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Manuel Frondel, Patrick Thiel, and Colin Vance*

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Abstract

Exploiting exogenous variation in retail fuel prices from a temporary fuel tax discount in Germany, we estimate how the pass-through of the discount varies over space and time. We draw on daily gasoline prices of virtually all gas stations in Germany and neighboring France, with France serving as a control, and estimate an event study model covering the full period of the discount from June to August 2022. We find average pass-through rates on the order of 87% for diesel and 71% for petrol, but with substantially lower rates in high-income regions and in regions with a low degree of competition. More strikingly, our results suggest pronounced heterogeneity over time: The magnitude of the pass-through rate dissipates sharply over the three months in which the discount was in effect, dropping to 50% by the final month, a pattern consistent with retailer responses to short-term changes in consumer attention. Taken together, our results indicate that average pass-through estimates may obscure a high degree of spatial and temporal heterogeneity that bears upon the assessment of competition and distributional effects: While our estimation of the budgetary costs of the discount confirms the government's a priori estimate of €3.1 billion, we find that about 61% of the discount's financial relief accrues to households with above-median incomes.

JEL-Codes: L13, L81, D43

Keywords: Competition; demand elasticity; fuel tax discount; gasoline market

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1 Introduction

The high visibility of gasoline prices makes motorists keenly aware when cost shocks reach the pump, often compelling policymakers to respond by reducing fuel taxes. Such was the context in Germany, as well as in many other countries, after the Russian attack on Ukraine in 2022, when fuel prices rose sharply to reach record levels of well over €2 per liter.

In response, the German government passed legislation to reduce the energy tax on fossil fuels – the Fuel Tax Discount (FTD) – for a period of three months, from June 1 to August 31, 2022. In this period, the energy tax on diesel of 47.04 Cents per liter was reduced to 33.0 Cents, the minimum tax rate required by the European Commission, and for petrol from 65.45 to 35.9 Cents per liter. Accounting for the value-added tax (VAT) of 19%, which is also raised on energy taxes, the overall discounts amounted to 35.16 Cents per liter for petrol and 16.71 Cents for diesel. The intent of the discount was to provide financial relief to motorists, the presumption being that retail filling stations would fully pass through the discount to consumers. Whether such "full shifting" in fact transpires is a fundamental question of public economics, one whose relevance extends to concerns about price dispersion, distributional implications, competition policy, and market power.

The present study takes up this question. Drawing on a panel of station-level data from Germany and France, with France serving as a control site, we explore the sources of heterogeneity in pass-through over space and time both for petrol and diesel fuel. Germany offers a particularly interesting setting for addressing this issue because of a longstanding public perception that, quoting a widely read newspaper, "competition on the fuel market does not function particularly well" (Süddeutsche Zeitung, 2022). This widely prevalent and persistent perception led Germany's Federal Cartel Office to undertake a study of price setting in 2011, which concluded that a handful of companies exercise market-dominating influence as oligopolists, leading to higher fuel prices than would otherwise prevail under perfect competition (Bundeskartellamt, 2011). A subsequent report by the International Energy Agency contradicts this assessment, concluding that "Germany has a largely deregulated and competitive oil market" with "a large number of independents in the refining and retail sectors" (IEA, 2012, p. 8).

Constituting an unanticipated and exogenous change to the fuel price, the introduction of the temporary tax discount, which was passed by the government a mere 10 days before going into effect on June 1, affords the opportunity to scrutinize these opposing perspectives by studying how retailers pass on the discount to consumers. Economic theory predicts that under perfect competition, the pass-through rate will vary between zero and one, depending on the elasticities of supply and demand. With perfectly elastic supply and downward-sloping demand, the rate will equal one, implying that the full discount from a tax reduction is passed through to consumers. Recent analyses that examine the first two weeks during which the discount was in effect suggest that the pass-through rate was indeed close to one (Fuest et al., 2022; Schmerer & Hansen, 2023), corroborating earlier studies that find near full shifting in the US market (Chouinard & Perloff, 2004, 2007; Li et al., 2014; Marion & Muehlegger, 2011).

Other scholarship has pointed to the possibility of differential pass-through rates according to differences in local market structure (Fuest et al., 2024). Theoretical analysis shows that competition is a particularly important determinant of pass-through, one whose influence depends fundamentally on the convexity of demand. Presuming that demand is not too convex, the pass-through rate increases with increases in competition, while it decreases when demand is highly convex (Weyl & Fabinger, 2013). The upshot is that imperfect competition renders a large range of possible pass-through rates, including values that fall below zero (Alexandrov, 2014; Gayle & Lin, 2021) or that exceed one (Barzel, 1976; Kenkel, 2005; Pless & van Benthem, 2019).

A challenge facing empirical investigations is that the convexity of demand is typically unknown. Nevertheless, several studies have found that, consistent with linear (or not too convex) demand, pass-through increases with competition. For instance, Doyle and Samphantharak's (2008) analysis of a gasoline tax moratorium in the US-Midwest reveals pass-through rates ranging from 70 to 100%, with less than full shifting occurring where market concentration is lower. This result aligns with Alm et al. (2009) and Byrne (2019), who find lower pass-through rates in rural areas of the US, where less competition is expected to prevail. More recently, Genakos and Pagliero (2022) examine a tax change on petroleum products among isolated markets on Greek islands, allowing them to pinpoint how pass-through varies with changes in the number of competitors. These authors obtain estimates ranging from 40% in markets with a single retailer to 100% in markets with four or more competitors. Dissenting evidence is presented by Harju et al. (2022) in their study of a carbon tax among gas stations in Finland: they find that pass-through is lower among stations that face the highest degree of competition.

Drawing on both difference-in-differences and event study approaches, this paper's overarching contribution is to consider both the supply- and demand-side channels through which a tax discount is passed through to retail gas prices, recognizing that each channel is relevant to the question of competition. Three features distinguish our analysis: First, we allow for differential pass-through rates according to regional income levels, measured as purchasing power, a thus far largely unexplored source of heterogeneity. To the extent that income moderates the demand elasticity for fuel (Kayser, 2000; Wadud et al., 2010), it is a potentially important determinant of pass-through, with implications for both incidence and distributional effects among consumer groups, as well as for the budgetary effects of fuel taxation. In one of the few papers to analyze this issue, Harju et al. (2022) find lower pass-through of a carbon tax in high-income areas of Finland, from which they conclude that ignoring pass-through heterogeneity leads to an underestimation of the regressivity of the tax.

Second, we account for differences in regional competition using a novel measure based on the spatial concentration of retail fuel outlets and registered vehicles, thereby combining both the demand and supply side of the market. Many previous studies measure competition by focusing exclusively on the supply side, using the count of stations in a region or, as in Alm et al. (2009) and Doyle and Samphantharak (2008), by geographical designations that are correlated with station density, such as urban versus rural. Our measure instead normalizes the count of stations through division by the count of regionally registered cars. The denominator of the resulting ratio thereby allows for the possibility that two stations with the same number of competitors face different levels of demand and, hence, a different degree of competition.

