarding the price elasticities of demand and supply. On the one hand, studies suggest that the price elasticity of fuel demand is, on average, relatively low in the short run: estimates typically range from -0.3 to -0.1 (Dahl 2012; Hughes, Knittel & Sperling 2008; Li et al. 2014). The inelasticity might be due to the high short-run costs associated with adjusting the consumption of transportation, which is often considered a necessity. Supply, on the other hand, is thought of being quite elastic as fuel suppliers can easily stock their storages in large amounts. Together, these insights imply rates of pass-through close to 100 percent at least under perfect competition.

3.1.1 Aggregate estimates

Only a small number of studies have provided empirical estimates of fuel tax pass-through. What nearly all the studies have in common is that they use monthly state-level panel data from the United States and exploit variation in state-level fuel taxes in estimating the average pass-through rate of numerous tax changes over the period of interest. The studies mainly apply fixed effects regressions and estimate a reduced form model of fuel demand, regressing fuel prices on state fuel taxes, the variable of interest, and a set of demand and supply sifters as covariates. These covariates are almost identical across the studies and include, among others, the price of crude oil, the wholesale price of the fuel considered, population density, socioeconomic variables, average heating degree days and heating oil use. Controlling on observables and state and time fixed effects, the studies attempt to estimate the causal effect of tax changes on fuel prices. Naturally, the estimates may be confounded by unobservable factors that both correlate with the tax changes and affect prices: for example, tax policies might be implemented in response to particular economic conditions.

Nevertheless, corroborating the hypothesis of nearly full pass-through, all the studies obtain pass-through estimates close to 100 percent. Using data from the forty-eight mainland states of the United States between 1989–1997, Chouinard and Perloff (2004) find that the average pass-through of the state gasoline tax was almost exactly 100 percent. Alm, Sennoga and Skidmore (2009) arrive at an identical conclusion using data on all fifty states and a longer time frame from 1984 to 1999. Marion and Muehlegger (2011) conclude that both state gasoline and diesel taxes were fully or slightly overshifted among a group of twenty-two states over the period 1983–2003. Finally, the study by Kopczuk, Marion, Muehlegger and Slemrod (2016) suggests that the pass-through of state diesel taxes was on average over 90 percent between 1986–2006. While not directly comparable to the studies examining per unit state fuel taxes, Doyle and Samphantharak (2008) analyze the effects of ad valorem gasoline sales tax repeals and the subsequent reinstatements in the neighboring states of Illinois and Indiana during 2000–2001. Applying a difference-in-differences regression using other bordering states as a control group, they find that the pass-through of the repeals was 70 percent while pass-through in the reinstatements was 80–100 percent.

The only study utilizing data from outside the United States, conducted by Stolper (2016b), employs a similar fixed effects regression and exploits variation in state-level diesel taxes in Spain between 2007–2013. What truly sets the study apart from the others is that rather than relying on state-wide average prices, Stolper (2016b) uses weekly firm-level price data from more than 2500 individual filling stations. This enables him to control for not only firm characteristics but also municipality-level market conditions and socioeconomic factors. However, whereas the studies in the United States examine up to a few hundred tax changes, the number of tax hikes in the Spanish study is limited to fourteen, the first of which did not take place until 2010. Despite the differences in data quality, the degree of variation in tax levels and the country of interest, the average pass-through estimate of 95 percent obtained by Stolper (2016b) is consistent with the estimates from the United States. Stolper (2016b) also supplements his analysis with an event study regression and provides graphical evidence that, controlling for observables, the pre and post-tax hike trends in diesel price changes between states were identical and were only disrupted by a discontinuous level change at the time of the tax raises. This observation lends support to a causal interpretation of the impact of the tax changes.

Even though the Spanish evidence is in line with the evidence from the United States, drawing conclusions on fuel tax pass-through from studies almost exclusively examining the impacts of tax changes and reforms in the latter country may lead to erroneous generalizations. Compared to European countries, fuel prices and fuel tax levels are significantly lower and private motoring is of higher importance in the United States. For example, despite both Germany and United States have similar high motorization rates, the share of trips made by automobiles is about 1.5 times higher in the United States, resulting in more than twice as many annual kilometers traveled by car per capita (Buehler 2011). If these differences play a role in determining the price elasticity of fuel demand or other factors affecting the pass-through rate, results may not be easily extrapolated to European countries.

3.1.2 Evidence on heterogeneity in pass-through

In addition to estimating the average country-wide pass-through over the whole period, nearly all the studies focus on some potential source of heterogeneity in pass-through. Chouinard and Perloff (2004) explicate how pass-through should vary with the share of gasoline supplied by each state in a perfectly competitive market. Following their approach, the residual supply of fuel in equilibrium in state i is $S^i(p) = S(p) - D^0(p)$, where $S(p)$ is the nation-wide supply and $D^0(p)$ is the demand in all other states except for i. Differentiating with respect to p, manipulating the expression and using the notation in Section 2.2.1, the price elasticity of supply in state i is $\epsilon_S^i = (1/s_i)(\epsilon_S + \epsilon_D^0) + \epsilon_D^0$, where $s_i = S^i/S$ is the share of supply in state i and ϵ_D^0 is the elasticity of demand in all states but i. Hence, ϵ_S^i decreases with s_i and pass-through is higher in states with low shares of fuel supply, all else equal. In line with this theoretical prediction, Chouinard and Perloff (2004) find that a lower share of gasoline sales, which is naturally related to the size of the state, is associated with higher pass-through: the disparity in shares translates up to a 25 percentage point difference in pass-through between states.

Alm et al. (2009), on the other hand, analyze heterogeneity with respect to the degree of urbanization. They divide states approximately into tertiles based on the proportion of residents living in urban areas and refer to the groups as low medium and high urbanicity states. The results suggest some heterogeneity in pass-through, but they are not robust to the choice of model specification and the relationship appears to be non-monotonic. Closely related to the degree of urbanization, Stolper (2016a, 2016b) explores whether pass-through in Spain is related to the degree of competition. In the first study, he compares pass-through rates between filling stations near state borders and those further away. Intuitively, stations experiencing a tax raise on one side of the border might be reluctant to fully shift taxes to prices when competitors operating on the same market on the other side of the border face no increases in marginal costs. Using the data described above, Stolper (2016a) finds that the average pass-through among the 459 stations within 5 kilometers from the state border is about 73 percent, more than 20 percentage points lower than the nation-wide pass-through. Furthermore, among the thirty-one stations with at least one cross-border rival within a 5-minute driving distance, the pass-through rate is only 57 percent.

The lower pass-through rates at state borders found by Stolper (2016a) may of course be explained by other factors: for instance, the number of distinct markets on which the 459 stations operate is only twelve, all of which are more rural than the average region in the sample. Nevertheless, Stolper (2016b) also approaches the problem by introducing three different measures of the degree of competition in the full sample of filling stations: the concentration of stations under the same refinery brand, the proportion of stations under the same ownership and the number of rival stations within a 5-minute driving distance. The results suggest a clear association with higher market power and higher pass-through in terms of all three measures. Again, the model potentially suffers from endogeneity, precluding a causal interpretation: filling station location choices might be systematically related to location-specific unobservable characteristics that also affect pass-through, such as the price elasticity of demand. The estimated degree of heterogeneity is, however, considerable. Stolper (2016b) illustrates the heterogeneity at the station-level by estimating station-specific pass-through rates and finds that they range from 70 up to 120 percent.

Testing a fundamental prediction of the theoretical models of pass-through, Marion and Muehlegger (2011) analyze whether more inelastic fuel supply results in lower pass-through. They concentrate on four types of common constraints in the supply chain of fuel consisting of refineries, bulk transporters, wholesalers, distributors and retailers. First, refinery constraints arise when the refinery capacity is almost fully utilized, for instance due to high demand during summer months, directly decreasing the elasticity of supply. Second, wholesaler storage constraints also lower the elasticity but the effect on pass-through depends on whether lower levels of inventory increase the market power of some retailers who may not be as dependent on wholesaler inventories. Third, the distillate used to produce diesel can also be distilled into heating oil, making the supply of diesel dependent on the demand of heating oil. Following similar logic as in Chouinard and Perloff (2004), the price elasticity of the residual supply of diesel increases with the share of heating oil sales. Fourth, environmental regulations that mandate retailers to provide special environmentally friendly blends of gasoline complicate the supply chain due to uncertainty related to the choice of which fuels to produce and store.

Comparing pass-through rates in time periods or states facing the constraints described above to those with no constraints, Marion and Muehlegger

(2011) find some evidence of a positive relationship between the price elasticity of supply and pass-through. When refinery capacity utilization is more than 95 percent, diesel tax pass-through is as low as 41 percent; then again, no effects are found at lower levels of utilization or on gasoline tax pass-through. However, diesel tax pass-through is higher in states with and periods of high demand for heating oil, as measured by the number of heating degree days and the prevalence of heating oil use. On the other hand, the evidence on the effect of inventories is mixed as the direction of the relationship between inventory size and pass-through is ambiguous and differs between the two fuels. Finally, pass-through is lower in states with a more heterogeneous gasoline supply, that is, a higher prevalence of special blends, but the effect is only significant at the 10 percent level. The analysis is again purely descriptive in nature because the elasticity measures are clearly not exogeneous but largely determined by both demand and supply, perhaps except for the environmental regulations on special fuel blends.

Kopczuk et al. (2016) also focus on different parts of the supply chain but test the validity of the independence between statutory and economic incidence, an even more fundamental premise in the theory of tax incidence. As noted earlier, this independence may not hold if consumers' reactions to taxes and prices are asymmetric due to low salience. Kopczuk et al. (2016) argue that the point of collection of the fuel tax in the supply chain is closely related to tax evasion opportunities: tax evasion is more difficult for prime suppliers mainly due to them being far fewer in number than distributors or retailers, and thus being more easily monitored. If tax evasion is relatively effortless, pass-through is also more likely lower. In fact, the authors find that pass-through is highest when the state diesel tax is collected at the bulk terminal, second highest when the point of collection is at the distributor-level and lowest when the tax is remitted by retailers. The changes in the level of pass-through after a change in the point of collection also appear discontinuous, supporting a causal interpretation. Furthermore, tax revenues exhibit a similar discontinuous rise in level when the point of collection is moved upstream in the supply chain. This suggest that the mechanism driving the results indeed has to do with tax evasion.

In addition to analyzing the relationship between the degree of competition and pass-through, Stolper (2016b) also considers heterogeneity with respect to regional wealth, which is proxied by house prices. According to the results, pass-through rises with regional house prices and, depending on the model specification, an increase in house prices of 1000 euros by square meter is associated with a pass-through rate up to 20 percent higher. This positive correlation has clear distributional implications to the extent that house prices are a suitable proxy for wealth. However, the sample of filling stations used by Stolper (2016b) is limited to urban areas which may very well differ from rural areas with respect to the parameters that determine the pass-through rate. As no other study offers any insight to the relationship between pass-through and income or wealth, drawing conclusions on the distributional effects of pass-through is unfeasible. On the other hand, empirical evidence on the broader distributional effects and progressivity of fuel taxes is presented in the next section.

3.2 Progressivity of fuel taxes

In spite of their potential effectiveness in reducing pollution and promoting environmental objectives, fuel taxes are often criticized and opposed because of their perceived regressivity. If low-income households devote a larger share of their income to fuel expenditure, they bear a larger monetary burden relative to their income than their high-income counterparts, thus making the tax regressive. This line of reasoning, however, ignores the dynamic effects of taxation, such as households' behavioral responses and general equilibrium effects, that affect the ultimate size of the tax burden. Furthermore, based on studies comparing the budget shares of fuel across different households, it is not evident that budget shares are higher among poorer households. This section provides a review of previous empirical studies on the distributional effects of transportation fuel taxes and focuses on the impact of the choice of methodology on the results.

3.2.1 Budget share comparisons

The distributional effects of fuel taxes have been studied most extensively by utilizing household survey data in different countries and comparing the reported budget shares of fuel across households. This is usually achieved by dividing households into quintiles or deciles based on annual income. However, income-based groupings and comparisons may not accurately capture the actual distribution of tax burdens, as noted by Poterba (1989, 1991). He was among the first to argue in favor of using a measure of lifetime income in studying the distributional effects of fuel and other excise taxes. His approach is based on the permanent income hypothesis introduced by Friedman (1957) which suggests that households' consumption depends on their expected income over a long horizon rather than just current income. Even if the permanent income hypothesis does not perfectly describe the observed consumption patterns, Poterba (1989, 1991) argues that annual total consumption nonetheless better reflects a household's ability to pay taxes in the long run.

Relying only on the income-based grouping method results in more pronounced distributional effects: progressive taxes seem more progressive and regressive taxes more regressive due to consumption being more evenly distributed than income (Poterba 1989). The lifetime income approach has been implemented in nearly all studies analyzing the distributional effects of fuel taxes by (i) dividing households into quantiles based on annual total consumption, (ii) dividing households into income quantiles but calculating the tax burden as a share of total consumption in each quantile, or (iii) constructing an estimate of lifetime income based on observed household characteristics, the first two of which are the most common strategies. Some studies employ both income and consumption-based methods of comparing the tax burden across households to assess the degree to which the results depend on the choice of income measure.

Studies employing the budget share comparison method of assessing fuel tax progressivity lend partial support to the hypothesis of regressivity. However, the distributions of fuel expenditure vary considerably across different countries and there appears to be a negative correlation between a country's GDP per capita and the degree of progressivity (Sterner, Cao, Carlsson & Robinson 2012). In many developing and newly industrialized countries in Africa, Asia and South America, car ownership is substantially more prevalent among higher income groups. Although the poor might spend relatively more on public transportation, its effect on fuel tax incidence is usually more than fully offset by the opposite effect resulting from the disparity in private motoring expenditure, thus making fuel taxes slightly or even significantly progressive (e.g, Agostini & Jiménez 2015; Blackman, Osakwe & Alpizar 2010; Datta 2010; Sterner et al. 2012). On the other hand, fuel taxes in the United States exhibit clear regressivity when examining the distribution of tax burdens across annual income deciles. Comparing the tax burdens across consumption deciles, however, considerably mitigates the degree of regressivity (Poterba 1991; Sterner et al. 2012).

Comparing the budget shares of fuel expenditure across annual income deciles around the year 2006 in a study covering six European countries, France, Germany, Serbia, Spain, Sweden and the United Kingdom, Sterner (2012) concludes that fuel taxes were slightly regressive in five of the countries. The Suits index values ranged from -0.17 to -0.06. By contrast, fuel taxes appeared progressive in the poorest country in the group, Serbia, where the Suits index took on a value of 0.19. However, dividing households into deciles based on annual consumption results in the taxes appearing to be close to proportional or even progressive. The only exception is Italy, which is only analyzed in terms of annual consumption, where the index takes on a value of -0.11. Italy also had the highest average tax burden, approximately 2–3 percent of annual consumption, among the countries studied.

Using data from the United Kingdom, Santos and Catchesides (2005) show that while the budget shares of fuel were the largest among the middle-income deciles during 1999–2000, and hence the fuel tax was neither regressive nor progressive over the whole distribution, the tax was clearly regressive among car-owning households. The difference is explained by car ownership being less prevalent among low-income households. According to a similar analysis conducted by Tuuli (2009), which covers six different years between 1985–2006, the degree of progressivity differed between car owners and the whole population in Finland as well. However, the fuel tax was actually slightly progressive among the whole population and nearly proportional among car owners.

The budget share comparisons only provide a static analysis of the distributional effects of fuel taxes, ignoring both demand responses and general equilibrium effects. One way of expanding the budget share analysis without modeling these effects is to consider a wider consumption bundle: because fuels are widely used in transportation and as intermediary products in a variety of production processes, fuel taxes may affect the market prices of other goods. Thus, differences in the consumption of the affected goods may contribute to the distributional effects of the taxes. Some studies estimate these indirect distributional effects by utilizing input-output tables that describe the flows of products and intermediary goods in the economy. This method is employed by Hasset, Mathur and Metcalf (2009) who estimate the distributional effects of a hypothetical carbon tax raise[3] in the United States and conclude that the indirect effects do not considerably alter the distribution of tax burdens. Blackman et al. (2010) arrive at a similar conclusion in their study of the distributional effects of a fuel tax raise in Costa Rica, a significantly less wealthy country.

3.2.2 Incorporating demand responses

Demand responses reduce the overall monetary burden of tax increases via a decrease in the consumption of fuel. They may also affect the distribution of the burdens if the price elasticity of demand varies over the income distribution. Relative to a constant price elasticity of demand across different income levels, an inverse relationship between the elasticity and income results in more progressivity while higher price responsiveness among the rich has the opposite effect. Despite its relevance to the distributional analysis of fuel taxes, the relationship between income and price elasticity has not been extensively studied. Kayser (2000) finds that in the United States the elasticity of gasoline demand increases with income. This could be attributed to the potentially more discretionary nature of driving or a wider selection of cars among high-income households, or the difficulty of adjusting miles traveled downward among low-income households. Then again, no statistically significant connection between vehicle miles traveled (VMT) and gasoline prices is established in the study, implying that the negative correlation between the price elasticity of gasoline consumption and income is due to differences in the fuel efficiency of cars owned by households. By contrast, the study by Bento, Goulder, Jacobsen and von Haefen (2009) suggests that the short run demand responses to fuel taxes are almost entirely explained by reductions in VMT.

The majority of the studies, however, have found a negative association between the price elasticity of demand and income. Blow and Crawford (1997) and Santos and Catchesides (2005) estimate a negative relationship between the elasticity of VMT and income in the United Kingdom. The analyses by Bureau (2011) in France and by West (2004) in the United States yield similar results, although the relation is reversed in the top income quintile in the latter. In addition, West and Williams (2004) establish a negative relationship between the price elasticity of gasoline demand and income. On the other hand, using nonparametric estimation methods, Yatchew and No (2001) find no connection between the variables in Canada while Blundell, Horowitz and Parey (2012) argue that middle-income households are the most price responsive in the United States, a result clearly inconsistent with the other studies. Wadud, Graham and Noland (2009) also suggest that the relationship is non-monotonic in the United States. However, their results are exactly the opposite, elasticity being lowest in the middle quintile.

---

[3] The tax covers not only the use of transportation fuels but also fuels for heating and electricity, so the results may not be directly comparable to the other studies discussed.

Nevertheless, the result is not entirely inconsistent with the studies finding a negative connection as the elasticity is estimated to be lower in the bottom quintiles than in the top quintiles.

Notwithstanding the similarities between most of the studies, no definite conclusion can be drawn about the association between the variables. First, elasticities were estimated using a variety of different models with a varying degree of success controlling for the inherent endogeneity of gasoline prices. Second, all the studies discussed above use cross-sectional household survey data except for Wadud et al. (2009) and Bureau (2011) who use time series and panel data respectively. Relying only on cross-sections and not being able to follow changes in time severely limits the possibility to combat endogeneity. Third, the magnitude of the differences between the elasticities across income groups varies substantially among the studies. The studies also mainly cover individual years in a handful of countries during different time periods without providing an overall picture over a longer horizon. Notably, Hughes et al. (2008) argue that the price elasticity of gasoline demand has significantly decreased in the United States between the late 1970's and the early 2000's, which raises the question of whether the differences between income groups could change in time as well. Last, the estimates discussed here are best interpreted as short-run elasticities; the relationship could be different in the long run when elasticities have been found to be higher overall (e.g., Dahl 1995; Graham & Glaister 2002, 2004; Brons, Nijkamp, Pels & Rietveld 2008). For example, high-income households may more readily replace their cars with newer and more fuel-efficient alternatives, hence implying a higher long-run elasticity.