Third, we augment our analysis with a model of price responsiveness for both petrol and diesel fuel using household data from the German Mobility Panel (MOP, 2023). By revealing the extent of demand convexity, these estimates allow us to sign the expected effect of differences in competition on the pass-through rate. The estimates also serve to anticipate differences in pass-through across fuel types.

Among our key results, we find that the average pass-through rates of 86% for petrol and 96% for diesel estimated using a difference-in-differences model obscure extensive heterogeneity. Allowing for differential effects over space reveals pass-through rates that range from about 50 to 150%, thereby reproducing the pattern of heterogeneity discovered by Genakos and Pagliero (2022) for Greek islands. Like those authors, we find that highly competitive regions have higher pass-through rates, which is consistent with the quasi-linear demand identified from the household model of driving behaviour using the mobility data. Income levels also appear to play a role in the pattern of spatial differentiation, with regions of lower purchasing power having higher pass-through rates, corroborating Harju et al.'s (2022) results from Finland.

Perhaps the most striking finding is the temporal heterogeneity revealed through the event study approach. Although the discount is passed on in full by the first day, its magnitude begins to dissipate rapidly roughly 30 days after its introduction, dropping to 50% by the final month, thereby heavily undermining the political endeavor of mitigating consumers' burden due to energy price shocks. We interpret this pattern through the lens of consumer search theory, positing that it reflects retailer responses to changes in consumer attention. The overall picture is thus one of pronounced heterogeneity over space and time, with a sizeable share of the population facing substantially less than full pass-through for much of the period.

The following section discusses how the pass-through rate of tax changes is determined theoretically, highlighting the role of competition and the impact of demand. Section 3 describes our data sources and the empirical strategy that we use to estimate pass-through rates. Section 4 presents results from a baseline difference-in-differences estimator and draws comparisons with existing evidence from the literature, followed by the presentation of a more flexible model in Section 5 that reveals heterogeneity over space. Temporal heterogeneity is explored in Section 6 with the estimation of event study models, which also includes robustness checks of the parallel trends assumption using the "honest DiD" framework of Rambachan and Roth (2023). Section 7 estimates the budgetary costs of the tax discount and addresses the question of its distributional impact. The last section summarizes and concludes.

2 Theoretical Background

The pass-through rate of a tax discount is defined as the ratio of the change in price p due to the tax discount t (see e.g. Weyl and Fabinger (2013)):

$$\rho := -\frac{dp}{dt}. \tag{1}$$

Under perfect competition, pass-through depends exclusively on the elasticities of demand and supply, ϵ_D and ϵ_S:[1]

$$\rho = \frac{1}{1 + \frac{\epsilon_D}{\epsilon_S}}, \tag{2}$$

[1]Perceiving the tax discount as a subsidy, to derive formula (2), we start with the equilibrium condition $D(p) = S(p + s)$ and differentiate this condition with respect to subsidy s, we get :

$$D' \cdot dp/ds = S' \cdot (dp/ds + 1),$$

where $D' := dD(p)/dp$ and $S' := dS(p + s)/dp$ and hence:

$$\rho = -dp/ds = \frac{S'}{S' - D'} = \frac{\epsilon_S}{\epsilon_S + \epsilon_D}.$$

where $\epsilon_D := -p/q \cdot dD(p)/dp$, $\epsilon_S := p/q \cdot dS(p)/dp$, and $D(p)$ and $S(p)$ denote demand and supply, respectively. Complete pass-through of the tax discount occurs when demand is perfectly inelastic, while zero pass-through occurs when demand is perfectly elastic. In other words, the more inelastic side of the market benefits disproportionately from a tax discount (or subsidy), whereas it bears disproportionately the burden of a tax.

To accommodate the possibility of imperfect competition, Weyl and Fabinger (2013) derive the following formula for pass-through rate ρ:

$$\rho = \frac{1}{1 + \frac{\theta}{\epsilon_\theta} + \frac{\epsilon_D - \theta}{\epsilon_S} + \frac{\theta}{\epsilon_{ms}}}, \tag{3}$$

where θ, the conduct parameter, is an indicator of competition and is defined as:

$$\theta := \frac{p - mc}{p}\epsilon_D, \tag{4}$$

with mc designating marginal costs. When θ equals zero, corresponding to perfect competition, formula (3) collapses to formula (2), whereas $\theta = 1$ indicates the polar case of pure monopoly.[2] The inverse elasticity of conduct parameter θ is defined by $1/\epsilon_\theta := q/\theta \cdot d\theta/dq$, while $1/\epsilon_{ms} := dms/dq \cdot q/ms$ is the inverse elasticity of the marginal consumer surplus, $ms := -qp' = -q \cdot dp/dq$. Parameter ϵ_{ms} determines the curvature of the logarithm of demand (Weyl & Fabinger, 2013).[3]

[2] Note that the definition of parameter θ is due to the normalization of Lerner's rule, which states that the extent of the markup $p - mc$ depends on the elasticity of demand: $L := \frac{p-mc}{p} = 1/\epsilon_D$. While oligopolists and monopolists charge $p > mc$, so that the Lerner index is $L > 0$, firms in a perfectly competitive market charge $p = mc$, and, hence, $L = 0$, indicating that such a firm has no market power. By multiplying Lerner index L by demand elasticity ϵ_D, the resulting parameter θ is normalized: $0 \leq \theta \leq 1$, like the Lerner index L, which ranges from 0 to 1, as well.

[3] ϵ_{ms} is associated with the curvature of the logarithm of demand, because $(\log D)' = \frac{d \log D}{dp} = \frac{D'}{D} = \frac{1}{qp'} = -\frac{1}{ms}$, where $D = q$ and $D' = dD/dp = 1/(dp/dq) = 1/p'$ due to the derivative of the inverse function $D = (p(q))^{-1}$. The curvature of the logarithm of demand, given by the second derivative, then reads:

$$(\log D)'' = \frac{d}{dp}(-\frac{1}{ms}) = \frac{1}{ms^2}(\frac{d}{dq}ms) \cdot \frac{dq}{dp} = \frac{ms'}{ms^2} \cdot 1/p' = -\frac{1}{\epsilon_{ms}} \cdot \frac{1}{ms}(-\frac{1}{p'q}) = -\frac{1}{\epsilon_{ms}} \cdot \frac{1}{ms^2}.$$

Hence, the curvature crucially depends on ϵ_{ms}: $1/\epsilon_{ms} < 0$ always implies log-convex demand; log-concave demand always has $1/\epsilon_{ms} > 0$.

Empiricists typically make simplifying assumptions in estimating pass-through, one of which is that the competition parameter θ is invariant to changes in q, as is the case under Cournot competition, implying that $1/\epsilon_\theta = 0$. We correspondingly assume that θ is invariant to tax changes, that is, that the intensity of competition remains unaltered, an assumption that seems reasonable given that we do not expect entry or exit of stations owing to the short-term and unexpected introduction of the tax discount. A second typically invoked assumption is constant marginal costs, which implies that ϵ_S is infinite. This assumption likewise seems reasonable over the short-run interval of the tax discount of three months. With these two assumptions, the terms $\frac{\theta}{\epsilon_\theta}$ and $\frac{\epsilon_D - \theta}{\epsilon_S}$ vanish from formula (3), resulting in:

$$\rho = \frac{1}{1 + \frac{\theta}{\epsilon_{ms}}}. \tag{5}$$

A third, but more difficult to justify, assumption is that demand is linear, implying that $\epsilon_{ms} = 1$.[4] When met, this assumption implies that the pass-through rate ρ equals $1/(1+\theta)$, meaning that ρ increases with decreases in θ, that is, with competition. Violations of the linear-demand assumption, however, open the door to alternative outcomes: When demand is sufficiently convex, a case investigated by Pless and van Benthem (2019), increases in competition *reduce* pass-through, and also allow the rate to exceed one. Consequently, the estimation of demand curvature that complements our analysis of pass-through frees us from the third assumption. Specifically, we fail to reject quasi-linear demand based on a model of mobility behavior using household data, supporting the hypothesis of a positive relationship between the degree of competition and the pass-through rate.

[4] Assume a linear demand function of the form $p(q) = a \cdot q + b$ with $a < 0$, then $p'(q) = a$ and marginal consumer surplus becomes $ms = -p' \cdot q = -a \cdot q$, so that $ms' := dms/dq = -a$. Hence, $\epsilon_{ms} := ms/(q \cdot ms') = -a \cdot q/(-a \cdot q) = 1$.

3 Data and Empirical Strategy

Data on fuel prices from Germany is drawn from an online portal referred to as the Market Transparency Unit for Fuels (MTU), established in 2013 under legislation requiring that retail fuel stations in Germany continually post prices for diesel and petrol when prices are changed. The MTU additionally records sundry station characteristics, such as the station's geographical coordinates, brand name, and opening hours. We retrieved this data from a repository that hosts all station-level data since the MTU's initiation – see the website creativecommons.tankerkoenig.de, where the data are offered for scientific purposes.

Our estimation strategy relies on neighboring France as a control group, which likewise maintains an online portal, Le Prix des Carburants, from which we retrieved prices for diesel and petrol, as well as the station coordinates. Upon appending these two sources, our data set contains information on 15,188 gas stations from Germany and 9,154 gas stations from France, effectively covering the entire market in each country. Considering the five-month daily coverage from April through August in our estimation sample, we are left with about 2.2 million observations from Germany and 640,000 observations from France.[5]

Our analysis of heterogeneity in the pass-through rate is facilitated by merging the fuel price data with data of RWI-GEO-GRID, a repository of socioeconomic variables covering all of Germany on a one-square-kilometer grid – see the comprehensive description of RWI-GEO-GRID by Breidenbach and Eilers (2018). Two variables are drawn from this source and aggregated to the level of a municipality: the number of registered motor vehicles and the annual purchasing power per person.[6] To construct the measure of competition, we divide the number of fuel stations in a municipality by the number of registered vehicles. Figure B1 and Figure C1 in the appendix present cartographic depictions of this variable and of purchasing power, demonstrating pro-

[5]The lower number of observations for France is not only due to the lower number of stations, but also by the lower frequency of price changes.

[6]There are about 11,000 municipalities in Germany, having an average size of 32 square kilometers.

nounced spatial heterogeneity in both measures.

To investigate the pass-through of the German fuel tax discount, we begin with a difference-in-differences (DiD) approach incorporating two-way fixed effects:

$$p_{it} = \beta \cdot FTD_t \times GER_i + \gamma_i + \tau_t + \epsilon_{it}, \tag{6}$$

where p_{it} designates the price of station i on day t, γ_i denote station-fixed effects, τ_t time-fixed effects at the daily level, and ϵ_{it} is an idiosyncratic error term. *FTD* denotes a dummy variable indicating the three-month period from June through August, 2022 in which the Fuel Tax Discount is in effect. *GER* is a dummy variable indicating stations in Germany, the base case being stations in France.

Two versions of the DiD approach are estimated, one in which p stands for prices for diesel and one in which it measures prices for E10, a petrol variant with a 10% share of ethanol. In 2022, of the roughly 48.5 million cars that were registered in Germany, about 31 million were petrol cars and about 14.8 million diesel cars (see Federal Ministry for Digital and Transport, 2022).

The parameter of interest is the coefficient β of the interaction term $FTD \times GER$, whose estimate, $\hat{\beta}$, gives the average treatment effect on the treated. With this estimate and Definition 1 of pass-through, $\rho = -\frac{dp}{dt}$, the pass-through rate $\hat{\rho}$ is given by:

$$\hat{\rho} = -\frac{\hat{\beta}}{FTD}, \tag{7}$$

where FTD either equals 35.16 Cents in case of E10 or 16.71 Cents for Diesel (see G1 in the appendix).

To allow for differential pass-through rates over the observation period, we estimate an event study specification:

$$p_{it} = \sum_{t=1}^{T} \beta \cdot Day_t \times GER_i + \gamma_i + \tau_t + \epsilon_{it} \ , \tag{8}$$

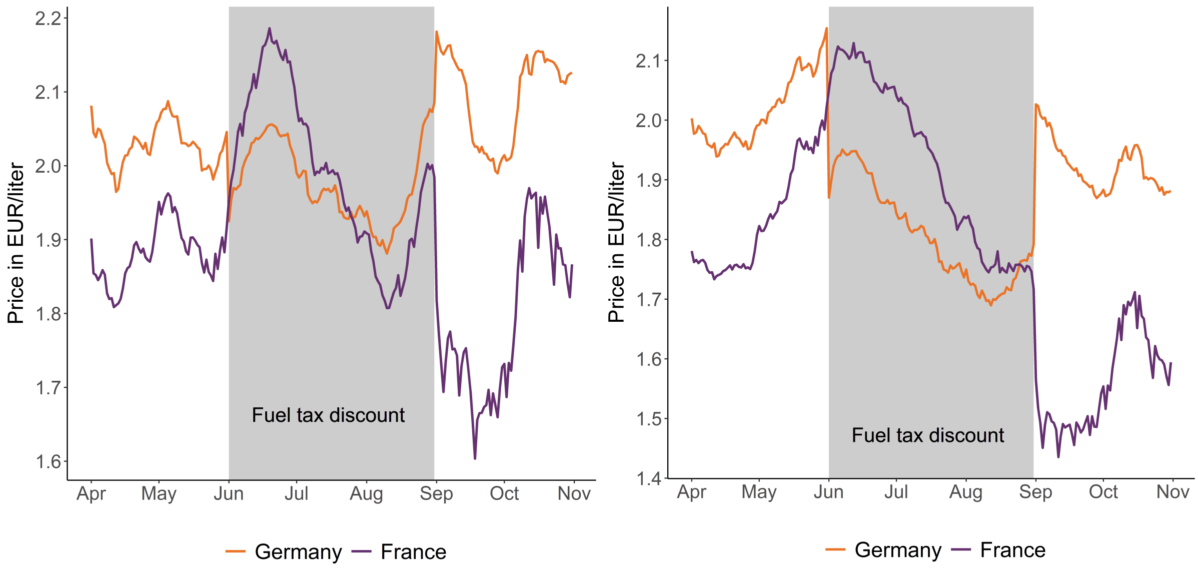
where the dummy variable for German stations is interacted with variable Day_t indicating day t, commencing on April 1. The reference day is May 31, the last day before the introduction of the tax discount, and T indicates the end of the time period during which the tax discount is in effect, spanning June through August, 2022. By allowing for dynamic treatment effects, the event study approach 8 facilitates insight into both the speed of adjustment to the discount and the persistency of its effect.