Demand responses are usually incorporated into the distributional analysis in conjunction with substituting budget share comparisons for other measures of the tax burden, such as consumer surplus or the more comprehensive equivalent variation. The advantage of these measures is that they also account for the negative welfare effects of reduced consumption. However, only a few studies exploit these other measures in their analyses. Utilizing consumer survey data from 1996–1998 and modeling the demand of gasoline, leisure and other goods with the widely used Almost Ideal Demand System developed by Deaton and Muellbauer (1980), West and Williams (2004) simulate the distributional effects of a substantial raise of 1.02 dollars per gallon in the gasoline tax in the United States. They compare three different measures of incidence across expenditure quintiles: the static budget share measure, change in consumer surplus and the equivalent variation. While the tax increase is regressive based on all three measures, using the latter two mitigates the degree of regressivity because the authors estimate a negative relationship between the price elasticity of demand and income: allowing for heterogeneity in the price elasticity increases the Suits index from -0.165 to -0.138.[4] The last two measures, however, produce almost identical estimates of the degree of regressivity despite the substantial size of the tax raise.

---

[4] These values were calculated based on the results provided in Table 3 in West and Williams (2004) as the authors use a slightly different progressivity index.

3.2.3 General equilibrium effects

Decisions regarding vehicle purchase and VMT may often be intertwined, causing endogeneity in the models and making it difficult to distinguish between the short-run and long-run responses to fuel tax changes. This problem has been addressed in a few studies by building a two-step model of vehicle choice and use: a discrete choice model is first constructed to estimate the probability of choosing cars with specific characteristics after which the continuous choice of VMT is estimated given the vehicle choice probabilities (e.g., Berkovec 1985; Mannering & Winston 1985; West 2004). The only study to analyze the distributional effects of fuel taxes using this two-step estimation procedure is West (2004). Using data from the United States between 1996–1998, West (2004) simulates a tax raise of two cents per mile, corresponding to about a 40-cent increase in the gasoline price. She finds that the tax raise is progressive among the lower deciles but regressive in the upper deciles and regressive overall with a Suits index value of about -0.15. The gasoline tax appears less regressive, but only slightly, when the vehicle choice endogeneity is not accounted for as the Suits index is about 0.01 lower in absolute value. Then again, the raise is both monotonically and more regressive among car-owning households, the Suits index being approximately -0.20.

A few studies also focus on the supply side effects of fuel taxation. Even fewer combine both demand and supply effects, the study by Bento et al. (2009) being the only one of these that discusses the distributional consequences of taxation as well. They build an equilibrium model of markets for new, used and scrapped cars. A 25-cent per gallon increase in the United States gasoline tax is simulated using the model and microdata on household characteristics, car ownership and car sales from 2001–2002. The distributional effects, measured by the equivalent variation relative to income across income deciles, consist of not only changes in the price of gasoline but also changes in the value of cars owned by households and changes in the profits of car producers. In line with the other studies on taxes in the United States, Bento et al. (2009) find that the tax increase is regressive over almost the entire income distribution. More interestingly, they conclude that the gasoline price effect clearly dominates the other more indirect effects which contribute relatively little to the overall effect. Assuming that this result holds true more generally, even the simpler budget share comparisons may provide reasonably reliable estimates of the distributional effects of fuel taxes. Furthermore, studies such as this require making numerous assumptions regarding the model specifics and are more complicated to conduct.

Perhaps the most insightful result arising from the various simulation models pertains to the relevance of tax revenue and transfers. In addition to agreeing on fuel tax increases being at least somewhat regressive, studies employing simulation methods unanimously conclude that the regressivity can be reduced or offset by implementing an appropriate tax recycling scheme. Both Bento et al. (2009) and West and Williams (2004) demonstrate that redistributing the fuel tax revenue in equal lump-sum payments to all households reduces the regressivity to such an extent that the increase becomes progressive. Moreover, raising the fuel tax but simultaneously implementing this flat tax recycling scheme actually results in a welfare gain among the lowest income quintiles in both studies. Bureau (2011) arrives at the same conclusions in his analysis in France and further finds that by implementing the lump-sum transfer scheme the tax raise is effectively proportional among car owners as well. Additionally, Ščasný (2012) shows using data from the Czech Republic that specific revenue-neutral wage tax cuts could also mitigate regressivity, a result consistent with the study conducted by West and Williams (2004) using data from the United States.

An important aspect not discussed even in the more intricate models is the role of externalities. The decrease in VMT resulting from an increase in the fuel tax also reduces the negative externalities associated with road traffic. The changes are most likely distributed unevenly geographically but potentially also with respect to income. For example, low-income households often live in areas with poorer air quality (e.g., Brooks & Sethi 1997), implying that they would benefit relatively more from reduced pollution. On the other hand, congestion is usually considered to have the largest marginal external costs of all road traffic externalities (Nash 2003; Parry, Walls & Harrington 2007) so decreased congestion might considerably affect the distribution of welfare. The magnitude of the distributional effects depends on both the extent of the geographical differences in congestion reduction and the differences in the monetary values assigned to travel time across income groups. Bureau (2011) estimates that while wealthier households in Paris have higher values of travel time, drive more and thus benefit more in absolute terms from reduced congestion, low-income households benefit more relative to their income. Hence, congestion reduction is progressive and mitigates the regressivity of the fuel tax increase. However, more research is required as Bureau (2011) is the only study to evaluate and quantify the significance of externalities in this context.

3.2.4 The role of pass-through

Two assumptions regarding the pass-through of fuel taxes to fuel prices characterize virtually all the studies discussed in this section. First, pass-through is assumed to be 100 percent so that consumers bear the entire burden of the tax. Even though this is a largely reasonable assumption based on the theoretical arguments and empirical evidence presented in Section 3.1 and simplifies the distributional analysis, it is not universally applicable considering the empirical estimates of less than full pass-through. The assumption probably leads to overstated estimates of the degree of regressivity in some studies given that the ownership of firms is usually concentrated in higher income deciles. Contrary to the other studies in this section, Bento et al. (2009) address this issue by allowing for changes in the profits of new car producers following the tax increase. The share of profits owned by a household is assumed to correspond to the household's share of aggregate income. While reducing the regressivity of the tax raise, the contribution of the reduction in profits to the total distributional effect is relatively small compared to the direct gasoline price effect.

The second assumption made is that pass-through is uniform across the whole market in which the tax is implemented. Surprisingly, this is not an assumption explicitly stated in any of the studies, and thus its implications have not been discussed. Stolper (2016b) is the first to point out this gap in the literature and argues that ignoring the variation in local price elasticities of demand and supply, which produce different rates of pass-through, may lead to even substantially incorrect estimates of the distributional effects of fuel taxes. Stolper (2016b) illustrates the potential impact of his result on the heterogeneity in pass-through with respect to house prices by comparing marginal diesel tax burdens across expenditure deciles, assuming both uniform and heterogeneous pass-through. The burdens are essentially equal over the expenditure distribution in the former case but allowing for heterogeneity would result in a burden 50 percent higher in the highest decile compared to the lowest decile if households in each expenditure decile experienced a pass-through rate equal to that in the corresponding house price decile.

Considering the substantial size of the pass-through effect in Stolper (2016b), drawing conclusions on the distributional effects of fuel tax raises based on the existing studies should be done cautiously. This is of particular relevance at present because of the rising trend in the level of fuel taxes. Variation in local pass-through rates should be studied more extensively to determine whether heterogeneities are prevalent in different markets, countries and time periods. A central limitation in Stolper (2016b) is that the distributional analysis is restricted to filling stations in urban areas which constitute approximately 25 percent of all stations in the sample. Given that incomes and the degree of competition are often lower in rural areas and a negative relationship between competitiveness and pass-through is estimated in the study, focusing only on urban areas may provide an incomplete picture of the variation in pass-through. The empirical analysis in this thesis aims to add to this limited evidence by examining the existence of pass-through heterogeneities in Finland.

All things considered, most studies suggest that the prevailing levels of fuel taxes are not as regressive as often thought: this is true especially if regressivity is measured in terms of lifetime income. Furthermore, fuel taxes are most likely regressive only in countries with a high standard of living, the United States having a higher degree of regressivity than the average European country. Taxes are, however, more regressive or less progressive among car owning households in these countries. By contrast, fuel taxes are progressive in many developing countries because car ownership is concentrated in higher income deciles. These results are relatively robust to the choice of methodology. That said, uncertainty related to the relationship between income and both the price elasticity of fuel demand and pass-through plays an important role in determining the distributional impacts of further changes in fuel taxes. Moreover, the studies mostly do not analyze the long-run distributional effects arising from, for instance, changes in the car fleet and also ignore effects related to externalities, such as congestion and air pollution.

4 DATA AND METHODS

Following the novel approach by Stolper (2016b), the potential heterogeneity in fuel tax pass-through in Finland is studied in this thesis to shed light on a central factor determining the distributional effects of fuel taxes. This chapter first gives an overview of fuel taxation in Finland and describes in more detail the tax reform to be studied to set the institutional context for the analysis, after which the data and methods are presented and discussed.

4.1 Fuel taxation in Finland

Transportation fuels are subject to both an excise tax and a value added tax (VAT) in Finland and there is no regional variation in the tax levels. The former is defined in euro cents per liter and consists of three parts: an energy content tax, a CO_2 tax and a security of supply fee, the first two of which constitute over 99 percent of the whole tax on both gasoline and diesel. The CO_2 tax was introduced in 2011 and constitutes about 25 and 37 percent of the whole excise tax on gasoline and diesel respectively. Despite gasoline being taxed to a lesser extent based on its CO_2 emissions, altogether gasoline is taxed more heavily. The excise taxes on both fuels have been raised six times between 2004–2017, diesel having been subject to a larger cumulative increase of 23 cents per liter compared to the raise of 13 cents per liter on gasoline. In 2017, the taxes were 70.25 cents per liter on gasoline and 53.02 cents per liter on diesel. The VAT on transportation fuels is currently 24 percent of the VAT-exclusive price including the excise tax and is remitted by retailers, while excise taxes are remitted by wholesalers.

A decomposition of average fuel prices in 2017 in euro cents per liter is presented in Table 1. The type of gasoline used in this calculation is called 95E10. It is the most widely used blend in Finland and has an octane rating of 95 and a maximum ethanol concentration of 10 percent. With average market prices of 1.46 euros per liter for the 95E10 gasoline and 1.29 euros per liter for diesel, taxes composed approximately 67.5 percent of the price of gasoline and 60.5 percent of the price of diesel in 2017, making the taxes a major determinant of fuel prices. Because of the higher excise tax on gasoline, the market price of gasoline was clearly higher than that of diesel even though the average gasoline price excluding taxes was slightly lower than the tax exclusive price of diesel in 2017.

Table 1 Decomposition of average gasoline and diesel prices in 2017 (c/l)

	Diesel	Gasoline (95E10)
Market price	129.0	146.0
VAT	25.0	28.3
Energy content tax	32.8	52.2
CO_2 tax	19.9	17.4
Security of supply fee	0.4	0.7
Total excise tax	53.0	70.3
Price excluding taxes	51.0	47.4
Total taxes	78.0	98.6
Total taxes, %	60.5%	67.5%

Five of the six tax reforms implemented between 2004–2017, namely the reforms of 2004, 2008, 2014, 2015 and 2017, featured a tax raise of about 2–5 cents per liter on both gasoline and diesel, each increase being slightly larger on diesel. However, on January 1, 2012, the excise tax on diesel was raised substantially by 10.55 cents per liter from 36.40 to 46.95 cents per liter, whereas the corresponding increase on gasoline was only 2.34 cents per liter from 62.70 to 65.04 cents per liter. These increases were actually a part of a reform implemented a year earlier and were originally intended to be smaller in size. Originally, the tax on diesel was supposed to be raised by 7.9 cents per liter and the tax on gasoline to remain at its prevailing level. The CO_2 component of the excise tax was also introduced in the 2011 reform, but its weight was increased later during 2011, leading to the additional raises in the taxes.

The empirical study in this thesis focuses on analyzing the degree of heterogeneity in the pass-through of the 2012 diesel tax raise. Compared to the other reforms, the 2012 reform is favorable due to its considerable increase which more likely makes it possible to discern between smaller percentage point differences in pass-through rates. However, the actual tax increases faced by consumers in 2012 differed from those stated earlier. This is because filling stations do not sell pure diesel and gasoline but blends containing biofuels and other additives, which are taxed at different rates. The amount of excise tax per liter included in the fuels sold on the consumer market is slightly lower mainly because of the lower rate on biofuels. Data on the precise quantities of these other components are not readily available but monthly estimates of taxes on market blends calculated by estimating the share of these biocomponents are provided by Statistics Finland. Furthermore, the tax increase faced by consumers were also affected by the VAT as the excise tax is included in the VAT-exclusive fuel price. Given the VAT rate of 23 percent in 2011–2012, the increase in the excise tax induced a 23 percent higher tax change. As seen from Table 2, the estimated tax increase in the market blend including the rise in the VAT component was 12.28 cents per liter on diesel and 1.94 cents per liter on gasoline.

Table 2 The exact excise taxes on gasoline and diesel in 2011 and 2012 (c/l)

Excise tax	Diesel			Gasoline (95E10)		
	2011	2012	Change	2011	2012	Change
Pure fuel	36.40	46.95	10.55	62.70	65.04	2.34
Market blend	36.28	46.27	9.99	60.79	62.37	1.58
Market blend×(1+VAT)	44.63	56.91	12.28	74.77	76.71	1.94

4.2 Data sources

The station-level diesel and gasoline price data used in this study were obtained from two different websites, polttoaine.net and tankkaus.com, where individuals can report observed fuel prices at different filling stations around Finland. The data extend from January 2000 or 2007 to October 2015, depending on the website. Each station is identified only by a name and some stations are clearly listed multiple times due to having minor differences in their names or being featured on both websites. Hence, the actual number of unique stations cannot be directly specified but utilizing the names and addresses of the stations reported on the websites, a random sample of about 50 percent of the stations were successfully located on the map using coordinates obtained from Google Maps. Based on the coordinates collected, a total of 1117 unique station locations were identified in the sample between 2011 and 2012, the main period of interest in the analysis. However, thirty-seven of these locations underwent one station chain change and two underwent two changes during the two-year period. Because of incomplete information on the ownership of each station, it cannot be determined whether the owners of these stations changed as well.[5]

In addition to coordinates, information on other station specific characteristics were collected based on the names and addresses of the stations in the 1117 different locations. These include the type of station, the services provided, and whether the station is located near a highway, in a city or in a rural area. Additionally, postal code-level data on income and population density as well as average house prices were obtained from Statistics Finland. The income concept used here is disposable income of adults at least the age of eighteen. A proper measure of household income would have been preferable because the measure based on individual adults inaccurately describes their actual financial situation which is affected by the incomes of other members of the household, the number of mouths to feed and economies of scale in household consumption. Although

---

[5] The pass-through analyses were repeated excluding the 39 locations that underwent a station chain change as the change might have influenced pricing decisions. However, the results were unaffected by the omission.

data on total household income were also available, the number of household members was not specified, preventing a sensible comparison between households.

Each postal code area was assigned one of seven regional classes based on an urban-rural classification provided by the Finnish Environmental Institute (Helminen, Nurmio, Rehunen, Ristimäki, Oinonen, Tiitu, Kotavaara, Antikainen & Rusanen 2014): inner urban area, outer urban area, peri-urban area, local center in a rural area, rural area close to an urban area, rural heartland area or sparsely populated rural area. The classification is a comprehensive measure of the degree of urbanization and complements the population density-based regional division. The class assigned to each postal code area depends on various characteristics, such as accessibility, intensity and efficiency. All the stations and a visualization of the urban-rural classification are graphically presented on the Finnish map in Figure A1 in the Appendix. It is evident that most stations are concentrated in larger municipalities, the borders of which are indicated by the dark lines, whereas rural areas have a sparser station network.

4.3 Descriptive statistics and data reliability

As multiple versions of the same station occur in the data, the daily price of each fuel at each station was calculated as the average of all the reported prices at each location on a given day. Descriptive statistics of the prices are presented in Table 3. Diesel was clearly cheaper on average than gasoline in both 2011 and 2012, but the disparity was evidently reduced in 2012. Based on the total number of observations and the number of stations, the average number of observations per station is roughly 50 in both 2011 and 2012 and on both fuels. However, the distribution of the number of observations per station is strongly skewed to the right with the median number of observations ranging from 24 to 28. This suggest that the majority of the observations are from a smaller number of more frequently visited filling stations. Thus, the analysis in this thesis primarily measures the potential differences in pass-through among the more popular filling stations and the results cannot necessarily be extrapolated to all filling stations.

Table 3 Descriptive statistics of the price data in 2011 and 2012

	Diesel price		Gasoline (95E10) price	
	2011	2012	2011	2012
Number of daily observations	56,503	54,259	55,759	52,513
Number of stations	1056	1041	1060	1027
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

Aside from the skewness in the number of observations per station, potential problems with using this data reported by individuals include inconsistency and unreliability. To remove evident outliers, the data were restricted to only include prices between 0.5–3.0 euros per liter. A comparison of monthly average diesel prices calculated from the data and monthly fuel prices reported by Statistics Finland is presented in Figure 2.[6] The price levels and changes are very similar over time in both data, indicating that the prices reported on the websites are quite accurate. Looking at the comparison presented in Figure A2 in the Appendix, the similarity is evident for gasoline prices as well. However, both price series in Figure 2 were calculated from a group of six municipalities – Helsinki, Mikkeli, Oulu, Rovaniemi, Seinäjoki and Turku – that are all among the twenty most populous in Finland. No price data from smaller municipalities are available for comparison. Nevertheless, due to the accuracy in the aforementioned municipalities and considering the fact that the prices in other municipalities exhibit virtually identical trends, the data are deemed sufficiently reliable.