Moreover, the event study's resulting graphical summary of results can be used to visually scrutinize one of the key identification assumptions that underpins it, parallel trends: In the absence of treatment, the difference in the fuel prices between the treatment and control group is assumed to be constant over time. This assumption cannot be formally tested, but visual support can be gleaned by studying patterns before the event. Figure 1, which shows the evolution of daily prices of diesel and E10 for both countries from April to the end of November 2022, already provides the basis for a preliminary assessment. The gray area marks the treatment period from June through August 2022, when the German fuel tax discount was in effect. Prior to the introduction of the discount in June, when there is a shift in price levels, fuel prices in Germany are seen to be consistently higher than those in France, with the difference between the two series remaining relatively steady.[7] Whether the difference is sufficiently steady to justify parallel trends is open to interpretation, but a further opportunity to assess this will be provided by the event study estimates. Moreover, in a robustness exercise, we will provide more formal support by drawing on the "honest DiD" framework developed by Rambachan and Roth (2023) (see Appendix A).

Identification also requires a stable unit treatment value assumption (SUTVA), implying that the treatment solely exerts a direct effect on the unit being treated, thereby excluding general equilibrium effects and treatment externalities. France's long border with Germany and comparative economic conditions make it an appropriate control site, but also raise the concern that SUTVA could be violated. It is conceivable, for example, that French stations near the border lower their prices in an effort to prevent

[7] In Figure E1 in Appendix B, we also show that the French price evolution prior to treatment tracks closely with other European countries.

Figure 1: Average Daily Diesel and Petrol (E10) Prices in Germany and France, April – November 2022.



(a) Diesel

(b) Petrol (E10)

Notes: The gray area marks the period during which the German Fuel Tax Discount was in effect. Dashed lines indicate period averages.

”tank tourism,” reflected by their customers driving across the border to take advantage of the discount-induced cheaper fuel in Germany. To explore this possibility, we plotted the daily prices of French stations near the German border (see Figure D1 in the appendix), where such an incentive would presumably be strongest. We find that the price evolution of these stations does not differ substantially from the national level in France, thereby assuaging concerns about a spatial spillover of the FTD.

Beyond understanding the response of fuel stations to the introduction of the FTD, it would also be of interest to understand the response to its expiration. Figure 1 provides some insight, evidencing an abrupt increase in prices in Germany with the end of the FTD on September 1, mirrored by an abrupt decrease in prices in France. The latter change resulted from the increase of an existing rebate in France that was initially introduced in April, when fuel taxes for diesel and petrol were reduced by 30 cents. This reduction was increased by an additional 18 cents as of September. An analysis that more formally explores the reinstatement of the full tax in Germany is therefore precluded by the concurrence of tax policy shifts in the two countries at this time.

4 Estimation Results

Table 1 reports coefficient estimates from the estimation of Equation 6 on the basis of a difference-in-differences approach estimated using two different estimation samples: Following Fuest et al. (2022) and Schmerer and Hansen (2023), Columns 1 and 3 present estimates from a sample that extends two weeks following the introduction of the discount. In the present application, this is balanced by a sample that extends two weeks prior. We note that the samples of Fuest et al. (2022) and Schmerer and Hansen (2023) do not have this symmetry; the former study extends the pre-treatment period to six weeks while the latter extends it to one week. Columns 2 and 4 report estimates based on the entire three months of the FTD and the three months preceding it.

Table 1: Estimation Results on the Pass-through of the Fuel Tax Discount from Difference-in-Differences Approach 6

	Diesel				Petrol (E10)			
	Two Weeks		Three Months		Two Weeks		Three Months	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
FTD × GER	-0.195***	(0.000)	-0.161***	(0.000)	-0.313***	(0.001)	-0.303***	(0.001)
Pass-through rate (%)	116.4***	(0.003)	96.5***	(0.003)	89.1***	(0.002)	86.2***	(0.002)
Station fixed effects	✓		✓		✓		✓	
Time fixed effects	✓		✓		✓		✓	
# Observations	567,337		2,790,710		518,237		2,548,778	
R^2	0.895		0.778		0.937		0.912	

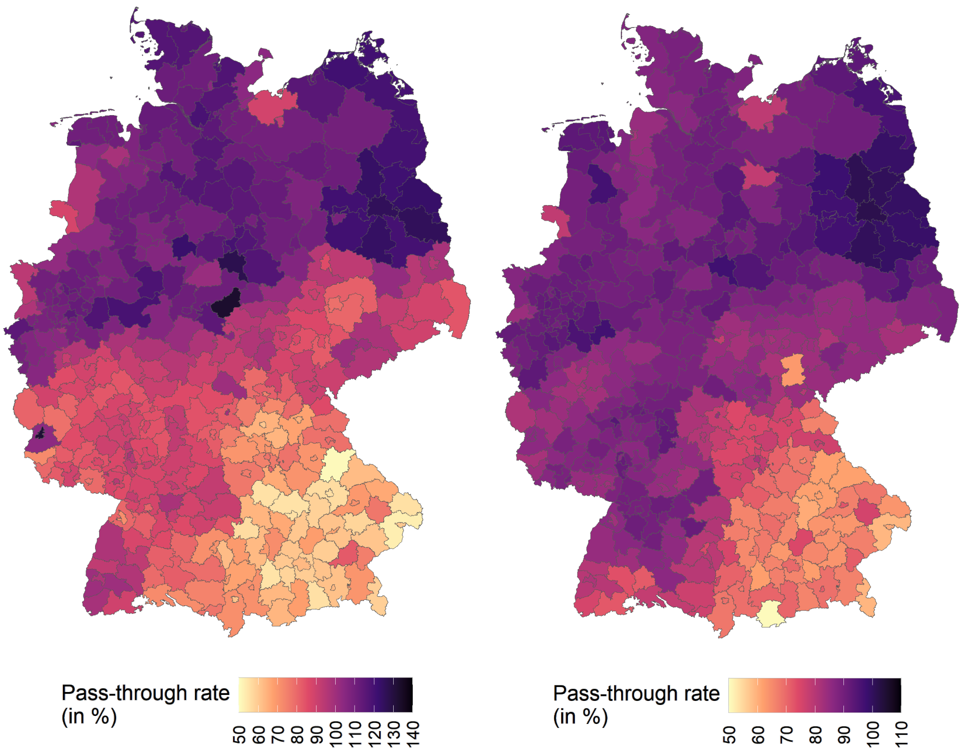
Note: Standard errors, clustered at the station-level, are in parentheses. ***, **, and * denote statistical significance at 1%, 5% and 10%.

For both diesel and petrol, we find that the samples including the full period of the FTD yield smaller effect sizes. In the case of diesel, the difference is substantial, with pass-through estimates ranging between 116.4% in Column 1 to 96.5% in Column 2. By way of comparison, the corresponding estimate of Fuest et al. (2022) is 102% while that of Schmerer and Hansen (2023) is 108%. We find more moderate differences in the pass-through estimates for petrol across the two samples, ranging between 89.1% and 86.2%, compared with 85% and 105% for Fuest et al. (2022) and Schmerer and Hansen

(2023), respectively.

To allow for heterogeneity over space, we estimate an expanded version of Equation 6 in which the term $FTD \times GER$ is interacted with dummy variables for each of Germany's 401 counties. The results of this exercise are plotted in Figure 2, which illustrates the estimates for each county. Two features stand out. First, the variation in pass-through rates is substantial, spanning a range of about 83 percentage points for diesel and 51 percentage points for E10. Second, a spatial clustering of pass-through rates for both fuel types is evident, evolving broadly along a north-south gradient. Particularly high pass-through values are seen in the Northeast, while particularly low values are seen in the Southeast.

Figure 2: Heterogenous Regional Pass-Through Rates of the Fuel Tax Discount



(a) Diesel

(b) Petrol (E10)

5 Spatial Heterogeneity

The question arises as to the mediating roles of supply and demand conditions in accounting for the above patterns. In particular, as is evident from Figure B1 and Figure C1, some degree of spatial clustering in the measures of competition and purchasing power is discernible, both of which are potential sources of differentials in the pass-through rates. High levels of competition prevail across large swaths in the north, while clusters of higher income are visible in the northwest and southeast. Although the patterns in Figure B1 and Figure C1 do not follow a clear north-south gradient, they do evidence pockets of distinctly varying socioeconomic conditions that could bear on both retail prices levels (Haucap et al., 2017) and pass-through.

With respect to the degree of local competition, theory would suggest that, conditional on linear fuel demand, areas characterized by higher competition would see higher pass-through rates. To pursue this hypothesis, we first assess the extent of linearity in demand by exploring fuel price responsiveness using panel data from the German Mobility Panel (MOP, 2023), a publicly available travel survey commissioned and financed by the German Federal Ministry of Transport and Digital Infrastructure since 1994.

We begin by replicating a model presented by Alberini et al. (2022). Using MOP data covering the period 2005 through 2019, they estimate a fixed-effects model of logged distance driven on the logged fuel price, allowing for a differential effect between petrol and diesel cars.[8] The estimates, presented in the first column of Table 2, indicate a fuel price elasticity of -0.37 for petrol cars and one essentially equal to zero for diesel cars. Expanding on the analysis of Alberini et al. (2022), Model 2 additionally includes the square of the logged fuel price to allow for curvature in the logarithm of demand. The estimates in this case are uniformly statistically insignificant. Models 3 and 4 measure the price and distance driven in levels rather than logs, where a similar pattern emerges. Specifically, Model 4 indicates no evidence for highly convex

[8]Distance is measured by odometer readings recorded by the households over a two-month interval for each of three years. Further details of the data and model are found in Alberini et al. (2022).

demand, supporting the hypothesis of increasing pass-through in the level of competition.

Table 2: Test for Convexity of Demand based on Data of the German Mobility Panel

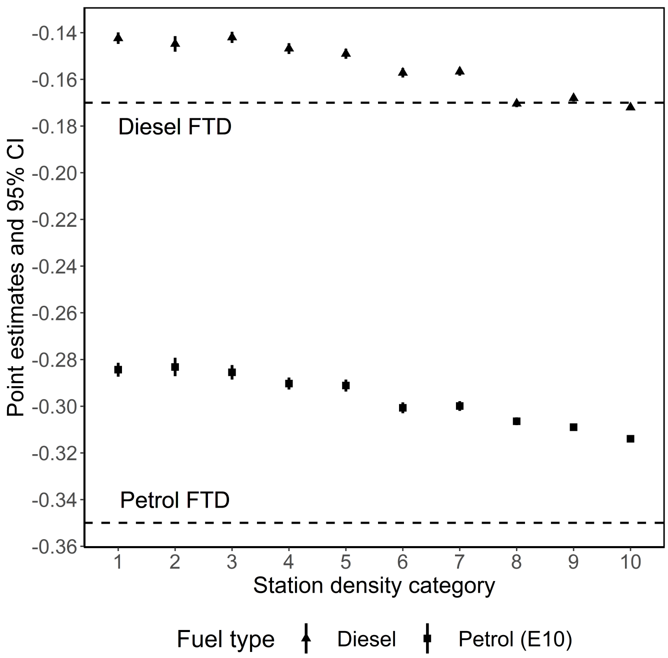
	logarithmic specification				linear specification			
	Model 1		Model 2		Model 3		Model 4	
	log(Monthly km driven)		log(Monthly km driven)		Monthly km driven		Monthly km driven	
	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error	Coeff.	Std. Error
log p	-0.371**	(0.180)	-0.202	(0.243)	–	–	–	–
$(\log p)^2$	–	–	-0.322	(0.386)	–	–	–	–
log p× diesel	0.386**	(0.179)	0.315	(0.193)	–	–	–	–
p	–	–	–	–	-265.489*	(137.166)	-553.623	(937.454)
p^2	–	–	–	–	–	–	102.184	(332.102)
$p \times$ diesel	–	–	–	–	393.416***	(148.383)	428.746**	(184.489)
Constant	6.704***	(0.132)	6.688***	(0.132)	1231.724***	(228.211)	1432.582**	(682.677)
# Observations	10,856		10,856		10,856		10,856	
R^2	0.729		0.729		0.717		0.717	

Note: Robust standard errors are in parentheses. ***, **, and * denote statistical significance at 1%, 5% and 10%.

Returning to the difference-in-difference approach specified in Equation 6, we proceed to test this hypothesis by estimating the model for each of the deciles of competition presented in Figure B1. The resulting pattern of estimates and their 95% confidence intervals are plotted in Figure 3. Consistent with linear demand, we observe an increasing pass-through rate with increasing competition intensity for both fuel types. For the first three deciles having the lowest level of competition, the pass-through is around 84% for diesel and 80% for E10. For the three deciles with the highest degree of competition, we obtain pass-through rates of about 100% for diesel and 89% for E10. A general pattern of higher pass-through for diesel than for E10 is also evident, which aligns with the smaller (in magnitude) demand elasticity for diesel presented in Table 2.