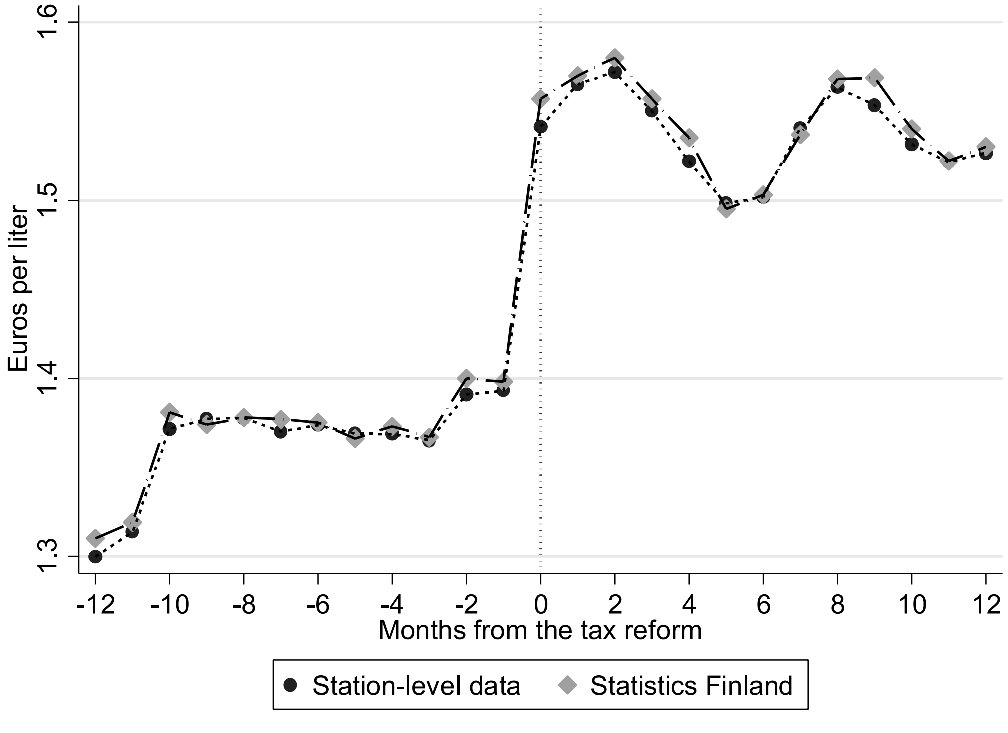

Figure 2 Comparison of monthly average diesel prices

Studying the heterogeneity in pass-through requires dividing the filling stations into groups based on regional income, wealth and the isolation measures. Two types of regions are worth considering: postal code areas and three-digit postal code areas. Finnish postal codes have five digits, the first two of which indicate the municipality or municipalities and the last three determine the areas in more detail. Utilizing three-digit postal codes in defining the regions provides more

---

[6] The prices reported by Statistics Finland are weighted averages of prices on the 15th day of each month. However, the station-level prices in the comparison figures are unweighted and represent an average of the whole month.

flexibility as not all five-digit postal code areas have a filling station and some lack data on income due to data protection issues arising from a small population. Provided that the pricing decisions made by stations are influenced by the income and wealth of individuals living in their vicinity, using too small regions may obscure the actual distributional effects if the relevant clientele resides in a larger area. A third alternative would to be use municipalities, but this would perhaps lead to an excessively broad categorization: municipalities often encompass multiple distinct local markets due to their vast geographical area, especially in the northern parts of Finland. Moreover, postal code areas, as well as municipalities, are artificially created and may correspond poorly to the primary markets on which stations operate. As a compromise, the subsequent analysis utilizes the three-digit postal code division to hopefully minimize these problems.[7]

Disposable income and population density on the three-digit level were calculated based on data on five-digit postal code areas. However, house prices could not be aggregated to the three-digit level because of missing data on the number of houses in each five-digit area. Furthermore, house prices were not available for all five-digit areas in the data, so some filling stations were excluded from the house price analysis. The data on all variables are from 2012 because the postal code data are not available for years prior to 2012. As the urban-rural classification has only seven classes, the most commonly used division into deciles was not employed here. By contrast, the postal code areas were divided into seven equal groups, or septiles, by income, house prices and population density. Using septiles instead of deciles is preferable not only because of comparability with the urban-rural classification but also because postal code areas in the lowest deciles would have had considerably less price observations, hindering statistical inference. The septiles were calculated based only on the postal codes areas included in the data as opposed to all postal code areas in the country. Lastly, the seven classes of the urban-rural classification were numbered in ascending order of urbanization so that 1 = “sparsely populated rural area” and 7 = “inner urban area”.

The number of distinct three-digit areas is 476 while the number of five-digit areas is 727, only 540 of which have data on house prices. The second, sixth and seventh urban-rural classes include around 150–160 five-digit areas and the rest between fifty and seventy. These differences are reflected in the number of stations and price observations in each class, as seen in Table 4. However, the share of observations originating from the more urban areas is considerably larger than one would expect solely based on the number of areas and stations. Although the number of postal code areas is equal across septiles, price observations are also substantially more plentiful in the higher income, house price and population density septiles. The skewedness of these distributions in the case of the urban-rural classification and population density septiles is of course natural

---

[7] The analysis was repeated using both five-digit postal code areas and 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 and the other classification variables as when using the postal code areas.

as the population is higher in urban and more densely populated areas. The similar distributions in income and house price septiles are at least in part explained by the significant overlap in rich and urban areas: for example, Spearman's rank correlation is 0.72 between the urban-rural classification and house price septiles and 0.50 between the classification and income septiles. As the disparities are not as striking in the number of filling stations, the data likely provide a sufficiently accurate representation of regional price levels and trends.

Table 4 Number of observations and filling stations in 2011-2012

Septile/	Income		House prices		Population density		Urban-rural class	
class	N	Stations	N	Stations	N	Stations	N	Stations
1	11,603	97	9797	106	8651	105	5629	83
2	19,269	143	14,761	144	6364	100	18,050	213
3	20,501	145	21,850	147	9328	112	8297	86
4	18,474	163	24,091	146	16,014	145	15,653	131
5	23,121	163	28,692	136	29,426	185	16,146	91
6	37,884	171	44,713	138	48,551	194	54,502	222
7	88,182	235	52,648	101	100,700	276	100,716	288
Total	219,034	1117	196,552	918	219,034	1117	218,993	1114

4.4 Methods and empirical strategy

The potential heterogeneity in diesel tax pass-through in the 2012 reform is studied by employing a difference-in-differences approach. Running state-level panel regressions similar to previous studies in the literature is unfeasible as there is no regional variation in the Finnish fuel tax. Instead, the identification is based on comparing diesel and gasoline prices around the 2012 reform, building on the approach taken by Harju, Kosonen and Laukkanen (2017) who estimate the average pass-through of the 2012 tax increase using the same station-level data. The focus here is, however, on analyzing the variation in the pass-through rate with regard to regional income and wealth but also spatial isolation, the latter being closely related to the former two in Finland and potentially affecting the actual fuel costs faced by individuals because of longer driving distances.

4.4.1 Basic econometric model

The difference-in-differences method rests on the assumption of an additive structure in potential outcomes (Angrist & Pischke 2009). The basic set-up includes two groups, a treatment and a control group, the first of which experiences a treatment at a given point in time. Here the treatment group is comprised of diesel prices while the control groups consists of gasoline prices and the treatment is the diesel tax increase on January 1, 2012. Imposing an additive structure means that the potential nationwide average fuel prices in the absence or presence of the tax increase are determined by

$$P_{sft} = \beta_1 + \beta_2 D_f + \beta_3 A_t + \beta_4 D_f A_t + \varepsilon_{sft} \tag{24}$$

where P_{sft} is the price of fuel f at station s on day t, D_f is an indicator variable for diesel and A_t for the post-reform period. In other words, the potential prices of each fuel are determined by the sum of a time-invariant fuel-specific effect and a time-specific effect common to both fuels. The model assumes that the prices of both fuels would have followed parallel time trends in the absence of the treatment. Thus, the change in gasoline prices is the counterfactual for the unobserved diesel price change in the absence of the tax raise. The coefficient β_4 is the difference-in-difference estimate of the impact of the tax increase:

$$\begin{aligned}\beta_4 = {} & E\left[P_{sft} \middle| D_f = 1, A_t = 1\right] - E\left[P_{sft} \middle| D_f = 1, A_t = 0\right] \\ & -\left(E\left[P_{sft} \middle| D_f = 0, A_t = 1\right] - E\left[P_{sft} \middle| D_f = 0, A_t = 0\right]\right)\end{aligned} \tag{25}$$

Provided that the assumption of common trends holds, β_4 identifies the causal effect of the tax increase.

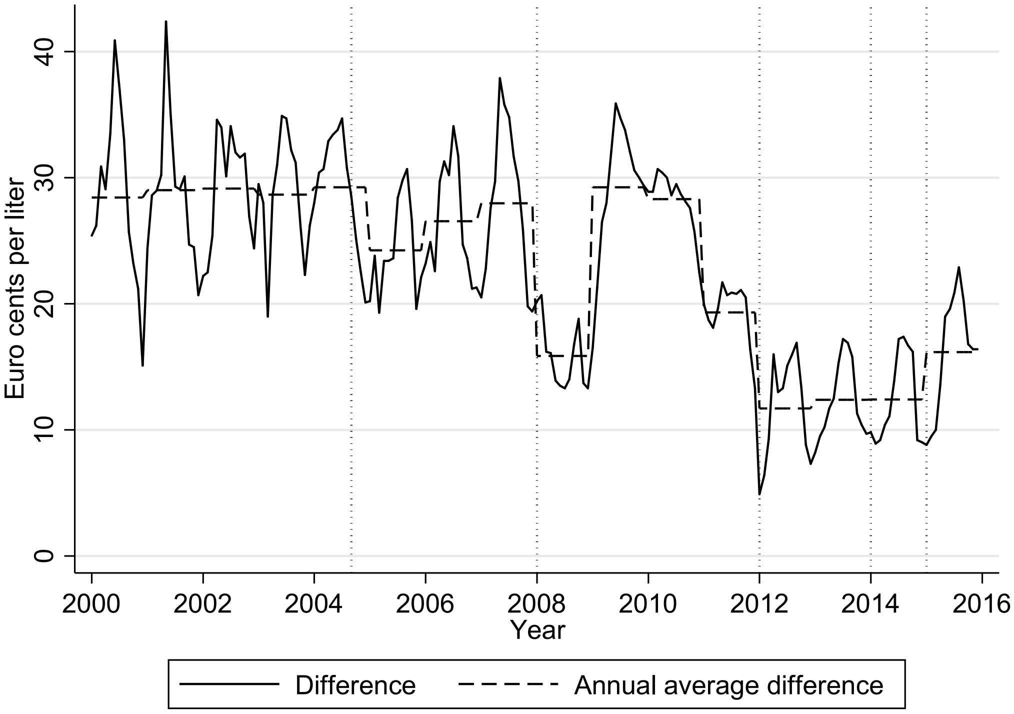

Figure 3 Difference between monthly gasoline and diesel prices

The credibility of the parallel trends assumption is examined by comparing the historical price trends of diesel and gasoline. The gasoline type chosen as the control in this study is 95E10. Another possibility would have been to opt for a more expensive blend called 98E5. However, the prices of the two different varieties of gasoline have nearly identical trends, and 95E10 was chosen due to the higher number of observations in the data. Figure 3 plots the difference between the monthly prices of gasoline and diesel between 2000–2016. There is an evident and a relatively strong annual cyclical component in the difference so that it reaches its peak during the summer months and is at its lowest in December or January. This is probably explained by both the statutory replacement of regular diesel with a more expensive winter blend and higher production costs during the winter. Despite the fluctuations, the average annual difference seems to be very stable in the absence of exogeneous shocks. On the other hand, most tax reforms indicated with the vertical lines clearly coincide with a sharp level change in the difference as do the oil price shocks and the economic crisis between 2008–2011. Moreover, a distinct decrease in the difference occurred at the turn of the year 2012 after which the difference remained stable for the next 2–3 years. In light of this evidence, the assumption of parallel trends seems plausible.

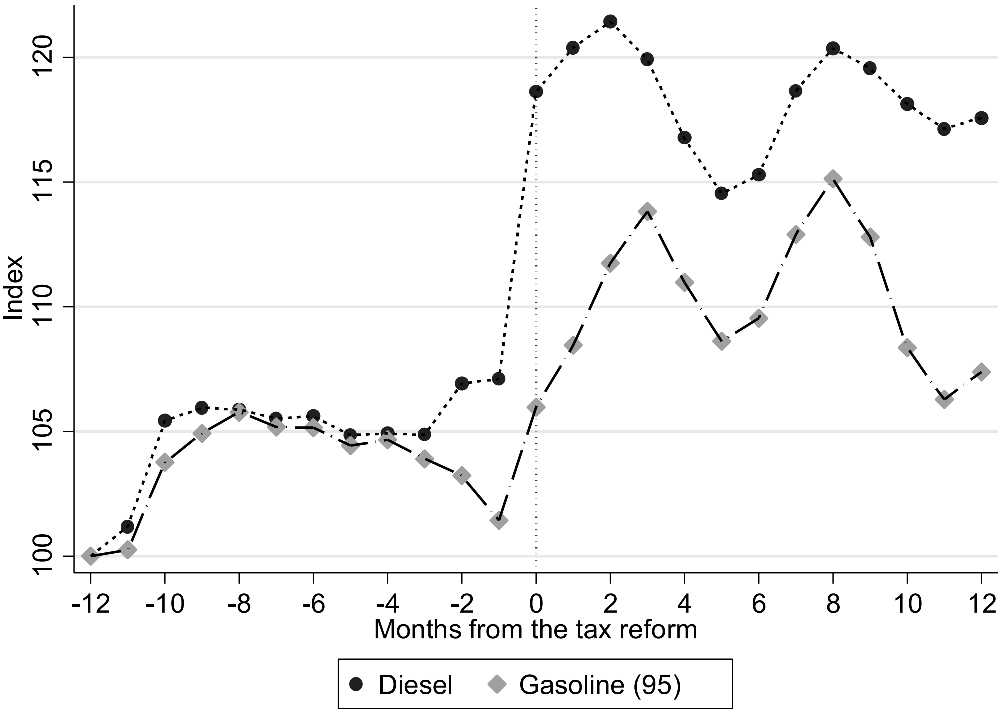

Figure 4 Price trends of diesel and gasoline

The price changes of diesel and gasoline between 2011–2012 are plotted in Figure 4. As seen in this figure as well, the two fuels exhibited similar trends both prior to and after the reform and the price of diesel increased sharply at the turn of the year.[8] However, the prices diverged just before the turn of the year so that a slight increase in diesel prices coincided with a decline in gasoline prices. As noted by Harju et al. (2017), the divergence may be due to anticipation effects or reflect the transition to winter diesel. The authors show that the amount of diesel imported

---

[8] The trends are similar in all the subregions considered in the analysis, but the trends are not plotted here for conciseness.

to Finland nearly doubled in late 2011 only to return to its previous level immediately after the turn of the year, suggesting a clear supply-side anticipation effect. This behavior might reflect the aim of wholesalers to pass a part of the tax burden onto consumers: Kopczuk et al. (2016) suggest that pass-through is higher when the fuel tax is remitted higher in the supply chain because of better opportunities for tax evasion. The potential impact of anticipation on market prices is, however, unclear as there might have been anticipation on the demand-side as well. Following Harju et al. (2017), an alternative model excluding six months around the reform is estimated to take into account the potential anticipation. Additionally, an indicator variable for winter months from October to March for the winter diesel effect is included in the main specification.

Using an income, house price, population density or urban-rural based classification for grouping individual filling stations, differences in the average pass-through rates between these groups are estimated using a modified difference-in-differences regression. If the parallel trends assumption holds in every group considered, the model identifies the causal effect of the diesel tax raise. The basic equation to be estimated using ordinary least squares is as follows:

$$\begin{aligned} P_{sft} = {} & \beta_1 + \beta_2 D_f + \beta_3 A_t + \beta_4 \boldsymbol{G}_s + \beta_5 D_f A_t + \beta_6 D_f \boldsymbol{G}_s + \beta_7 A_t \boldsymbol{G}_s \\ & + \beta_8 D_f A_t \boldsymbol{G}_s + \beta_9 \boldsymbol{X} + \delta_c + \varepsilon_{sft} \end{aligned} \tag{26}$$

where $\boldsymbol{G}_s$ is a vector of indicator variables representing each group (i.e., septile or class) of the classification variable, and $\boldsymbol{X}$ is a vector of covariates that include the daily price of Brent crude oil, the daily EU ETS CO_2 emission permit price, the daily EUR/USD exchange rate, the winter diesel indicator and its interaction with D_f, and an indicator for unmanned self-service stations[9]. Both these covariates, which represent fuel demand and supply shifters, and the station chain fixed effects δ_c are included to increase estimation precision. Lastly, to mitigate any bias emerging from the annual cyclical trend in the difference between gasoline and diesel prices, the full calendar years of 2011 and 2012 are chosen as the pre and post-reform periods in the model.

4.4.2 Interpretation and additional econometric considerations

Due to the diesel tax raise coinciding with a raise in the gasoline tax, the interpretation of the coefficients in (26) is not straightforward. In the absence of a gasoline tax raise, the coefficient β_5 would identify the causal effect of the diesel tax raise on diesel prices in the baseline group. Further, the coefficients in vector β_8 would indicate the difference in price change in each of the other groups relative to the baseline group. Pass-through in the baseline group would be calculated as $\beta_5/\Delta t_d$, where Δt_d is the change in the diesel tax between 2011–2012. The difference in

---

[9] Whether or not a station is an unmanned self-service station largely determines the other station characteristics on which data were acquired. Thus, the other variables provide little additional information and are excluded from the model for parsimony.

pass-through in the other groups, on the other hand, would be calculated by replacing β_5 with the appropriate coefficient in vector β_8. In reality, however, the coefficients measure the extent to which the adjustment of diesel prices to the tax raise differed from that of gasoline prices. Determining the pass-through rates now requires taking into account the change in the gasoline tax, Δt_g, as well. This is implemented here by dividing the estimated coefficients by $\Delta t_d - \Delta t_g$ instead of Δt_d. That is, the difference in price changes is proportioned to the difference in tax increases. Additionally, because P_{sft} is the VAT-inclusive retail price, Δt_d and Δt_g must also be defined as the VAT-inclusive excise tax raises calculated in Table 2. An alternative but identical approach would have been to define P_{sft} as the VAT-exclusive price and ignore the VAT component in Δt_d and Δt_g.

The validity of this pass-through calculation, however, depends on a crucial assumption regarding the pass-through rate of the gasoline tax. Denoting the difference between the average prices of diesel in the pre and post-reform periods by Δp_d and the corresponding difference in gasoline prices by Δp_g, the estimated coefficient $\hat{\beta}_5$ in Equation (26) can be expressed as follows:

$$\hat{\beta}_5 = \Delta p_d - \Delta p_g = \Delta t_d PT_d + \Delta p_{t,d} - \left(\Delta t_g PT_g + \Delta p_{t,g}\right) \tag{27}$$

where PT_d and PT_g are the pass-through rates of the diesel and gasoline tax respectively and $\Delta p_{t,d}$ and $\Delta p_{t,g}$ are the potential price changes in the absence of the tax raise. If the assumption of parallel trends holds, these potential price changes are equal, $\Delta p_{t,d} = \Delta p_{t,g}$, and the expression simplifies to $\hat{\beta}_5 = \Delta t_d \times PT_d - \Delta t_g \times PT_g$. Hence, assuming that the trends were in fact parallel, and dividing $\hat{\beta}_5$ by $\Delta t_d - \Delta t_g$, the estimated diesel tax pass-through, $PT_{d,est}$, is:

$$PT_{d,est} = \frac{\hat{\beta}_5}{\Delta t_d - \Delta t_g} = \frac{\Delta p_d - \Delta p_g}{\Delta t_d - \Delta t_g} = \frac{\Delta t_d \times PT_{d,act} - \Delta t_g \times PT_{g,act}}{\Delta t_d - \Delta t_g} \tag{28}$$

where act refers to the actual unobserved pass-through rates.