We repeat the analysis for income, using Equation 6 to estimate pass-through rates by purchasing power decile, which are plotted in Figure 4. The plot reveals a decline in pass-through rates from stations in low-income areas to those in high-income areas for

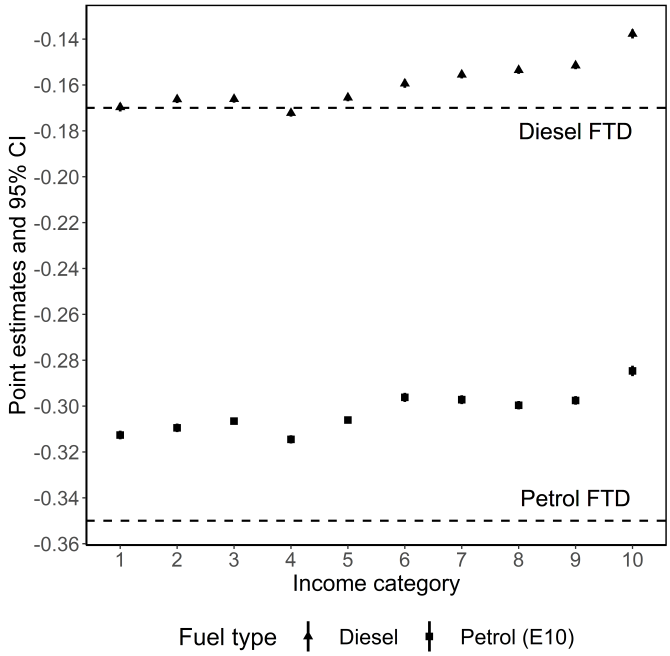
Figure 3: Competition Results: Fuel Tax Discount and Deciles of Relative Station Density



Note: Group 1 indicates low station density and low competition, Group 10 high station density and high competition levels. Dashed lines indicate the FTD levels: 16.71 Cents for diesel and 35.16 Cents for E10.

both fuel types. For the case of diesel, the first four lowest purchasing power deciles have perfect pass-through of near 100%, a ratio that drops to 82% by the highest decile. The pattern is similar for E10, with pass-through rates reaching 89% in low-income areas and dropping to 81% in high-income areas. The results thereby corroborate the finding of Harju et al. (2022) that pass-through decreases with income, albeit with a different welfare implication in the present case owing to the focus on a tax reduction rather than a tax increase. While Harju et al. (2022) conclude a regressive effect of a carbon tax given a higher tax incidence among poorer segments of the population, the higher pass-through of the price discount among less wealthy segments seen in Figure 4 suggests a progressive effect, an interpretation we pursue further below.

Figure 4: Purchasing Power Results - Spatial Pattern



Note: The graph shows the estimation results for various purchasing power groups: Group 1 represents low-income regions, while Group 10 represents high-income regions.

6 Heterogeneity over Time

Beyond its magnitude, the speed of adjustment and the persistency of the pass-through rate are also of relevance to its welfare effects. To explore these aspects, we estimate the event study specification in Equation (8), which allows for differential effects by day, covering 60 days prior to the introduction of the discount and the full 90 days of its implementation. The results for diesel are presented in Figure 5,[9] where three features bear noting. First, the estimates for the 30 days leading up to the discount hover close to zero, providing support for the assumption of parallel trends. Prior to this date, however, they drift upward, the implications of which are explored more closely below. Second, the speed of adjustment to the discount is immediate; in fact, an overshooting of the pass-through rate for diesel occurs through most of the first month. Third, the rate begins to abate rapidly as of day 30, reaching a level of about 50% by day 60.

[9]Confidence intervals in this and the remaining figures are hardly visible because the standard errors are typically around 0.001.

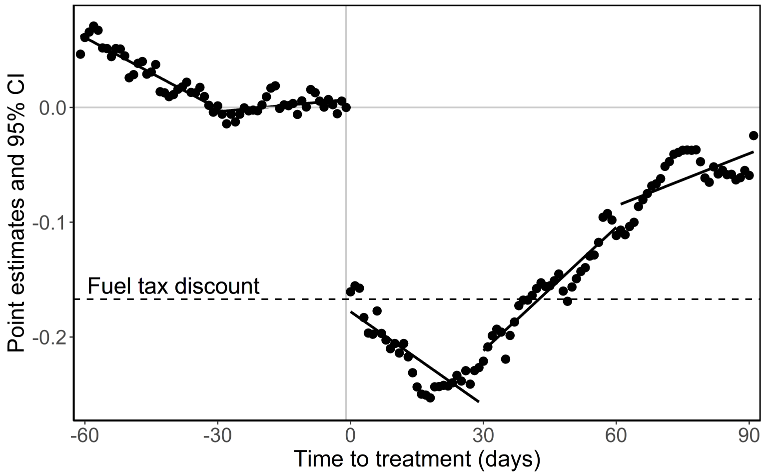
The pattern for E10, presented in Figure 6, is similar to the case of diesel but with two distinctions, one being evidence that parallel trends may be violated already as of 15 days prior to the introduction of the discount. To scrutinize the parallel trends assumption more closely, we availed of the ”honest DiD” method developed by Rambachan and Roth (2023), a robust inference approach that yields confidence intervals under violations of parallel trends. Specifically, it allows inspection of the extent to which violations of parallel trends in the post-treatment period exceed those in the pre-treatment period. The details of this analysis, which focus on the first week of the treatment period, are presented in Appendix A. We note here that the results suggest that the results are robust to allowing for violations of parallel trends up to twice as large as the maximum violation in the pre-treatment period.

The other feature distinguishing the temporal pattern of E10 is that while the speed of adjustment to the discount is immediate, it is not complete. Unlike in the case of diesel, there is no overshooting. The pass-through rate holds steady at about 90% through the first 30 days of the discount, after which, like diesel, it abates sharply. Recalculating the pass-through rate to reflect the diminishing effects over time yields average estimates of 71% for E10 and 87% for diesel, about 15 and 9 percentage points lower than the difference-in-difference estimates that ignore this temporal pattern.

We additionally estimated the event study models with specifications that allowed for differential effects across the highest and lowest deciles of the measures of competition and purchasing power analyzed above. In line with the earlier results, Figure 7 indicates that the pass-through rate is lower in regions of low competition throughout the period of the discount. In fact, for diesel drivers in low-competition regions, notwithstanding the initial overshooting, the pass-through rate effectively reaches zero for the final month of the policy. Figure 8 also confirms the above results for purchasing power: higher pass-through rates are seen among lower-income segments. The effect sizes dissipate as of day 30. For diesel, high-income segments face pass-through rates of nearly zero by day 60.

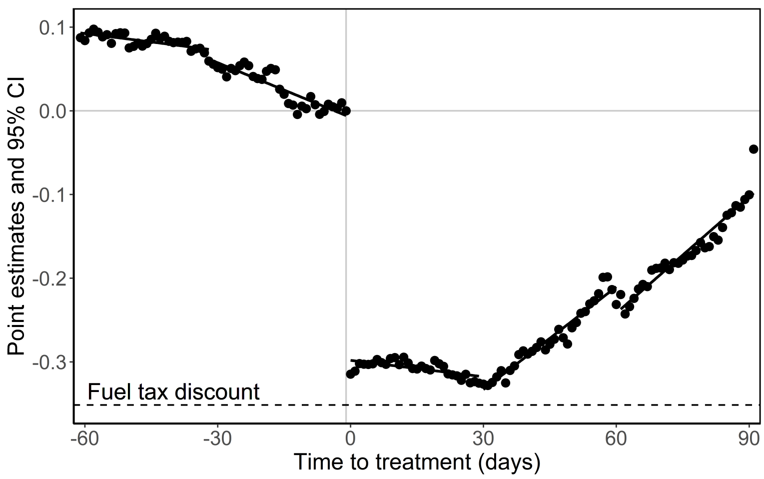
What accounts for the declining magnitude of the pass-through rate observed in

Figure 5: Pass-through Estimation Results over Time for Diesel



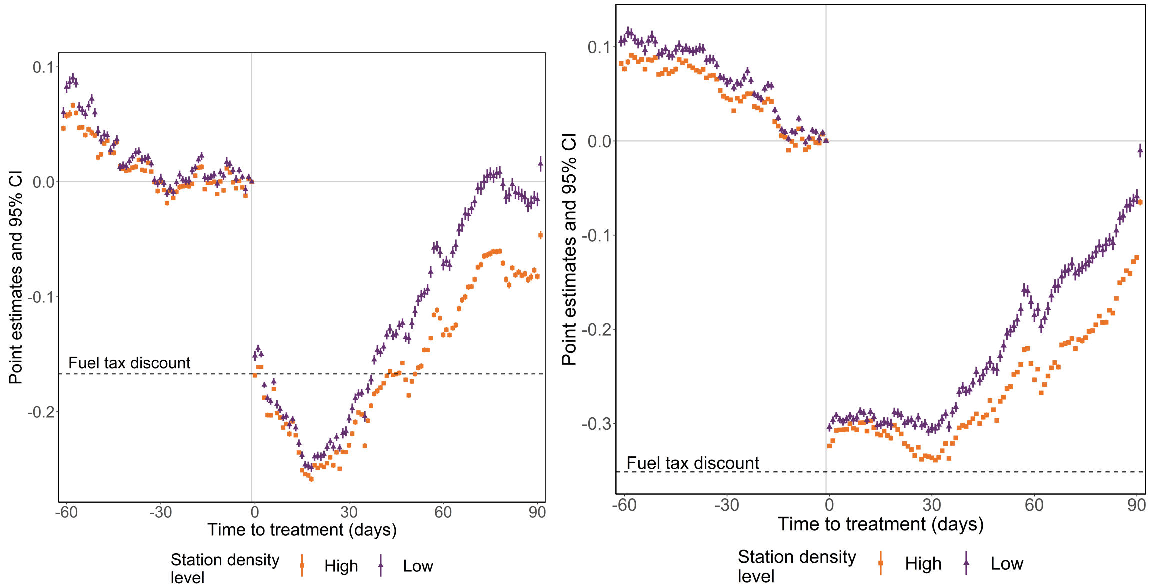
Note: The figure shows the results for diesel with respect to May 31, the last day before the introduction of the FTD. Black solid lines indicate the monthly trend. The dashed line represents the magnitude of the tax discount: 16.71 Cents per liter.

Figure 6: Pass-through Estimation Results over Time for E10



Notes: The figure shows the baseline results for E10 with respect to May 31, the last day before the introduction of the FTD. The black solid lines indicate the monthly trend, the dashed line represents the magnitude of the price discount: 35.16 Cents per liter.

Figure 7: Pass-through Estimation Results for Competition

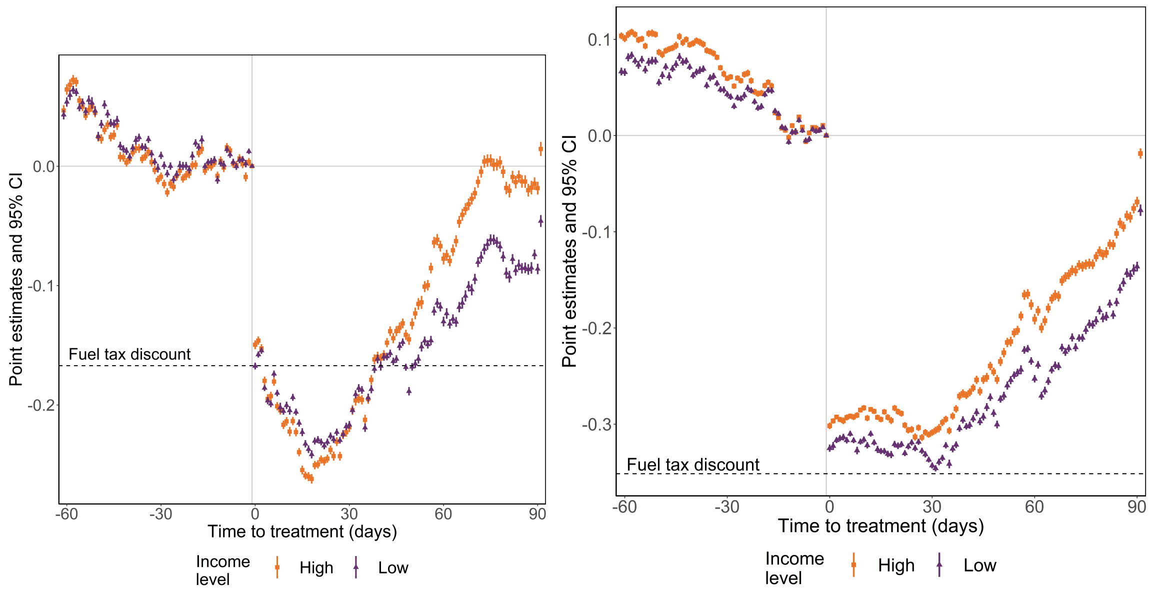


(a) Diesel

(b) Petrol (E10)

Notes: The figure shows the price effect of the FTD over time with respect to May 31. The results are shown for high station density values (high competition) and low station density values (low competition). The dashed lines indicate the FTD levels: 16.71 Cents for diesel and 35.16 Cents for E10.