From Equation (28), it can be inferred that $PT_{d,est} = PT_{d,act}$ only if $PT_{d,act} = PT_{g,act}$. That is, obtaining an unbiased estimate of diesel tax pass-through requires not only that the assumption of parallel trends holds but also that the actual unobserved pass-through rates of the gasoline and diesel taxes were equal. The same holds true for all the coefficients of the other regional groups in vector β_8. Applying Equation (28) for each regional group separately implies, for instance, that if gasoline tax pass-through was higher in richer regions but the actual unobserved diesel pass-through was constant across all the regions, the model in (26) would estimate that diesel tax pass-through was higher in poorer regions. The severity and relevance of this issue are further discussed in the Section 5.3. The section also introduces alternative specifications as robustness checks. Additionally, Equation (27) imposes a restriction on the possible values of PT_d and PT_g that could produce the estimated value of $\hat{\beta}_5$:

$$PT_d = \frac{\hat{\beta}_5 + \Delta t_g PT_g}{\Delta t_d} \tag{29}$$

where it is assumed that $\Delta p_{t,d} = \Delta p_{t,g}$. In other words, this expression can be used in determining the diesel pass-through rate that would give rise to the observed $\hat{\beta}_5$, given a specific gasoline pass-through rate.

Finally, as noted by Bertrand, Duflo and Mullainathan (2004), standard errors are often substantially underestimated, and hence null hypotheses over-rejected when employing difference-in-differences regressions if serial correlation and clustering are ignored. The standard ordinary least squares method requires that observations are independently and identically distributed so that the estimated standard errors are unbiased. However, it seems unlikely that fuel prices at different stations are independently determined; for example, prices in certain regions or prices of stations belonging to the same station chain are probably systematically similar. This interdependence leads to the error term, ε_{sft}, being correlated both in time and between observations. In this study the error correlation is taken into account by using the "vce(cluster)" command in Stata. It uses a sandwich estimator that allows for correlation within specific clusters of data and results in more correct standard errors. It should be noted that the estimator still assumes independence of errors across clusters. Nevertheless, even if this assumption does not hold, the cluster robust standard errors are preferable compared to the standard non-robust errors.

The errors in the difference-in-differences regression are clustered on municipalities. Choosing municipalities enables a sufficiently high number of clusters. Too small a number of clusters may not provide a solution to the clustering problem because the sandwich estimator provides consistent estimates of the standard errors only as the number of clusters approaches infinity (Cameron, Gelbach & Miller 2008). The number of clusters could be increased by clustering on the three-digit postal code areas used in grouping the regions. Cameron and Miller (2015) emphasize that there is no rule for choosing the appropriate level of clustering but nonetheless remark that the consensus among empirical researchers is to cluster on the broadest possible level on which errors are likely correlated as long as the number of clusters remains sufficiently high. Another possibility would have been to cluster the errors on station chains, but this approach was not taken in the main specification as it would have resulted in only eleven clusters; by contrast, a general rule of thumb for the minimum number of clusters is at least fifty (Cameron & Miller 2015). However, station chains are used as clusters in an alternative specification which employs a wild bootstrap method of estimating cluster-robust standard errors. The method was first applied to error clustering by Cameron et al. (2008) who demonstrated its effectiveness in producing accurate rejection rates even with as few as 5–10 clusters.

5 RESULTS

This chapter presents and discusses the diesel tax pass-through results obtained from estimating the difference-in-differences regression in (26). Heterogeneity is studied with respect to regional income and wealth but also population density and the degree of urbanization. First, graphical evidence on heterogeneous station-level price responses is offered, after which the main pass-through results are provided. This chapter also extensively covers issues related to the robustness and validity of the results, especially due to the interpretational problems arising from the simultaneous gasoline tax raise. The chapter concludes by considering the economic significance and distributional implications of the results along with the limitations of the methodological approach.

5.1 Preliminary graphical evidence

Before delving into the regression results, preliminary graphical evidence on the potential degree of heterogeneity in pass-through is presented in Figure 5. Based on price observations from 641 stations, the mean diesel price increase between December 2011 and January 2012 was approximately 14.7 euro cents per liter. The corresponding gasoline price increase was 6.6 euro cents per liter based on data from 591 filling stations. However, rather than being narrowly focused around these values, the price changes exhibited clear variation and ranged between about -5 and 5 cents per liter around the mean price changes. Some of this variation may naturally arise from errors in the data or missing observations on some days of the months, but similar dispersion persists even if the sample is restricted to stations with at least 15 observations in each month. If this variation in price changes was systematically related to regional characteristics, regional differences in pass-through rates may have been substantial and the tax raise may have had considerable distributional effects.

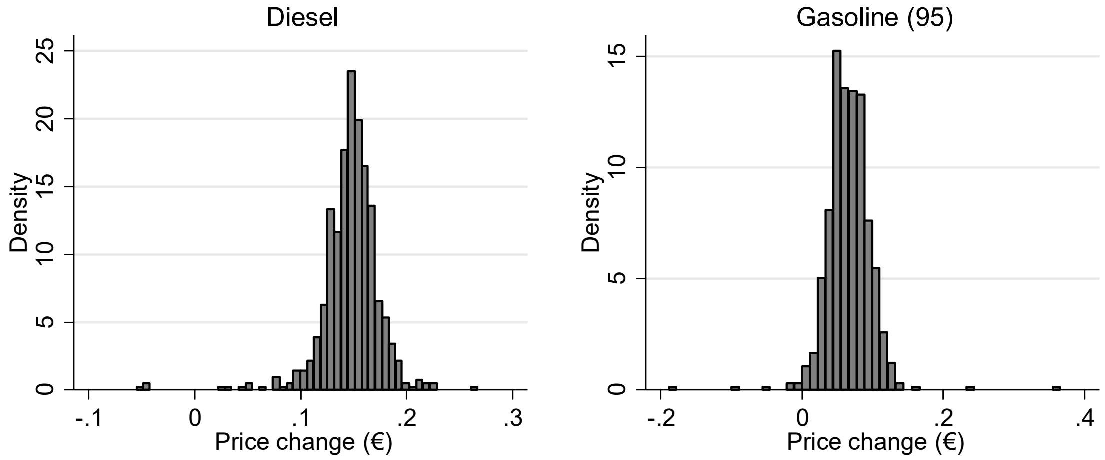

Figure 5 Diesel and gasoline price changes between 12/2011–1/2012

5.2 Main results: regional differences in diesel tax pass-through

Table 5 presents the pass-through results for the three-digit postal code income septiles. The first two columns represent the models using the whole period 2011–2012 whereas the six-month period from October to March around the tax reform is excluded from the models in the last two columns. The results suggest clear heterogeneity in the price impacts of the diesel tax raise as the estimated coefficients of the three-way interactions between the fuel variable, the post-tax raise period and the income septile are all negative and decrease with regional income. The corresponding pass-through rates were calculated by dividing the sum of the estimated coefficients in the first septile and the septile of interest by the difference in tax changes between diesel and gasoline. Depending on the model specification, the pass-through rates range from 75–80 percent in the lowest income septile to 61–67 percent in the highest income septile. Figure 6 plots the three-way interaction coefficient from the second column of Table 5 divided by the excess tax change on diesel relative to gasoline along with 95 percent confidence intervals and illustrates the clear monotonic decrease in pass-through with respect to income.

The models excluding the six-month period around the reform produce lower pass-through rate estimates as they ignore both the divergence in the price trends of diesel and gasoline prior to the tax reform and the sharper increase in diesel prices immediately after the reform. Crucially, however, all the four models indicate the presence of heterogeneity in pass-through. In fact, the models in the third and fourth columns even suggest a slightly higher degree of asymmetry in the price responses than the first two models. Based on graphical evidence, in addition to the prices of diesel and gasoline exhibiting divergent trends before the turn of the year 2012, the upward adjustment in the prices of diesel during the last months of 2011 was more pronounced in the lowest income septiles. This disparity potentially accounts for the more substantial heterogeneity. The results are also virtually unaffected by the inclusion of control variables, which only increase estimation precision. Although the estimated coefficients are statistically significant at the 5 or 1 percent level only in the three highest septiles, the evident negative linear relationship between income and the estimated size of the coefficient lend support to the hypothesis of heterogeneity in pass-through. The joint significance tests of the three-way interactions also clearly support this conclusion at the 5 percent level in all the specifications except for the third.

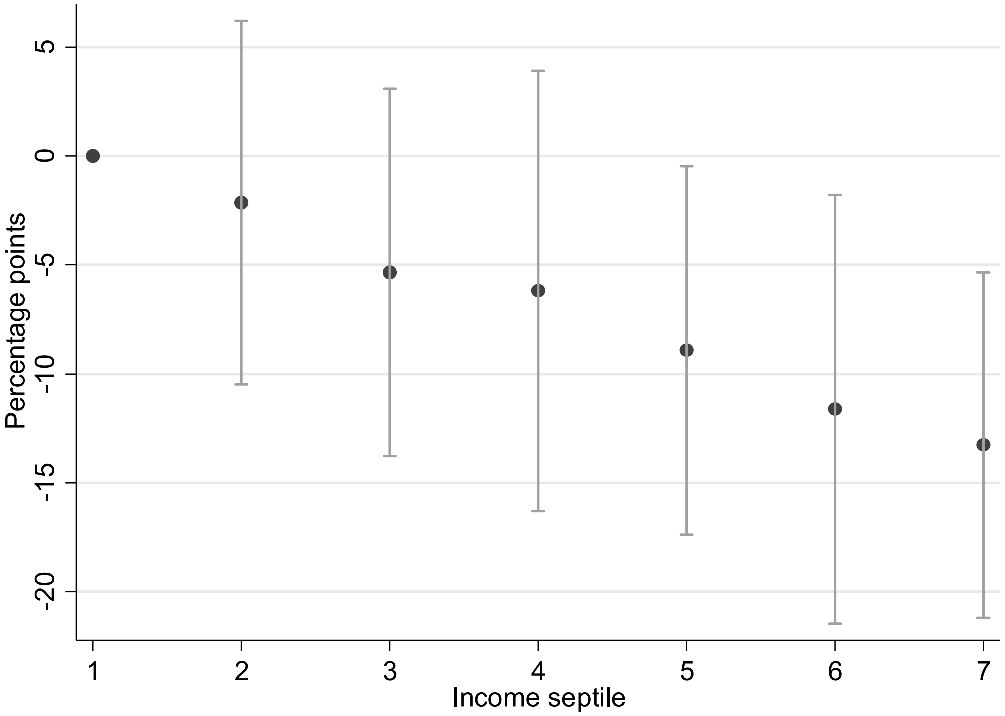

Figure 6 Difference in pass-through by income septile

Table 6 presents the results for house price septiles. As is evident from the estimated three-way interaction coefficients and the corresponding pass-through rates, higher regional house prices are clearly associated with lower diesel tax pass-through. The individual coefficients are statistically significant only in the highest septiles, but the F-test results indicate that the group differences as a whole are statistically significant in all the model specifications. The differences in pass-through are nearly identical to, and even slightly more pronounced than those across income septiles, ranging from 76–82 percent in the lowest septile to 58–65 percent in the highest septile. These results are also robust to including control variables and station chain fixed effects, both of which serve to increase precision. Similarly, pass-through rates appear 5–7 percentage points lower in the specifications in columns three and four in addition to exhibiting a steeper downward slope with respect to house prices. The latter is, again, driven by the asymmetric turn-of-the-year price dynamics between the septiles. Insofar as house prices are a suitable proxy for wealth, these results along with the results between income septiles potentially contribute to regressivity in diesel taxation.

Table 5 Pass-through results: income

	Whole period		Six months excluded	
	(1)	(2)	(3)	(4)
Estimated coefficients				
D	-0.199***	-0.224***	-0.211***	-0.223***
	(0.004)	(0.004)	(0.004)	(0.003)
A	0.108***	0.084***	0.112***	0.116***
	(0.003)	(0.003)	(0.005)	(0.004)
D×A	0.082***	0.083***	0.077***	0.079***
	(0.004)	(0.004)	(0.005)	(0.004)
D×A×G 2nd septile	-0.003	-0.002	-0.004	-0.004
	(0.005)	(0.004)	(0.005)	(0.004)
D×A×G 3rd septile	-0.006	-0.006	-0.010	-0.009
	(0.005)	(0.004)	(0.006)	(0.005)
D×A×G 4th septile	-0.009	-0.006	-0.009	-0.008
	(0.006)	(0.005)	(0.007)	(0.006)
D×A×G 5th septile	-0.007	-0.009*	-0.007	-0.010*
	(0.005)	(0.004)	(0.006)	(0.005)
D×A×G 6th septile	-0.012*	-0.012*	-0.013*	-0.015**
	(0.006)	(0.005)	(0.006)	(0.006)
D×A×G 7th septile	-0.013**	-0.014**	-0.014**	-0.016***
	(0.005)	(0.004)	(0.005)	(0.005)
Constant	1.564***	1.383***	1.567***	1.270***
	(0.008)	(0.012)	(0.007)	(0.014)
Controls	No	Yes	No	Yes
Pass-through				
1st septile	79.5%	80.1%	74.5%	76.3%
2nd septile	77.0%	78.0%	70.8%	72.1%
3rd septile	73.5%	74.8%	64.9%	67.6%
4th septile	70.6%	73.9%	65.5%	68.5%
5th septile	72.4%	71.2%	67.6%	66.5%
6th septile	68.2%	68.5%	61.6%	62.0%
7th septile	67.2%	66.9%	61.2%	61.0%
F-test D×A×G all	3.18**	4.16***	2.02	2.91**
	[0.005]	[0.001]	[0.063]	[0.009]
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 euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. Pass-through in septile s is the sum of the coefficients on $D \times A$ and $D \times A \times G_s$ divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 0.1034. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the D×A×G coefficients is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Table 6 Pass-through results: house prices

	Whole period		Six months excluded	
	(1)	(2)	(3)	(4)
Estimated coefficients				
D	-0.200***	-0.225***	-0.210***	-0.223***
	(0.004)	(0.004)	(0.003)	(0.003)
A	0.106***	0.078***	0.112***	0.112***
	(0.004)	(0.004)	(0.006)	(0.006)
D×A	0.084***	0.086***	0.079***	0.081***
	(0.004)	(0.004)	(0.004)	(0.004)
D×A×G 2nd septile	-0.006	-0.007	-0.003	-0.006
	(0.005)	(0.004)	(0.006)	(0.005)
D×A×G 3rd septile	-0.008	-0.008	-0.004	-0.006
	(0.005)	(0.005)	(0.005)	(0.005)
D×A×G 4th septile	-0.012*	-0.011*	-0.014**	-0.013**
	(0.005)	(0.004)	(0.005)	(0.005)
D×A×G 5th septile	-0.009*	-0.009*	-0.011*	-0.011**
	(0.005)	(0.004)	(0.005)	(0.004)
D×A×G 6th septile	-0.014**	-0.015***	-0.016**	-0.018***
	(0.005)	(0.004)	(0.005)	(0.005)
D×A×G 7th septile	-0.017***	-0.019***	-0.018***	-0.021***
	(0.004)	(0.004)	(0.005)	(0.004)
Constant	1.568***	1.385***	1.570***	1.272***
	(0.007)	(0.012)	(0.006)	(0.014)
Controls	No	Yes	No	Yes
Pass-through				
1st septile	81.6%	82.7%	76.0%	78.1%
2nd septile	76.1%	75.5%	73.1%	72.6%
3rd septile	74.3%	75.0%	71.8%	72.3%
4th septile	70.1%	71.8%	62.8%	65.1%
5th septile	72.9%	74.3%	65.2%	67.2%
6th septile	68.0%	68.2%	60.6%	60.8%
7th septile	65.1%	64.2%	58.6%	57.8%
F-test D×A×G all	4.62***	5.65***	5.02***	6.44***
	[<0.001]	[<0.001]	[<0.001]	[<0.001]
N	196,552	196,552	146,603	146,603
R^2	0.81	0.87	0.83	0.89

The dependent variable is fuel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. Pass-through in septile s is the sum of the coefficients on $D \times A$ and $D \times A \times G_s$ divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 0.1034. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the D×A×G coefficients is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

The estimated differences in pass-through across population density septiles are presented in Table 7. The results bear remarkable similarity to those obtained from the income and house price regressions: pass-through decreases with population density in a nearly linear fashion and the difference between the first and seventh septiles is about 13 percentage points in all four model specifications. The estimated pass-through rates again range between roughly 60–80 percent and the differences relative to the first septile are statistically significant in the highest septiles. The F-tests also support the existence of group differences. This inverse relationship is visualized in Figure 7 which plots the coefficients and their 95 percent confidence intervals from the model in the second column. Finally, the pass-through results with respect to the urban-rural classes reported in Table 8 neatly follow the observed pattern of heterogeneity in the three previous regressions. Pass-through appears to fall with urbanicity as well, the difference between the urban and rural extremes being close to 15 percentage points.

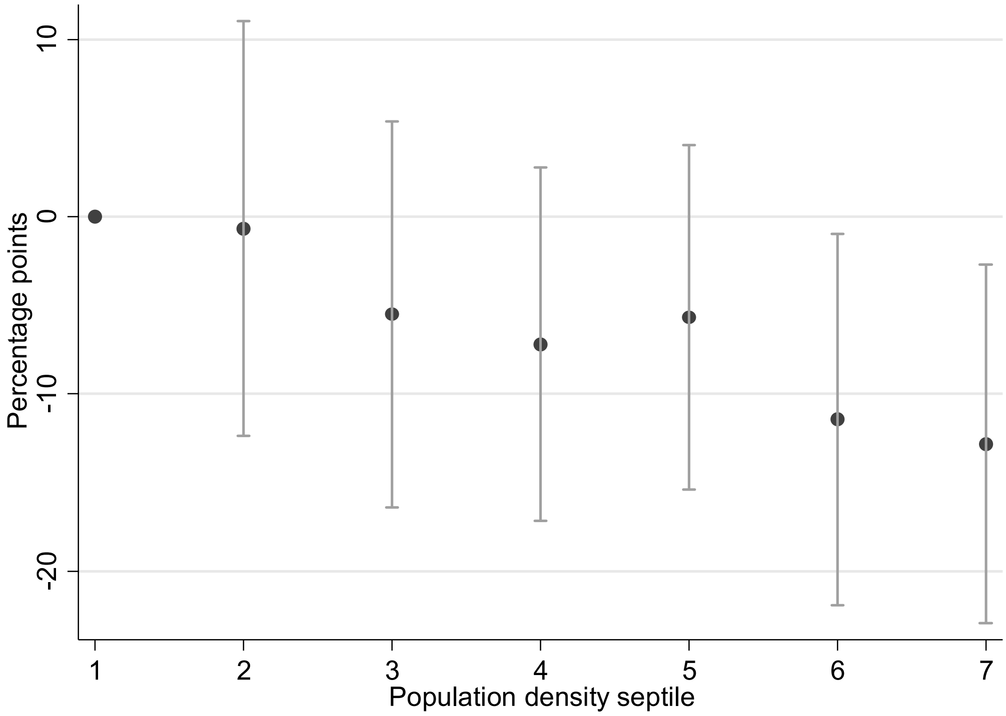

Figure 7 Difference in pass-through by population density septile

While potentially having more modest distributional consequences in a strictly monetary sense, the results in Table 7 and Table 8 nevertheless shed light on the asymmetricity in regional price responses. Pass-through seems to decrease with the degree of urbanization in terms of both population density and the urban-rural classification. Based on Table 4, both low income and low urbanicity areas typically have less extensive station networks, and thus are often less competitive. As rural areas are also often poorer, more sparsely populated and characterized by longer driving distances, demand may be more inelastic in rural than in urban areas. This connection between income, wealth and urbanicity is a conceivable source of the observed differences in pass-through.

Table 7 Pass-through results: population density

	Whole period		Six months excluded	
	(1)	(2)	(3)	(4)
Estimated coefficients				
D	-0.200***	-0.224***	-0.210***	-0.221***
	(0.005)	(0.005)	(0.004)	(0.004)
A	0.109***	0.084***	0.117***	0.119***
	(0.004)	(0.005)	(0.006)	(0.006)
D×A	0.082***	0.083***	0.075***	0.077***
	(0.005)	(0.005)	(0.006)	(0.005)
D×A×G 2nd septile	0.001	-0.001	0.002	0.000
	(0.007)	(0.006)	(0.007)	(0.006)
D×A×G 3rd septile	-0.003	-0.006	0.005	0.001
	(0.006)	(0.006)	(0.007)	(0.007)
D×A×G 4th septile	-0.006	-0.007	-0.004	-0.006
	(0.006)	(0.005)	(0.007)	(0.006)
D×A×G 5th septile	-0.006	-0.006	-0.004	-0.004
	(0.006)	(0.005)	(0.006)	(0.006)
D×A×G 6th septile	-0.012*	-0.012*	-0.009	-0.010
	(0.006)	(0.006)	(0.006)	(0.006)
D×A×G 7th septile	-0.012*	-0.013*	-0.013*	-0.014*
	(0.005)	(0.005)	(0.006)	(0.006)
Constant	1.576***	1.385***	1.577***	1.271***
	(0.007)	(0.012)	(0.006)	(0.014)
Controls	No	Yes	No	Yes
Pass-through				
1st septile	79.4%	80.3%	72.1%	74.1%
2nd septile	80.1%	79.7%	73.8%	74.2%
3rd septile	76.3%	74.8%	77.1%	75.2%
4th septile	73.2%	73.1%	67.7%	68.0%
5th septile	73.3%	74.7%	68.0%	69.8%
6th septile	68.0%	68.9%	63.2%	64.1%
7th septile	67.5%	67.5%	59.9%	60.2%
F-test D×A×G all	2.90**	2.60*	3.55**	3.46**
	[0.009]	[0.018]	[0.002]	[0.003]
N	219,034	219,034	163,693	163,693
R^2	0.81	0.88	0.83	0.89

The dependent variable is fuel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. Pass-through in septile s is the sum of the coefficients on $D \times A$ and $D \times A \times G_s$ divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 0.1034. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the D×A×G coefficients is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Table 8 Pass-through results: urban-rural class

	Whole period		Six months excluded	
	(1)	(2)	(3)	(4)
Estimated coefficients				
D	-0.198***	-0.221***	-0.207***	-0.218***
	(0.005)	(0.005)	(0.005)	(0.005)
A	0.110***	0.086***	0.117***	0.120***
	(0.004)	(0.005)	(0.005)	(0.006)
D×A	0.083***	0.083***	0.079***	0.080***
	(0.005)	(0.006)	(0.006)	(0.006)
D×A×G 2nd class	-0.004	-0.003	-0.003	-0.003
	(0.006)	(0.006)	(0.007)	(0.007)
D×A×G 3rd class	-0.006	-0.008	-0.004	-0.008
	(0.007)	(0.006)	(0.008)	(0.007)
D×A×G 4th class	-0.004	-0.005	-0.004	-0.005
	(0.006)	(0.006)	(0.007)	(0.007)
D×A×G 5th class	-0.013	-0.012	-0.013	-0.013
	(0.008)	(0.008)	(0.008)	(0.009)
D×A×G 6th class	-0.012*	-0.011	-0.014*	-0.013*
	(0.006)	(0.006)	(0.006)	(0.006)
D×A×G 7th class	-0.014*	-0.013*	-0.016*	-0.017**
	(0.006)	(0.006)	(0.006)	(0.007)
Constant	1.575***	1.385***	1.575***	1.271***
	(0.004)	(0.012)	(0.004)	(0.014)
Controls	No	Yes	No	Yes
Pass-through				
1st class	80.6%	80.7%	76.2%	77.2%
2nd class	77.0%	78.2%	73.1%	74.8%
3rd class	74.8%	72.9%	72.4%	69.4%
4th class	77.0%	75.6%	72.4%	72.0%
5th class	68.5%	69.2%	63.4%	64.9%
6th class	69.2%	70.5%	62.8%	64.2%
7th class	67.6%	67.7%	60.4%	60.7%
F-test D×A×G all	3.13**	2.63*	3.69**	3.60**
	[0.006]	[0.017]	[0.002]	[0.002]
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 euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. Pass-through in septile s is the sum of the coefficients on $D \times A$ and $D \times A \times G_s$ divided by the difference between the VAT-inclusive diesel and gasoline tax changes, or 0.1034. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the D×A×G coefficients is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

5.3 Robustness and validity

Despite the substantial size of the differences in the estimated pass-through rates, the validity of the results is largely dependent on the credibility of the difference-in-differences identification strategy. On the one hand, the simultaneous gasoline tax raise complicates the interpretation of the estimated treatment effects and the calculation of the pass-through rates. On the other hand, the difference-in-differences approach rests on the assumption of parallel time trends in diesel and gasoline prices and a violation of the assumption could completely invalidate the results. Hence, the validity of the empirical strategy crucially depends on how suitable a control gasoline is for diesel. This section elaborates on the problems related to the empirical approach and examines the robustness of the results to different model specifications. Overall, the analyses suggest that while gasoline is not an appropriate control for diesel, the conclusions drawn on the degree of pass-through heterogeneity in the previous section are likely warranted. However, the estimated pass-through rates are most likely downward biased.

5.3.1 Simultaneous gasoline tax raise

Using gasoline prices as a control poses a threat to the validity of the results particularly because of the simultaneous raise in taxes on both diesel and gasoline in 2012. As demonstrated in Section 4.4.2, the estimated diesel tax pass-through rates reported in the previous section are unbiased only if both the assumption of parallel trends holds and the actual unobserved gasoline tax pass-through rates in each group were equal to those of the diesel tax. For example, the observed negative relationship between diesel tax pass-through and income, wealth and urbanicity could have arisen even in the absence of any differences in the actual diesel tax pass-through rates if the actual gasoline tax pass-through rates were higher in wealthier and more urban areas. In fact, a positive relationship between gasoline tax pass-through and the four grouping variables in general would strengthen the observed negative relationship.

However, the change in the gasoline tax in 2012 was considerably smaller in size than the simultaneous diesel tax change. Provided that that the assumption of parallel trends holds and noting that $\Delta t_d = 12.28$ and $\Delta t_g = 1.94$ in euro cents per liter, it can be inferred from equation (28) that

$$\frac{\partial PT_{d,est}}{\partial PT_{g,act}} = \frac{-\Delta t_g}{\Delta t_d - \Delta t_g} \approx -0.19 \tag{30}$$

In other words, given the actual diesel tax pass-through rate, a 10-percentage point difference between the actual pass-through rates of diesel and gasoline corresponds to an error of 1.9 percentage points in the opposite direction in the estimated diesel tax pass-through rate. Considering that the difference in the estimated pass-through rates between the highest and lowest septiles or classes using any of the grouping variables is approximately 13–18 percentage points, completely invalidating the result of heterogeneity and regressivity would require that the actual gasoline tax pass-through rates substantial deviated from the assumed rates.

5.3.2 Assumption of parallel time trends

The other crucial assumption for identifying the causal effect of the tax increase is the assumption of parallel time trends. The difference-in-differences equation in (26) imposes an additive and linear structure and posits that changes in the price levels of both fuels are determined by a common time effect in the absence of the tax reform. Despite the seemingly similar trends in diesel and gasoline price levels at the annual level shown in Figure 3, the assumption of parallel trends may not, in reality, hold for price levels but rather for some strictly monotonic transformation of prices, if at all. For example, Figure 4 suggests that the prices of diesel and gasoline might exhibit similar trends in percentage terms. If the actual price trends were multiplicative, that is, the prices would have had a common growth rate in the absence of the tax reform, the linear specification in (26) underestimates the effect of the tax increase and results in too low pass-through rates. This is because diesel prices were lower than gasoline prices in the pre-reform period, and thus an identical increase in the price levels would be larger than an identical percentage growth in diesel prices in absolute terms, resulting in an exaggerated counterfactual growth trajectory.

Following the general nonlinear "difference-in-differences" approach developed by Athey and Imbens (2006) and further elaborated on by Puhani (2012), Ciani and Fisher (2018) provide an exposition of the multiplicative "difference-in-differences" model. Assuming a common trend in growth rates, the expected nationwide prices without (P^0_{sft}) and with (P^1_{sft}) the tax reform in the model are

$$\begin{aligned} E\left[P^0_{sft} \middle| D_f, A_t\right] &= \exp(\mu_D + \lambda_A) \\ E\left[P^1_{sft} \middle| D_f, A_t\right] &= \exp(\mu_D + \lambda_A + \delta) \end{aligned} \tag{31}$$

where μ_D are fuel specific time-invariant effects, λ_A are common time effects and δ is the treatment effect. The treatment effect is proportional so that:

$$\frac{E\left[P^1_{sft} \middle| D_f, A_t\right] - E\left[P^0_{sft} \middle| D_f, A_t\right]}{E\left[P^0_{sft} \middle| D_f, A_t\right]} = \exp(\delta) - 1 \tag{32}$$

Hence, δ measures the additional percentage growth in diesel prices attributable to the tax increase relative to the counterfactual growth. The nonlinear "difference-in-differences" model is specified as:

$$P_{sft} = \exp\left(\beta_1 + \beta_2 D_f + \beta_3 A_t + \beta_4 D_f A_t\right) \varepsilon_{sft} \tag{33}$$

where ε_{sft} is a multiplicative error term satisfying $E\left[\varepsilon_{sft}\middle|D_f, A_t\right] = 1$. Here, β_4 identifies the causal effect of the tax increase on diesel prices:

$$\exp(\beta_4) = \frac{E\left[P_{sft}\middle|D_f = 1, A_t = 1\right]}{E\left[P_{sft}\middle|D_f = 1, A_t = 0\right]} / \frac{E\left[P_{sft}\middle|D_f = 0, A_t = 1\right]}{E\left[P_{sft}\middle|D_f = 0, A_t = 0\right]} = \exp(\delta) \qquad (34)$$

(Ciani & Fisher 2018.)

Assuming multiplicative trends is not, however, devoid of interpretational problems. Equation (34) states that if $\bar{P}_{10}$ and $\bar{P}_{11}$ are the average prices of diesel in the pre and post-treatment periods respectively and $\bar{P}_{00}$ and $\bar{P}_{01}$ are the corresponding gasoline prices, $\exp(\beta_4) = (\bar{P}_{11}/\bar{P}_{10})/(\bar{P}_{01}/\bar{P}_{00})$ which is the ratio of price ratios. It follows that $\bar{P}_{11} = (1+g)\exp(\beta_4)\,\bar{P}_{10}$, where $g = \bar{P}_{01}/\bar{P}_{00} - 1$ is both the percentage growth in gasoline prices over the period and the assumed counterfactual growth in diesel prices. Because the diesel tax is a unit tax, one would naturally assume that increasing the tax would result in a level change in diesel prices so that $\bar{P}_{11} = (1+g)\bar{P}_{10} + PT_d \times \Delta t_d$, where PT_d is diesel tax pass-through and Δt_d the diesel tax raise. However, the nonlinear model specifies that the effect of the tax is measured in percentage terms, implying that $\exp(\beta_4) = 1 + PT_d \times \Delta t_d/\bar{P}_{10}$. Thus, the average price of diesel in the post-reform period is instead determined by

$$\bar{P}_{11} = (1+g)\left(1 + \frac{PT_d \Delta t_d}{\bar{P}_{10}}\right)\bar{P}_{10} = (1+g)\bar{P}_{10} + (1+g)PT_d\Delta t_d \qquad (35)$$

In other words, the price effect arising from the tax raise is augmented by the trend growth. While the structure imposed by the nonlinear model may be inappropriate in this unit tax scenario, the expression in (35) is close to $\bar{P}_{11} = (1+g)\bar{P}_{10} + PT_d \times \Delta t_d$ with small values of g.

Moreover, the simultaneous gasoline tax increase complicates matters in the nonlinear model as well. It can be inferred from above that the pass-through rate is calculated simply by $PT_d = (\exp(\beta_4) - 1) \times \bar{P}_{10}/\Delta t_d$ in the absence of a gasoline tax increase. Instead of being determined by the common growth trend so that $\bar{P}_{01} = (1+g)\bar{P}_{00}$, the average price of gasoline in the post-treatment period is also determined by Equation (35) when a gasoline tax raise is implemented: $\bar{P}_{01} = (1+g)(1 + PT_g \times \Delta t_g/\bar{P}_{00})\,\bar{P}_{00}$. This complication does not render the model useless but makes the estimated diesel tax pass-through rate dependent on the assumed gasoline tax pass-through rate, as was the case in the linear specification. The definition of $\exp(\beta_4)$ can be used to derive the exact relationship between the estimated treatment effect, $\exp(\beta_4)$, and the actual unobserved pass-through rates, PT_d and PT_g:

$$\exp(\beta_4) = \frac{\frac{\bar{P}_{11}}{\bar{P}_{10}}}{\frac{\bar{P}_{01}}{\bar{P}_{00}}} = \frac{(1+g)\left(1+\frac{PT_d \Delta t_d}{\bar{P}_{10}}\right)}{(1+g)\left(1+\frac{PT_g \Delta t_g}{\bar{P}_{00}}\right)}$$

$$\Rightarrow PT_d = \frac{\exp(\beta_4)\frac{\bar{P}_{10}}{\bar{P}_{00}}\left(\bar{P}_{00} + PT_g \Delta t_g\right) - \bar{P}_{10}}{\Delta t_d} \tag{36}$$

The expression for PT_d in (36) is the nonlinear equivalent of Equation (29) and it determines the diesel tax pass-through rate that would produce the estimated treatment effect, $\exp(\beta_4)$, given the actual gasoline tax pass-through rate.

Using the expression above to assign numerical values to PT_d requires an estimate of β_4. One could of course substitute $\exp(\beta_4)$ in the formula for its definition, the ratio of price ratios, but this would complicate statistical inference because the standard error for β_4 would have to be calculated separately. The usual way of obtaining an estimate of β_4 is to transform the model in (33) into a log-linear form so that an additive common trend is assumed to hold for the log of the dependent variable:

$$\log P_{sft} = \beta_1 + \beta_2 D_f + \beta_3 A_t + \beta_4 D_f A_t + \log \varepsilon_{sft} \tag{37}$$

However, if the true model is identical to (33), employing this log-linear specification poses a threat to the reliability of the estimate of β_4. Ciani and Fisher (2018) remark how the assumption that $E\left[\varepsilon_{sft} \middle| D_f, A_t\right] = 1$ does not guarantee that $E\left[\log \varepsilon_{sft} \middle| D_f, A_t\right] = 0$, and thus using ordinary least squares may lead to a biased estimate of β_4. However, they demonstrate how using a Poisson pseudo maximum likelihood estimator could avoid this problem.

Even if the multiplicative model produces correct pass-through rates, the linear model is the preferred main specification. This is because the linear model is more readily understood whereas interpreting the degree of heterogeneity is less straightforward in the nonlinear model due to the results being in percentage terms. After all, the focus of this thesis is on regional differences in pass-through and not on the rates per se. Nevertheless, the nonlinear model is used to obtain aggregate estimates of the nationwide diesel tax pass-through to evaluate the size of the potential bias in the estimates provided in the previous section. To avoid problems related to the choice of functional form and estimation procedure in estimating β_4, the treatment effect is obtained simply by calculating the ratio of price ratios, $\exp(\beta_4) = (\bar{P}_{11}/\bar{P}_{10})/(\bar{P}_{01}/\bar{P}_{00})$. Statistical inference is not an issue as this analysis ignores the regional differences in pass-through and merely aims to approximate the magnitude of the downward bias in the estimates in the linear model.

Table 9 presents the diesel tax pass-through rates that would give rise to the observed country-level changes in diesel and gasoline prices over the tax reform, given a gasoline tax pass-through rate between 60–140 percent and assuming either a common trend in price levels or growth rates. The former assumption is equivalent to the linear difference-in-differences model in (24) while the latter means that prices are determined by the multiplicative model in (33). The second column on the left-hand side of the table presents the diesel tax pass-through rates from the linear model calculated using the formula in (29) and the third column contains the rates from the multiplicative model derived from the formula in (36). The results indicate a modest difference between the two models: the pass-through rates obtained from the multiplicative model are approximately 5 percentage points higher. Assuming full gasoline tax pass-through, the nationwide diesel tax pass-through is 75 percent in the linear and 80 percent in the multiplicative model. These figures also serve to illustrate the reasonably small effect the underlying gasoline tax pass-through rate has on the estimated diesel tax pass-through rate: an 80 percentage point range in the former corresponds to a range of about 12 percent in the latter in both model specifications.

Table 9 Pass-through rates from multiplicative models

Gasoline tax pass-through	Diesel tax pass-through		Swedish diesel tax pass-through	Diesel tax pass-through
	Linear	Multiplicative		Multiplicative
60%	68.6%	74.0%	60%	90.9%
80%	71.8%	76.9%	80%	93.6%
100%	74.9%	79.9%	100%	96.4%
120%	78.1%	82.8%	120%	99.1%
140%	81.3%	85.7%	140%	101.9%

The diesel tax pass-through rates in the linear specification on the left-hand side of the table were calculated by estimating the nationwide difference-in-differences regression in (24) and using the formula in (29). The corresponding rates in the multiplicative models were calculated by first calculating the ratio of price ratios, $\exp(\beta_4) = (\bar{P}_{11}/\bar{P}_{10})/(\bar{P}_{01}/\bar{P}_{00})$ and using the formula for PT_d in (36). The variables $\bar{P}_{10}$ and $\bar{P}_{00}$ denote either Finnish gasoline prices or Swedish diesel prices depending on the control group used.

5.3.3 Suitability of gasoline as a control

Opting for the alternative nonlinear specification may not do much to alleviate the bias in the pass-through estimates if gasoline prices are not a decent control for diesel prices in the first place. To explore this issue, the multiplicative difference-in-differences model is also estimated using Swedish diesel prices as a control group. Due to Finland and Sweden being neighboring countries and being subject to similar economic and institutional conditions, the prices of diesel in these countries might exhibit similar trends as well. This intuition is supported by the graphical evidence in Figure 8 which suggests that the Swedish prices are an even better fit for a control group than the Finnish gasoline prices. The Swedish price data used here are mean daily prices of diesel at all manned Circle K stations in Sweden. The monthly prices plotted in Figure 8 are identical to the monthly prices reported by Svenska Petroleum & Biodrivmedel Institutet, a Swedish fuel trade association that collects and reports data on fuel prices, sales and taxes from a large number of stations and station chains around Sweden. Hence, the data are deemed well-representative of the whole country and suitable for comparison with Finnish prices.

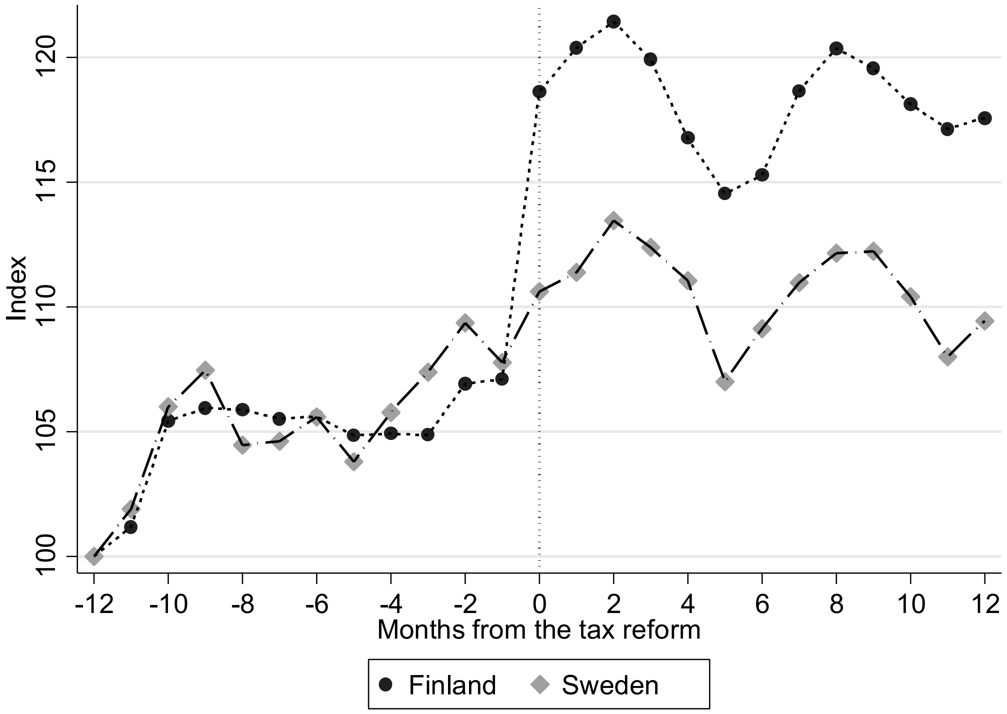

Figure 8 Finnish and Swedish diesel prices

Unfortunately, this comparison suffers from a similar problem as the gasoline comparison because the Swedish diesel tax was raised on January 1, 2012 as well. That said, the size of the tax raise was only 13 öre per liter, or about 1.45 euro cents per liter at the exchange rate on that day, enabling a sensible pass-through analysis. The steps taken to calculate the pass-through rates in this model are identical to those in the previous section. However, both the prices and the tax changes used in the calculation are VAT-exclusive because the 25 percent VAT rate in Sweden was 2 percentage points higher than the Finnish rate of 23 percent in 2012. The estimated Finnish diesel tax pass-through rates are presented on the right-hand side of Table 9. Varying the Swedish diesel tax pass-through rate all the way from 60 to 140 percent only produces a 10 percentage point difference between the two extremes of the Finnish pass-through rates because of the small size of the Swedish tax raise. However, what is striking is the disparity between the pass-through rates between the two multiplicative models: assuming full pass-through in Sweden, the corresponding pass-through in Finland is 96 percent, that is, 16 percentage points higher than in the nonlinear gasoline comparison.

Given that the Swedish comparison produces pass-through estimates closer to those obtained in the existing literature and that the Finnish diesel price trends better coincide with Swedish diesel prices than Finnish gasoline prices, the pass-through rate estimates presented in the previous section are probably downward biased. Because of the substantial differences in the pass-through estimates between the different models in Table 9, considering whether the use of gasoline prices as a control group distorts the heterogeneity results is also crucial. This aspect is analyzed by focusing solely on diesel prices changes and ignoring control groups altogether. Figure 9 plots the average diesel prices in the 1st and 7th regional income septiles and illustrates how the asymmetry in regional price responses is evident merely by graphically examining the diesel price trends. The price jump was more pronounced in the poorest regions around the turn of the year 2012 and the prices remained higher. The graphical evidence is similar for house prices, population density and the urban-rural classification as well.

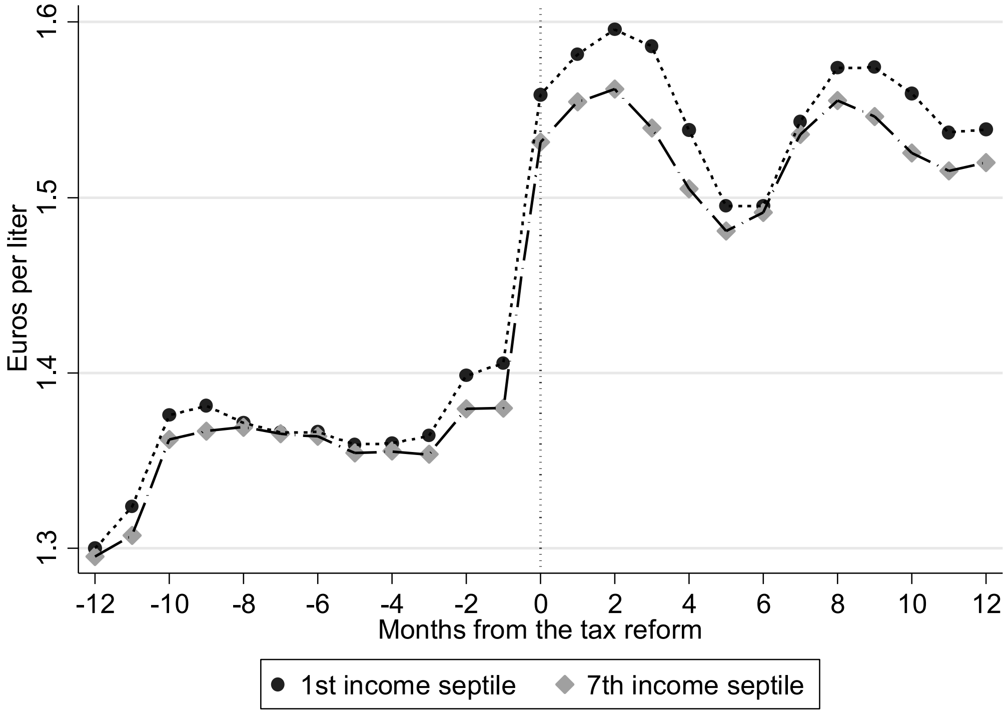

Figure 9 Diesel prices in the highest and lowest income septiles

In order to more rigorously compare these regional price trends around the tax reform and evaluate the extent to which using gasoline prices as a control induces bias in the estimated degree of heterogeneity, an alternative regression focusing only on diesel price changes is employed:

$$P_{st} = \beta_1 + \beta_2 A_t + \beta_3 \boldsymbol{G}_s + \beta_4 A_t \boldsymbol{G}_s + \beta_5 \boldsymbol{X} + \varepsilon_{st} \tag{38}$$

where P_{st} is now only the price of diesel, $\boldsymbol{X}$ includes the same covariates as in the main specification in (26), and the estimation period is the full two-year period between 2011–2012. The coefficients in vector β_4 measure the difference in diesel price change relative to the first septile or urban rural class. Provided that the prices in different regions would have had a common additive trend in the absence of the tax increase, the coefficients identify the causal effect of the tax increase.

Table 10 Results from the diesel price change regression

Septile/	Income		House prices		Population density		Urban-rural class	
class	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Estimated coefficients								
2	-0.015*	-0.015*	-0.009	-0.006	-0.004	-0.006	-0.009	-0.010
	(0.007)	(0.006)	(0.006)	(0.006)	(0.007)	(0.007)	(0.006)	(0.007)
3	-0.007	-0.009	-0.006	-0.005	-0.001	-0.002	-0.007	-0.009
	(0.006)	(0.005)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
4	-0.017**	-0.017***	-0.016**	-0.015*	-0.014*	-0.013*	-0.015*	-0.013*
	(0.006)	(0.005)	(0.006)	(0.006)	(0.007)	(0.007)	(0.006)	(0.006)
5	-0.010	-0.014**	-0.014*	-0.013*	-0.012	-0.014*	-0.020**	-0.019**
	(0.006)	(0.005)	(0.006)	(0.006)	(0.007)	(0.007)	(0.007)	(0.007)
6	-0.016***	-0.016***	-0.017**	-0.015*	-0.015*	-0.016*	-0.018**	-0.019**
	(0.005)	(0.004)	(0.006)	(0.006)	(0.007)	(0.007)	(0.006)	(0.006)
7	-0.016**	-0.017***	-0.019***	-0.017**	-0.020**	-0.021**	-0.021***	-0.022***
	(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Controls	No	Yes	No	Yes	No	Yes	No	Yes
Difference in pass-through								
2	-12.0%	-12.1%	-7.0%	-4.6%	-3.2%	-4.5%	-7.7%	-8.5%
3	-6.1%	-7.7%	-5.2%	-3.9%	-0.7%	-1.5%	-6.1%	-7.7%
4	-13.6%	-13.7%	-12.8%	-12.0%	-11.0%	-11.0%	-11.9%	-11.0%
5	-8.5%	-11.2%	-11.6%	-11.0%	-9.7%	-11.4%	-16.0%	-15.9%
6	-13.3%	-13.2%	-13.5%	-12.1%	-12.3%	-12.9%	-14.7%	-15.8%
7	-12.8%	-13.8%	-15.5%	-13.9%	-15.9%	-17.1%	-17.2%	-18.0%
F-test all	3.27**	3.43**	5.71***	8.41***	7.26***	9.03***	4.69***	4.89***
	[0.004]	[0.003]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
N	110,762	110,762	98,871	98,871	110,762	110,762	110,739	110,739
R^2	0.77	0.85	0.78	0.85	0.77	0.85	0.77	0.85

The dependent variable is diesel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. The difference in pass-through relative to the baseline group in each septile or class has been calculated by dividing the appropriate coefficient by the VAT-inclusive diesel tax change, or 0.1228. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the coefficients in the table is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

The estimated coefficients and the corresponding pass-through rate differences, calculated by dividing the estimated difference-in-differences coefficients with the diesel tax change, are presented in Table 10. The overall picture emerging from these results is largely consistent with the main results, suggesting that the latter are primarily driven by differences in diesel price responses. First, pass-through rates are the highest in the poorest and the most rural regions and the lowest in the wealthiest and the most urban regions. Second, the difference in pass-through between the lowest and highest septiles or urban-rural classes is again 13–18 percentage points and the results are robust to including covariates. Third, the pass-through rates exhibit a clear, albeit not as monotonic, negative relationship with three of the four grouping variables over all the seven groups, the exception being income with a more fluctuating pattern.

5.3.4 Other regional differences

Even though the analysis concentrating on diesel price changes in the previous section bolsters the case for heterogeneous pass-through, the results might still, at least in part, be explained by "normal" turn-of-the-year price dynamics. That is, prices in different regions might have exhibited divergent trends for example due to harsher winter conditions in the northern parts of Finland. To test this hypothesis, a placebo difference-in-differences regression identical to (26) is employed using the whole period 2009–2010 when no tax changes were implemented. The results from the regressions that include all the covariates are reported in Table 11.[10] As expected, all the estimated three-way interaction coefficients are very close to zero, only two out of the twenty-four being statistically different from zero at the 5 percent level. In addition, the magnitude of the coefficients is not systematically related to the septile or urban-rural class number. The hypothesis of identical price changes across groups is also supported by the joint significance tests.

However, the relatively large and statistically significant price change differences relative to the first population density septile in the second and fourth population density septiles suggest that there might have been actual price divergence across these regions. The large coefficients also increase the F-test statistic, nearly making the group differences as a whole significant at the 5 percent level. On the other hand, the estimated coefficients might imply that the asymmetry in diesel and gasoline price trends in the first population density septile was anomalously large. In fact, the excess diesel price increase of 1.4 cents relative to gasoline was the largest among all the septiles or classes of the four grouping variables. That said, the positive and statistically significant coefficients on the interaction $D_f \times A_t$ in all the four regressions indicate that diesel prices in all the baseline groups increased by approximately 1 euro cent per liter more than gasoline prices. This suggests that diesel and gasoline price trends are in fact not perfectly parallel, further challenging the validity of the set-up in the main regressions. Running the diesel price change regression in (38) for the period 2009–2010 shows that differences in diesel price changes between the regions were almost nonexistent. Thus, the observed disparities in Table 11 are almost fully accounted for by differences between diesel and gasoline price trends.

---

[10] The results are identical without including the covariates.

Table 11 Placebo difference-in-differences regression results

	Income	House prices	Population density	Urban-rural class
	(1)	(2)	(3)	(4)
D	-0.319***	-0.315***	-0.319***	-0.316***
	(0.003)	(0.003)	(0.004)	(0.004)
A	0.004	0.008**	0.005	0.009**
	(0.002)	(0.003)	(0.003)	(0.003)
D×A	0.011**	0.008*	0.014***	0.012**
	(0.004)	(0.004)	(0.004)	(0.004)
D×A×G 2nd group	-0.001	-0.001	-0.014*	-0.005
	(0.004)	(0.005)	(0.006)	(0.005)
D×A×G 3rd group	-0.004	-0.001	-0.006	-0.005
	(0.005)	(0.004)	(0.005)	(0.006)
D×A×G 4th group	-0.004	-0.001	-0.010*	-0.009
	(0.004)	(0.004)	(0.004)	(0.005)
D×A×G 5th group	-0.005	-0.003	-0.006	-0.003
	(0.004)	(0.004)	(0.004)	(0.005)
D×A×G 6th group	-0.003	0.003	-0.006	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)
D×A×G 7th group	-0.002	0.001	-0.005	-0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Constant	1.549***	1.550***	1.556***	1.551***
	(0.008)	(0.008)	(0.008)	(0.008)
Controls	Yes	Yes	Yes	Yes
F-test D×A×G all	1.02	1.36	2.09	0.86
	[0.412]	[0.231]	[0.055]	[0.523]
N	229,820	206,797	229,820	229,787
R^2	0.95	0.95	0.95	0.95

The dependent variable is fuel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. Standard errors (in parentheses) are clustered at the municipality level. The p-value of the joint significance test of all the D×A×G coefficients is in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Another, unrelated problem with a regional aspect is worth addressing. As briefly discussed in Section 4.3, using prices voluntarily reported by individuals means that the data are dominated by observations from the more popular stations and more populous regions. If the pricing decisions of these stations significantly differ from those of the less frequently visited stations, the regional pass-through estimates may not accurately represent the regions as a whole. Estimating the diesel price change regression in (38) using weekly average prices, thus giving a higher weight to the stations with fewer daily observations, lends support to this hypothesis: the results exhibit patterns similar to those presented in Table 10 but the estimated differences in pass-through rates are generally 1–3 percentage points lower. Then again, using daily prices may be preferable because the more popular stations also serve a larger customer base, and thus the skewedness in the number of observations per station implicitly imposes weights on the stations based on the quantity of diesel sold.

5.3.5 Standard errors and clustering

The robustness checks conducted in the previous sections suggest that the pass-through rate estimates obtained from the main regressions presented in Section 5.2 are probably too low due to gasoline not being an ideal control for diesel. In fact, the comparison with Swedish diesel prices suggests that the actual rates could be up to 15 percentage points higher. However, the regressions focusing solely on diesel price changes yield similar estimates of the degree of regional differences in pass-through and support the conclusions drawn in Section 5.2. That is, pass-through rates decreased with regional income, wealth, population density and the degree of urbanization, the differences between the regional extremes being about 15 percentage points. Whether or not these regional differences are real or merely a statistical fluke largely depends on how the standard errors are estimated in the difference-in-differences regressions employed in the analyses. As noted in Section 4.4.2, ignoring the serial and regional correlation in fuel prices would lead to over-rejection of null-hypotheses in the regressions. This correlation was taken into account in all the analyses by clustering the standard errors on municipalities.

However, the fuel prices and standard errors might be correlated on other levels besides the regional level. This section examines the sensitivity of the standard error estimates to an alternative clustering approach, namely clustering on station chains. Stations operating under the same chain name might have similar pricing guidelines and business strategies. Thus, the prices and unobserved characteristics might be correlated within the station chains regardless of where the stations are located. What is more, nearly all the Finnish filling stations in the data belonged to one of the five largest station chains – ABC, Neste, ST1, Shell or Teboil – between 2011–2012, making the potential clustering a large-scale issue. As discussed in Section 4.4.2, the small number of clusters also complicates statistical inference. Even though stations from ten other chains are also included in the data during this period, 96 percent of all price observations come from the five largest station chains. Further, five of these ten smaller chains have so few observations that they have to be combined into one cluster; having excessively unbalanced clusters further weakens the reliability of the clustered standard error estimates (Cameron & Miller 2015). This makes the total number of station chain clusters eleven.

Having only eleven clusters effectively precludes using the standard sandwich estimator in estimating standard errors as it relies on asymptotics in the number of clusters. Instead, this section employs the wild bootstrap method suggested by Cameron et al. (2008). The most effective implementation of the method in Stata is the “boottest” command described in more detail by Roodman, MacKinnon, Ørregaard Nielsen and Webb (2018), the first of whom is the original developer of the command. Instead of directly estimating standard errors for each estimated regression coefficient, the wild bootstrap method constructs a bootstrapped distribution of the normal Wald test statistic for each coefficient and uses it to calculate the p-value for the null hypothesis that the coefficient is zero (Cameron et al. 2008).

The results from the main difference-in-difference regression in (26) clustering on station chains are reported in Table A1 in the Appendix. The wild bootstrapped p-values are reported in brackets below the estimated coefficients. Overall, the results in Table A1 bear resemblance to those in the main specifications in Section 5.2 in terms of statistical significance: the estimated coefficients are significant at the 5 percent level only in the highest two septiles. However, the wild bootstrap method in conjunction with clustering on station chains produces slightly more conservative p-values and results in some of the coefficients being significant only at the 10 percent level in the models comparing population density septiles and urban-rural classes. Then again, including covariates in the models increases estimation precision and makes these coefficients in the seventh septile and class significant at the 5 percent level. Table A2 in the Appendix, on the other hand, reports the results from the diesel price change regression in (38) using this alternative clustering approach. While also being more conservative than the values obtained in Section 5.3.3, the p-values in Table A2 indicate that the differences in price changes are statistically significant at the 5 percent level in the three or even four highest septiles or classes. In conclusion, even though the significance of the results is weaker in the gasoline comparison, the strongly significant differences in the diesel price change regressions indicate that the results are relatively robust to the choice of the clustering variable.

5.4 Discussion and distributional consequences

Having established a likely negative relationship between pass-through and income, house prices and urbanicity, this chapter concludes by considering the practical implications of this finding. Figure 10 plots both the monthly and annual average difference in diesel prices between the seventh and first house price septiles in 2012 over the period 2006–2014. The series illustrate how the price difference remained reasonably constant in the absence of tax reforms indicated by the vertical lines. They also demonstrate the magnitude of the unprecedented asymmetric price movement in 2012: while the prices in the first septile increased by approximately 2 euro cents per liter more at the annual level, the initial difference in price responses was up to 4 cents per liter. Figure A3 in the Appendix reveals a similar pattern between the seventh and first urban-rural classes.

What is worth noting, however, is that the increased price disparity was later mitigated with the prices slowly converging towards each other during 2013. This might be, for instance, due to slower price adjustment in the first septile but also heterogeneous anticipation effects of the 2014 tax change that roughly seemed to revert the price difference to its pre-2012 level. Nevertheless, both the graphical evidence and a more careful analysis of diesel price changes between 2011–2014 employing the diesel price change regression in (38) suggest that the asymmetric effect of the 2012 tax increase might not have been permanent, at least between the regional income and house price extremes. In fact, the regression results show that the diesel price differences between the first and the top two income and house price septiles were first drastically reduced in 2013 while the differences between all the septiles almost completely disappeared by 2014. However, the differences between the population density septiles and the urban-rural classes persisted over the three-year period after the tax increase, only slightly diminishing between the extremes.

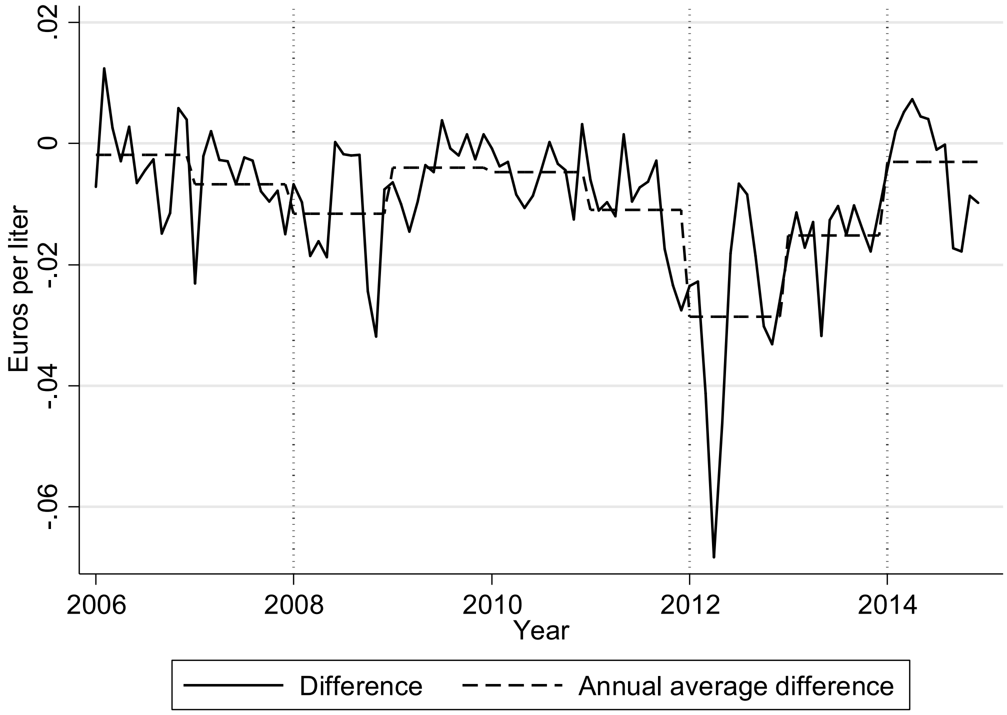

Figure 10 Diesel price difference between the 7th and 1st house price septiles

Even if the longer-term price adjustment is ignored, drawing explicit distributional conclusions from the findings is complicated. The regional grouping implemented here is based on postal codes, and the individuals residing in these areas may or may not represent the primary clienteles of the stations. The denser station network in urban areas offers potential customers a higher number of options and allows them to travel a slightly longer distance to another station after cheaper prices. The choice of station is also naturally affected by commuting routes. In rural areas, stations are often located along main roads and mainly serve inter-city travelers. On the other hand, the number of stations in an average rural municipality or postal code area is relatively low, and thus the residents are practically compelled to patronize the stations in their vicinity.

Another, indirectly locational factor potentially obscuring the distributional implications stems from the fact that diesel is widely used in both passenger cars and commercial vehicles. This implies that the customer bases of some stations selling diesel consist of not only private motorists but perhaps also a considerable number of firms. While stations intended specifically for refueling semi or full-trailer trucks were excluded from the data used in this thesis, this insight might nevertheless influence the distributional consequences. For example, if other vehicles in commercial use regularly visited stations that raised their prices relatively more, a share of the increased tax burden would have been borne by firms in addition to consumers.

As is evident from the literature review in Section 3.1.2, only one study has directly addressed and attempted to quantify the distributional effects arising from heterogeneous regional pass-through, namely Stolper (2016b). Interestingly, the observed negative relationship between pass-through and house prices in this thesis stands in stark contrast to the results obtained by Stolper (2016b) who finds a strong positive correlation between house prices and pass-through in Spain. He also demonstrates using fuel consumption data how his finding might drastically increase the progressivity of fuel taxation. Two explanations for the discrepancy between the results are apparent. The first is that urban regions in Finland often both have higher house prices and host a higher number of filling stations, and thus are more competitive. The two studies by Stolper (2016a, 2016b) suggest that pass-through is lower in more competitive environments in Spain as well. Hence, the spatial relationship between competitiveness and house prices might be different between the two countries. The second explanation is closely related to the first: Stolper (2016b) only uses data from urban areas whereas the results in thesis are heavily influenced by the disparities between urban and rural areas.

Regardless of the interpretational limitations of the analyses in this thesis discussed above, the differences in pass-through probably did have actual distributional implications. This is due to the considerably large size of both the tax increase in absolute terms and the estimated degree of pass-through heterogeneity. The estimated negative relationship between pass-through and both income and house prices naturally translates to less progressivity or more regressivity in fuel taxation – provided that house prices are a suitable proxy for wealth. This holds true more indirectly for population density and the degree of urbanization as well. Pass-through rate differences of up to 15 percentage points could give rise to substantial distributional effects even if demand and other behavioral responses are taken into account: the studies reviewed in Section 3.2 suggest that the direct price changes induced by taxes contribute the most to the distributional effects of fuel taxes as a whole. Unfortunately, approximating the size of the distributional impacts of the observed heterogeneity in pass-through similar to Stolper (2016b) is unfeasible in this thesis because regional fuel consumption data were not available.

6 CONCLUSION

The aim of this thesis was to examine the degree of heterogeneity in diesel tax pass-through in the Finnish fuel tax reform of 2012. The unprecedentedly large tax raise of 10.55 euro cents per liter on January 1, 2012 corresponded to a 29 percent increase in the excise tax on diesel. Thus, the thesis was motivated by the fact that even relatively small disparities in regional pass-through in percentage terms could have given rise to substantial differences in the real economic costs faced by consumers around the country. Existing studies suggest that fuel taxes are nearly proportional or only slightly regressive in wealthier countries. This conclusion is mainly based on the observation that the budget shares of fuel consumption are virtually uniform across the income distribution, at least in a lifetime perspective (see, e.g., Sterner et al. 2012). Moreover, studies suggest that other factors only moderately affect the degree of progressivity. This implies that pass-through heterogeneity might play a critical role in determining the distributional consequences of increased fuel taxation. However, Stolper (2016b) is the only study thus far delving into this issue. The study suggests that there has been a strong positive relationship between regional wealth, proxied by house prices, and diesel tax pass-through in Spain. This finding implies that the tax raises analyzed in the study may in fact have been strongly progressive.

The empirical study in this thesis set out to analyze the potential pass-through heterogeneity with respect to not only income and house prices but also population density and the degree of urbanization. All the four aspects are closely intertwined in Finland, a country characterized by the contrast between few vibrant urban centers and the surrounding vast and sparsely populated rural areas. Individuals residing in these peripheral areas are typically more reliant on private motoring due to longer driving distances and a poorer public transportation network. Insofar as this reliance or other factors affecting fuel demand translate into differences in the price elasticity of fuel demand between urban and rural regions, they could directly produce variation in regional pass-through rates as well. This argument stems from the partial equilibrium models of tax incidence. They predict that pass-through decreases with the price elasticity of demand under both perfect and imperfect competition. The models also emphasize the role of firm characteristics and suggest that pass-through increases with the price elasticity of supply, regardless of the underlying market structure. However, the degree of competition in itself also influences pass-through in the models, but the direction of the relationship depends on model specifics. Given that regional differences in the price elasticities of demand and supply and the degree of competition are probable, these theoretical insights further justify the approach taken in this thesis.

The degree of heterogeneity in diesel tax pass-through in this thesis was studied by comparing diesel price changes to gasoline price changes around the tax reform in a difference-in-differences framework. Using station-level fuel price data from around the country enabled analyzing price responses on a remarkably fine level. After determining the exact geographical location of each individual station in the data, the price data were combined with data on income, house prices and population density on the postal code level. These postal code regions were then divided into seven equal groups, or septiles, with respect to each of the three grouping variables. Additionally, each postal code region was assigned one of seven classes of a regional urban-rural classification developed by the Finnish Environmental Institute (Helminen et al. 2014). Results from the difference-in-differences regression using gasoline prices as a control group suggested that diesel price responses to the tax raise were in fact asymmetric: pass-through rates fell with income, house prices, population density and the degree of urbanization, as measured by the urban-rural classification. The estimated pass-through rates in the first income, house price and population density septiles, as well as in the most rural areas, were approximately 80 percent, while pass-through rates in the other extremes were about 15 percentage points lower.

However, the difference-in-differences set-up suffered from two main problems: (i) the excise tax on gasoline was also slightly raised on January 1, 2012 and (ii) the gasoline price trends appeared not to have been perfectly parallel to diesel price trends. Comparing diesel prices in Finland to Swedish diesel prices, a seemingly more suitable control group, using a nonlinear “difference-in-differences” model suggested that the pass-through rate estimates obtained from the main model were potentially biased downwards by up to 15 percentage points. The credibility of this alternative approach was bolstered by the fact that pass-through rates closer to 100 percent would have been consistent with estimates in existing studies. Despite the potential unreliability of the initial pass-through rate estimates, the results on the degree of pass-through heterogeneity appeared to be valid. A difference-in-differences regression focusing solely on diesel price changes around the tax reform indicated that the main results were driven by actual variation in diesel price responses that corresponded to pass-through differences of about 15 percentage points. While the disparities in the initial price responses in early 2012 were considerable in size, further analyses revealed that the increase in regional price differences between income and house price septiles was substantially mitigated during the following two to three years; on the other hand, differences between population density septiles and urban and rural areas largely persisted.

Even though the results implied that the regional differences in pass-through had more adverse effects on the poor, quantifying the distributional consequences would have been challenging. This was primarily due to having no information on the clientele of each filling station. Provided that individuals had the option to patronize stations on a broad enough geographical area, the burdens arising from larger price increases in certain postal code regions were not necessarily borne by the local residents. Furthermore, diesel is widely used in commercial vehicles, implying that firms might constitute a considerable share of diesel consumers. If firms systematically and more often patronized certain stations in poorer and more rural areas, determining the incidence of the tax raise on individuals would have been even more complicated as firms would have borne a part of the burden as well. Data on household diesel expenditure were not available either, thus precluding an analysis of the actual monetary effects caused by the differences in regional pass-through rates.

Notwithstanding the challenges related to the interpretation of the results, this thesis contributes to the fuel tax incidence literature in two ways. First, it provides European evidence to complement the existing evidence mainly originating from the United States. Second, and perhaps more importantly, it adds to the extremely limited evidence on the potential distributional implications of heterogeneous pass-through. While the observed negative relationship between house prices and pass-through is totally opposite to the results obtained by Stolper (2016b) in Spain, the contradicting results may simply be attributable to differences in the data used. To be more specific, Stolper (2016b) focuses exclusively on urban areas in whereas the data used in this thesis covers both urban and rural regions. The contradiction may also reflect a variety of structural differences between the two countries. Resolving these differences and uncovering the underlying mechanisms determining regional pass-through rates, however, requires considerably more empirical work from different countries, institutional settings and market environments.

REFERENCES

Agostini, C. A. & Jiménez, J. 2015. The distributional incidence of the gasoline tax in Chile. Energy Policy 85, 243–252.

Alm, J., Sennoga, E. & Skidmore, M. 2009. Perfect Competition, Urbanization, and Tax Incidence in the Retail Gasoline Market. Economic Inquiry 47 (1), 118–134.

Anderson, S. P., de Palma, A. & Kreider, B. 2001. Tax incidence in differentiated product oligopoly. Journal of Public Economics 81 (2), 173–192.

Angrist, J. D. & Pischke, J. 2009. Mostly Harmless Econometrics: An Empiricist's Companion. Princeton, NJ: Princeton University Press.

Athey, S. & Imbens, G. W. 2006. Identification and Inference in Nonlinear Difference-in-Differences Models. Econometrica 74 (2), 431–497.

Bento, A. M., Goulder, L. H., Jacobsen, M. R. & von Haefen, R. H. 2009. Distributional and Efficiency Impacts of Increased US Gasoline Taxes. American Economic Review 99 (3), 667–699.

Berkovec, J. 1985. New Car Sales and Used Car Stocks: A Model of the Automobile Market. RAND Journal of Economics 16 (2), 195–214.

Bertrand, M., Duflo, E. & Mullainathan, S. 2004. How Much Should We Trust Differences-In-Differences Estimates? Quarterly Journal of Economics 119 (1), 249–275.

Blackman, A., Osakwe, R. & Alpizar, F. 2010. Fuel tax incidence in developing countries: The case of Costa Rica. Energy Policy 38, 2208–2215.

Blow, L. & Crawford, I. 1997. The distributional effects of taxes on private motoring. Institute for Fiscal Studies. London.

Blundell, R., Horowitz, J. L. & Parey, M. 2012. Measuring the price responsiveness of gasoline demand: Economic shape restrictions and nonparametric demand estimation. Quantitative Economics 3, 29–51.

Brons, M., Nijkamp, P., Pels, E. & Rietveld, P. 2008. A meta-analysis of the price elasticity of gasoline demand. A SUR approach. Energy Economics 30 (5), 2105–2122.

Brooks, N. & Sethi, R. 1997. The Distribution of Pollution: Community Characteristics and Exposure to Air Toxics. Journal of Environmental Economics and Management 32 (2), 233–250.

Buehler, R. 2011. Determinants of transport mode choice: a comparison of Germany and the USA. Journal of Transport Geography 19 (4), 644–657.

Bureau, B. 2011. Distributional effects of a carbon tax on car fuels in France. Energy Economics 33, 121–130.

Cameron, A. C., Gelbach, J. B. & Miller, D. L. 2008. Bootstrap-Based Improvements for Inference with Clustered Errors. Review of Economics and Statistics 90 (3), 414–427.

Cameron, A. C. & Miller, D. L. 2015. A Practitioner's Guide to Cluster-Robust Inference. Journal of Human Resources 50 (2), 317–372.

Chetty, R., Looney, A. & Kroft, K. 2009. Salience and Taxation: Theory and Evidence. American Economic Review 99 (4), 1145–1177.

Chouinard, H. & Perloff, J. M. 2004. Incidence of federal and state gasoline taxes. Economics Letters 83, 55–60.

Ciani, E. & Fisher, P. 2018. Dif-in-Dif Estimators of Multiplicative Treatment Effects. Forthcoming in Journal of Econometric Methods.

Dahl, C. A. 2012. Measuring global gasoline and diesel price and income elasticities. Energy Policy 41, 2–13.

Dahl, C. A. 1995. Demand for transportation fuels: a survey of demand elasticities and their components. Journal of Energy Literature 1 (2), 3–27.

Datta, A. 2010. The incidence of fuel taxation in India. Energy Economics 32, S26–S33.

Deaton, A. & Muellbauer, J. 1980. An Almost Ideal Demand System. American Economic Review 70 (3), 312–326.

Delipalla, S. & Keen, M. 1992. The comparison between ad valorem and specific taxation under imperfect competition. Journal of Public Economics 49 (3), 351–367.

Doyle Jr., J. J. & Samphantharak, K. 2008. $2.00 Gas! Studying the effects of a gas tax moratorium. Journal of Public Economics 92, 869–884.

European Environmental Agency. 2017. Transport fuel prices and taxes. [online]. Available at: http://www.eea.europa.eu/data-and-maps/indicators/fuel-prices-and-taxes/assessment-6. [Accessed 13 November 2017].

Friedman, M. 1957. A Theory of the Consumption Function. Princeton: Princeton University Press.

Fullerton, D. & Metcalf, G. E. 2002. Tax Incidence. In A. J. Auerbach & M. Feldstein (eds.) Handbook of Public Economics, Vol. 4. Amsterdam: Elsevier Science B.V., 1787–1872

Graham, D. & Glaister, S. 2002. The Demand for Automobile Fuel: A Survey of Elasticities. Journal of Transport Economics and Policy 36 (1), 1–25.

Graham, D. & Glaister, S. 2004. Road Traffic Demand Elasticity Estimates: A Review. Transport Reviews 24 (3), 261–274.

Hamilton, S. F. 2009. Excise Taxes with Multiproduct Transactions. American Economic Review 99 (1), 458–471.

Harju, J., Kosonen, T. & Laukkanen, M. 2017. Tax incidence in the fuel market: Evidence from station-level data. Mimeo.

Hassett, K. A., Mathur, A. & Metcalf, G. E. 2009. The Incidence of a U.S. Carbon Tax: A Lifetime and Regional Analysis. Energy Journal 30 (2), 155–177.

Hausman, J. A. 1981. Exact Consumer's Surplus and Deadweight Loss. American Economic Review 71 (4), 662–676.

Helminen, V., Nurmio, K., Rehunen, A., Ristimäki, M., Oinonen, K., Tiitu, M., Kotavaara, O., Antikainen, H. & Rusanen, J. 2014. Kaupunki-maaseutualueluokitus. Suomen ympäristökeskuksen raportteja 25/2014.

Hicks, J. R. 1939. Value and Capital: An Inquiry into Some Fundamental Principles of Economic Theory. 1st ed. Oxford: Oxford University Press.

Hughes, J. E., Knittel, C. R. & Sperling, D. 2008. Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand. Energy Journal 29 (1), 93–114.

Kayser, H. A. 2000. Gasoline Demand and Car Choice: Estimating Gasoline Demand Using Household Information. Energy Economics 22 (3), 331–348.

Klemperer, P. D. & Meyer, M. A. 1989. Supply Function Equilibria in Oligopoly under Uncertainty. Econometrica 57 (6), 1243–1277.

Kopczuk, W., Marion, J., Muehlegger, E. & Slemrod, J. 2016. Does Tax-Collection Invariance Hold? Evasion and the Pass-Through of State Diesel Taxes. American Economic Journal: Economic Policy 8 (2), 251–286.

Lerner, A. P. 1934. The Concept of Monopoly and the Measurement of Monopoly Power. Review of Economic Studies 1 (3), 157–175.

Li, S., Linn, J. & Muehlegger, E. 2014. Gasoline Taxes and Consumer Behavior. American Economic Journal: Economic Policy 6 (4), 302–342.

Mannering, F. & Winston, C. 1985. A Dynamic Empirical Analysis of Household Vehicle Ownership and Utilization. RAND Journal of Economics 16 (2), 215–36.

Marion, J. & Muehlegger, E. 2011. Fuel tax incidence and supply conditions. Journal of Public Economics 95, 1202–1212.

Marshall, A. 1890. Principles of Economics. Vol. 1. London: Macmillan & Co.

Nash, C. 2003. UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Final Report for Publication. University of Leeds. Institute for Transport Studies. Leeds.

Nicholson, W. & Snyder, C. 2012. Microeconomic Theory: Basic Principles and Extensions. 11th ed. Cengage Learning.

Parry, I. W. H., Walls, M. & Harrington, W. 2007. Automobile Externalities and Policies. Journal of Economic Literature 45 (2), 373–399.

Roodman, D., MacKinnon, J. G., Ørregaard Nielsen, M. & Webb, M. D. 2018. Fast and Wild: Bootstrap Inference in Stata using boottest. Working Paper No. 1406. Queen's University, Department of Economics.

Poterba, J. M. 1989. Lifetime Incidence and the Distributional Burden of Excise Taxes. American Economic Review: Papers and Proceedings 79 (2), 325–330.

Poterba, J. M. 1991. Is the Gasoline Tax Regressive? Tax Policy and the Economy 5, 145–164.

Puhani, P. A. 2012. The treatment effect, the cross difference, and the interaction term in nonlinear ''difference-in-differences'' models. Economics Letters 115 (1), 85–87.

Santos, G. & Catchesides, T. 2005. Distributional Consequences of Gasoline Taxation in the UK. Transportation Research Record 1924, 103–111.

Ščasný, M. 2012. Who pays taxes on fuels and public transport services in the Czech Republic? Ex post and ex ante measurement. In T. Sterner (ed.) Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy. New York: RFF Press, 269–298.

Seade, J. 1985. Profitable Cost Increases and the Shifting of Taxation: Equilibrium Response of Markets in Oligopoly. The Warwick Economics Research Paper Series 260.

Stern, N. 1987. The Effects of Taxation, Price Control and Government Contracts in Oligopoly and Monopolistic Competition. Journal of Public Economics 32 (2), 133–158.

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

Sterner, T. 2012. Distributional effects of taxing transport fuel. Energy Policy 41, 75–83.

Sterner, T., Cao, J., Carlsson, E. & Robinson, E. 2012. Conclusions. In T. Sterner (ed.) Fuel Taxes and the Poor: The Distributional Effects of Gasoline Taxation and Their Implications for Climate Policy. New York: RFF Press, 309–332.

Stolper, S. 2016a. Competition and Incidence: Automotive Fuel Tax Pass-Through at State Borders. Working Paper.

Stolper, S. 2016b. Who Bears the Burden of Energy Taxes? The Role of Local Pass-Through. Working Paper.

Suits, D. B. 1977. Measurement of Tax Progressivity. American Economic Review 67 (4), 747–752.

Tiezzi, S. & Verde, S. F. 2016. Differential demand response to gasoline taxes and gasoline prices in the U.S. Resource and Energy Economics 44, 71–91.

Tuuli, J. 2009. Polttoaineveron ja muiden ympäristöverojen tulonjakovaikutukset. Valtion taloudellinen tutkimuskeskus. VATT Muistiot 6.

Wadud, Z., Graham, D. J. & Noland, R. B. 2009. Modelling fuel demand for different socio-economic groups. Applied Energy 86, 2740–2749.

West, S. E. 2004. Distributional effects of alternative vehicle pollution control policies. Journal of Public Economics 88, 735–757.

West, S. E. & Williams III, R. C. 2004. Estimates from a Consumer Demand System: Implications for the Incidence of Environmental Taxes. Journal of Environmental Economics and Management 47 (3), 535–558.

Weyl, E. G. & Fabinger, M. 2013. Pass-Through as an Economic Tool: Principles of Incidence under Imperfect Competition. Journal of Political Economy 121 (3), 528–583.

Willig, R. D. 1976. Consumer's Surplus Without Apology. American Economic Review 66 (4), 589–597.

Yatchew, A. & No, J. A. 2001. Household Gasoline Demand in Canada. Econometrica 69 (6), 1697–1709.

APPENDIX

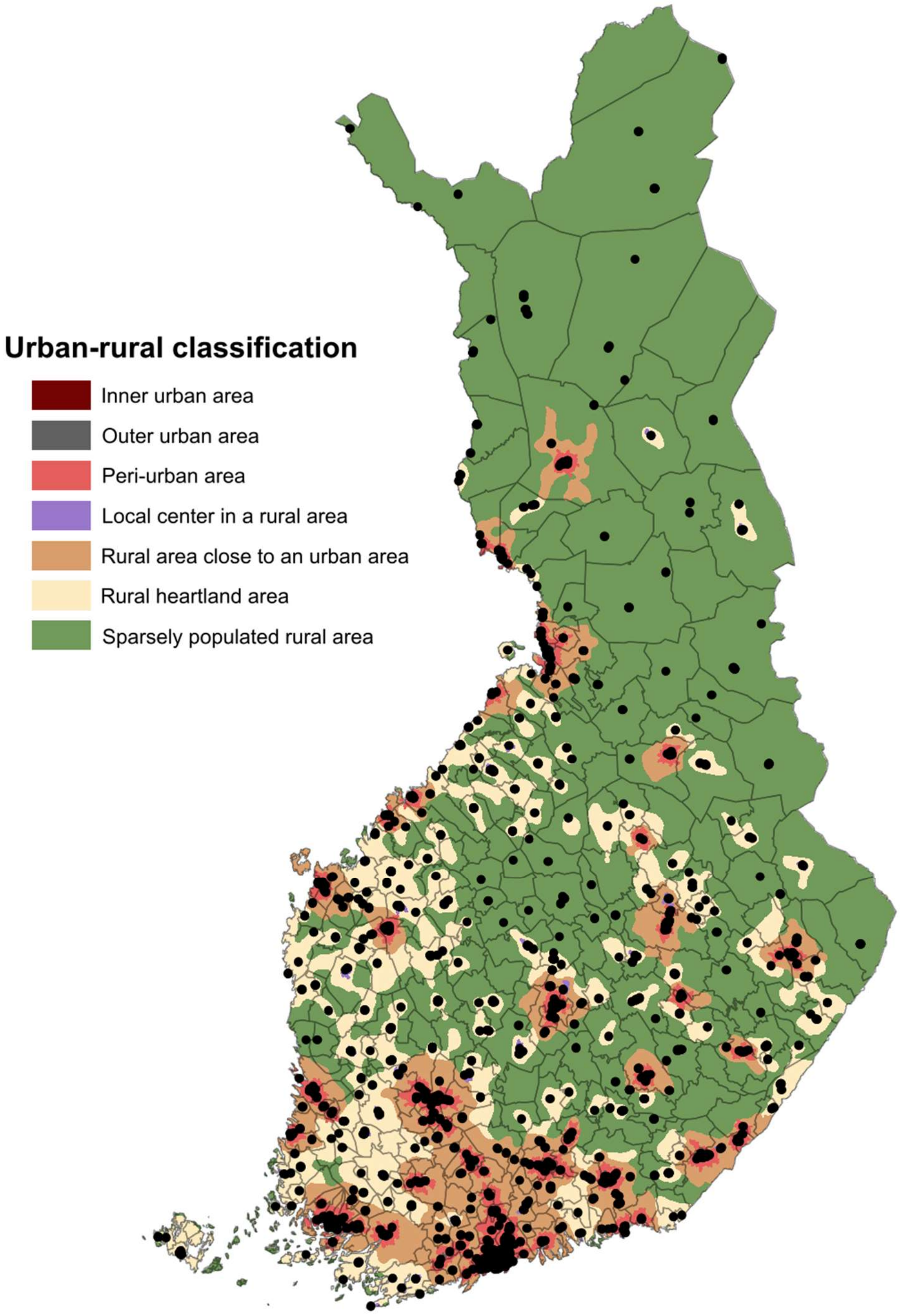

Figure A1 Filling stations in the sample between 2011 and 2012

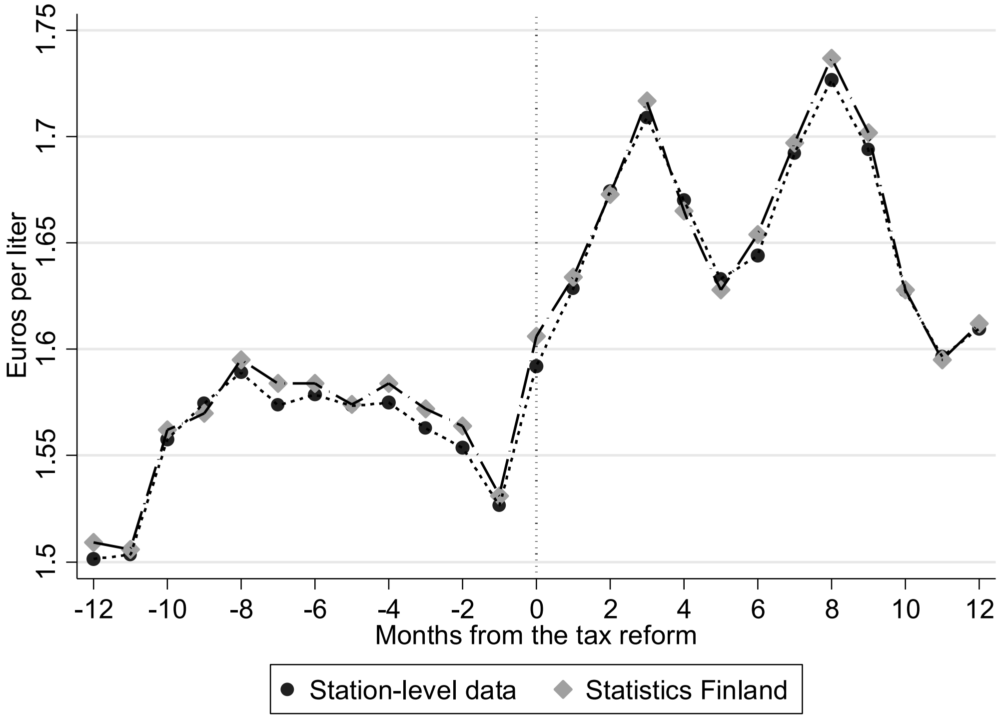

Figure A2 Comparison of monthly average gasoline prices

Table A1 Pass-through results with clustering on station chains

	Income		House prices		Population density		Urban-rural class	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
D	-0.199***	-0.224***	-0.200**	-0.225***	-0.200***	-0.224***	-0.198***	-0.221**
	[0.001]	[<0.001]	[0.003]	[0.001]	[<0.001]	[<0.001]	[0.001]	[0.002]
A	0.108**	0.084*	0.106**	0.078***	0.109**	0.084***	0.110**	0.086**
	[0.009]	[0.015]	[0.004]	[<0.001]	[0.006]	[0.001]	[0.007]	[0.007]
D×A	0.082**	0.083***	0.084**	0.086*	0.082**	0.083**	0.083**	0.083**
	[0.004]	[0.001]	[0.004]	[0.023]	[0.003]	[0.003]	[0.003]	[0.003]
D×A×G 2	-0.003	-0.002	-0.006	-0.007	0.001	-0.001	-0.004	-0.003
	[0.750]	[0.787]	[0.301]	[0.220]	[0.813]	[0.837]	[0.464]	[0.576]
D×A×G 3	-0.006	-0.006	-0.008	-0.008	-0.003	-0.006	-0.006	-0.008
	[0.509]	[0.509]	[0.454]	[0.498]	[0.399]	[0.180]	[0.158]	[0.138]
D×A×G 4	-0.009	-0.006	-0.012	-0.011	-0.006	-0.007	-0.004	-0.005
	[0.159]	[0.251]	[0.280]	[0.221]	[0.183]	[0.143]	[0.474]	[0.235]
D×A×G 5	-0.007	-0.009	-0.009	-0.009	-0.006	-0.006	-0.013	-0.012
	[0.553]	[0.222]	[0.072]	[0.125]	[0.297]	[0.279]	[0.086]	[0.099]
D×A×G 6	-0.012*	-0.012*	-0.014*	-0.015*	-0.012*	-0.012*	-0.012	-0.011
	[0.034]	[0.020]	[0.013]	[0.012]	[0.011]	[0.013]	[0.095]	[0.111]
D×A×G 7	-0.013***	-0.014***	-0.017*	-0.019*	-0.012	-0.013*	-0.014	-0.013*
	[<0.001]	[<0.001]	[0.015]	[0.016]	[0.089]	[0.035]	[0.076]	[0.045]
Constant	1.564***	1.383***	1.568**	1.385***	1.576***	1.385***	1.575***	1.385***
	[<0.001]	[0.001]	[0.003]	[0.001]	[<0.001]	[0.001]	[<0.001]	[0.001]
Controls	No	Yes	No	Yes	No	Yes	No	Yes
N	219,034	219,034	196,552	196,552	219,034	219,034	218,993	218,993
R^2	0.81	0.88	0.81	0.87	0.81	0.88	0.81	0.87

The dependent variable is fuel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. All the eight model specifications use the whole two-year period between 2011–2012. Standard errors are clustered on station chains using the wild bootstrap method. The p-values of the estimated coefficients are in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

Table A2 Diesel price change results with clustering on station chains

Septile/	Income		House Prices		Population density		Urban-rural class	
class	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2	-0.015	-0.015	-0.009	-0.006	-0.004	-0.006	-0.009	-0.010
	[0.084]	[0.100]	[0.334]	[0.635]	[0.709]	[0.523]	[0.317]	[0.175]
3	-0.007	-0.009	-0.006	-0.005	-0.001	-0.002	-0.007	-0.009
	[0.263]	[0.239]	[0.590]	[0.864]	[0.886]	[0.840]	[0.453]	[0.283]
4	-0.017*	-0.017	-0.016	-0.015	-0.014	-0.013	-0.015*	-0.013*
	[0.034]	[0.051]	[0.177]	[0.093]	[0.057]	[0.089]	[0.016]	[0.039]
5	-0.010	-0.014**	-0.014***	-0.013*	-0.012	-0.014*	-0.020**	-0.019**
	[0.059]	[0.002]	[0.001]	[0.047]	[0.099]	[0.036]	[0.003]	[0.004]
6	-0.016**	-0.016**	-0.017*	-0.015*	-0.015	-0.016*	-0.018*	-0.019*
	[0.008]	[0.008]	[0.017]	[0.026]	[0.057]	[0.047]	[0.014]	[0.014]
7	-0.016**	-0.017***	-0.019*	-0.017***	-0.020**	-0.021**	-0.021**	-0.022**
	[0.002]	[0.001]	[0.034]	[0.001]	[0.009]	[0.005]	[0.002]	[0.004]
Controls	No	Yes	No	Yes	No	Yes	No	Yes
N	110,762	110,762	98,871	98,871	110,762	110,762	110,739	110,739
R	0.77	0.85	0.78	0.85	0.77	0.85	0.77	0.85

The dependent variable is diesel price in euros per liter. The controls include the daily prices of Brent crude oil and EU ETS CO_2, the EUR/USD rate, dummies for winter diesel, self-service stations and station chains. All the eight model specifications use the whole two-year period between 2011–2012. Standard errors are clustered on station chains using the wild bootstrap method. The p-values of the estimated coefficients are in brackets. *, ** and *** denote significance at the 5%, 1% and 0.1% level respectively.

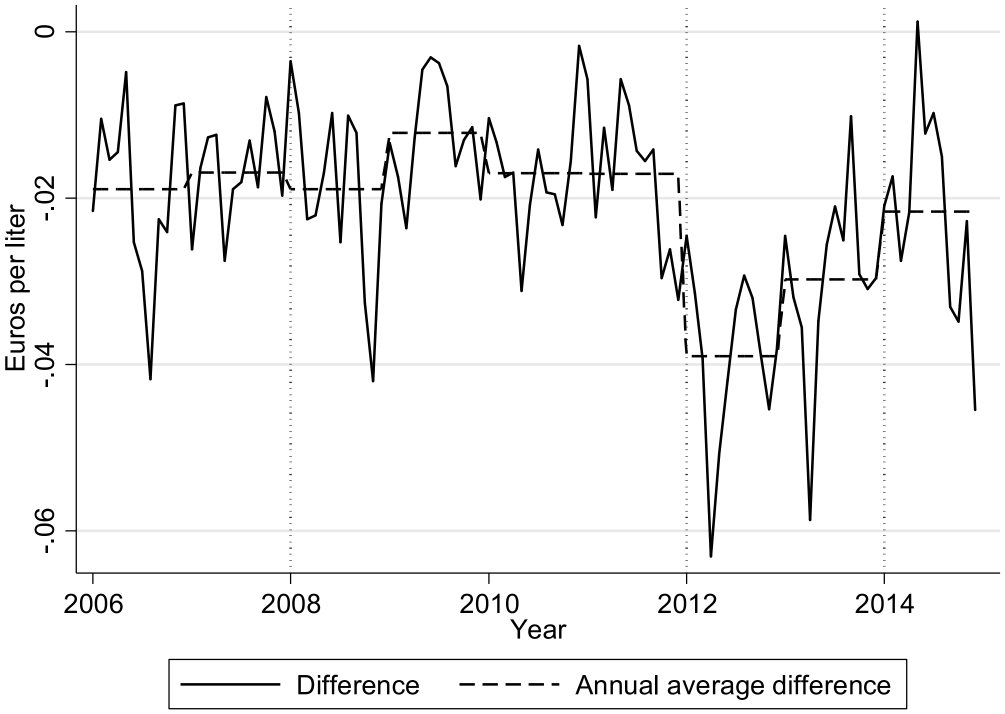

Figure A3 Diesel price difference between the 7th and 1st urban-rural classes