Figure 8: Pass-through Estimation Results for Purchasing Power



(a) Diesel

(b) Petrol (E10)

Note: The figure shows the price effect of the FTD over time with respect to May 31. Dashed lines indicate the fuel tax discount levels: 16.71 Cents for diesel and 35.16 Cents for E10.

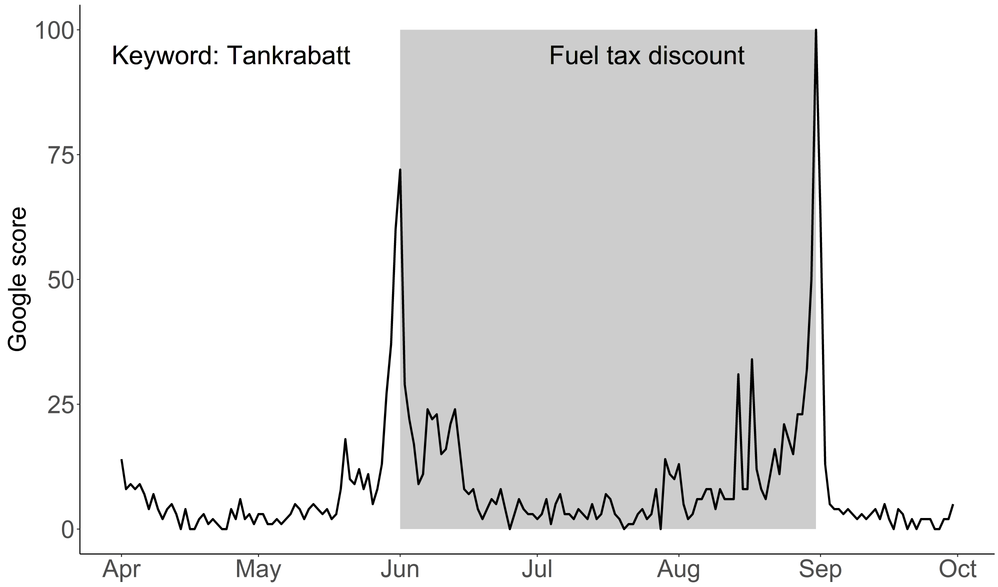
Figure 5 through Figure 8? The conduct-parameter approach to pass-through discussed in Section 2, being a static framework, is ill-equipped on its own to provide a full explanation. We therefore draw on consumer search theory for additional insight, acknowledging that data constraints prevent us from reaching more than speculative conclusions. A central premise of consumer search theory is that the information available in the marketplace has a bearing on the prices that firms charge. When prices and costs are decreasing, consumers tend to search less (Byrne & de Roos, 2017; Lewis & Marvel, 2011). Less search, in turn, implies a less elastic demand and a higher pass-through rate.

Such was the context with the introduction of the fuel price discount. While relatively sudden, the discount was well covered in the media. Many newspapers reported and speculated about whether service station operators would pass on the FTD to consumers or whether the tax reductions would instead amount to a subsidy to the oil companies.[10] This media attention plausibly created an environment of highly informed consumers, increasing competition among retailers, and ultimately resulting in lower retail margins and higher pass-through (Lewis & Marvel, 2011). Some support for this narrative is seen in Figure 9, which shows an analysis of Google trends for the keyword "Tankrabatt" (fuel discount). It shows that public interest in this keyword was high at the outset of the FTD, but that it dropped within the first month thereafter, with interest only reviving shortly before the discount came to an end.

With interest in and information about the FTD dissipating, fuel retailers may have seen an opportunity to start increasing prices toward the end of the first month. The literature on consumer search has established that rising prices stimulate more search, corresponding to a more elastic demand. From Equation (5), when demand elasticity increases, pass-through rates fall, which would account for the decreasing pass-through rate seen in Figure 5 through Figure 8.

[10]See, for example, the online article in ZDF (2022) ("Streit über hohe Spritpreise: Verpufft der Tankrabatt?") on March 30, 2022 or Tagesschau (2022) ("Wie stark sinken die Spritpreise?") on June 1, 2022.

Figure 9: Public Attention



Notes: The figure shows the trend graph according to Google Trends for the keyword "Tankrabatt" (fuel discount) for April 1 to September 30, 2022. The grey area marks the period of the German fuel discount, which lasted from June 1 to August 31, 2022. The Google Score is defined as interest over time relative to the highest point in the observed period. A value of 100 represents the highest search popularity. *Source*: The raw data is based on Google Trends.

7 Economic Impacts of the Fuel Tax Discount

The foregoing analysis demonstrates a high degree of heterogeneity in the pass-through rate over space and time, which is otherwise obscured in the fixed-effects estimates presented in Table 1. The question remains as to the economic impacts of this heterogeneity, both on the economy as a whole and on the different consumer segments therein. We examine this question by first estimating the discount's net budgetary costs, followed by an assessment of who benefited.

The gross budgetary costs implied by the tax discount consist of reduced revenues from the energy taxes on diesel and petrol and the foregone value-added tax. These costs are obtained by multiplying the total volume of petrol and diesel consumed over the three months June, July and August by the respective tax reductions: 35.16 and 16.71 cents per liter including value-added tax. Altogether, gross budgetary costs sum to a total of €4.14 billion (Table 3).

These costs are partially offset by higher tax revenues due to consumption increases

Table 3: Gross Budgetary Costs of the Fuel Tax Discount in Terms of forgone Energy and Value-added Tax Revenues

	Fuel consumption (in million liters)		Costs (in million euros)	
	Diesel	Petrol	Diesel	Petrol
June	3,625.6	2,213.8	605.8	778.4
July	3,591.2	2,033.2	600.1	714.9
August	3,930.4	2,227.1	656.8	783.0
Total	11,147.2	6,474.0	1,862.7	2,276.3
			Total cost:	4,139.0

Note: Gross budgetary costs are calculated based on the tax discounts of 16.71 cents per liter for diesel and 35.16 cents for petrol, where the VAT is included.

during the three-month period during which the discount is valid (Figure 10). Our crude estimate of these revenues results from subtracting the average consumption during the two months prior to the introduction of the tax discount from the respective fuel consumption in the discount months June, July and August (Table 4). Multiplying these differences with the minimum energy taxes required in the EU of 33,0 and 35,9 cents per liter of diesel and petrol, respectively, yields additional energy tax revenues of about €832 million (Table 4). Accounting for additional value-added tax revenues of about €160 million due to a tax rate of 19%, our estimation yields tax revenue gains of almost one billion euros for the three-month period in which the tax discount was valid. Subtracting this figure from the €4.1 billion presented in Table 3, we arrive at the net budgetary cost of the tax discount, which amounts to about €3.1 billion. As it happens, the government reached an identical cost estimate of €3.1 billion in a publication released prior to the implementation of the FTD (see Federal Ministry of Finance, 2022). This figure comprises about 4% of Germany's €80 billion budget deficit in 2023 (BMF, 2024) or roughly 26% of its €11.7 billion annual outlay for official development assistance (BMZ, 2024).

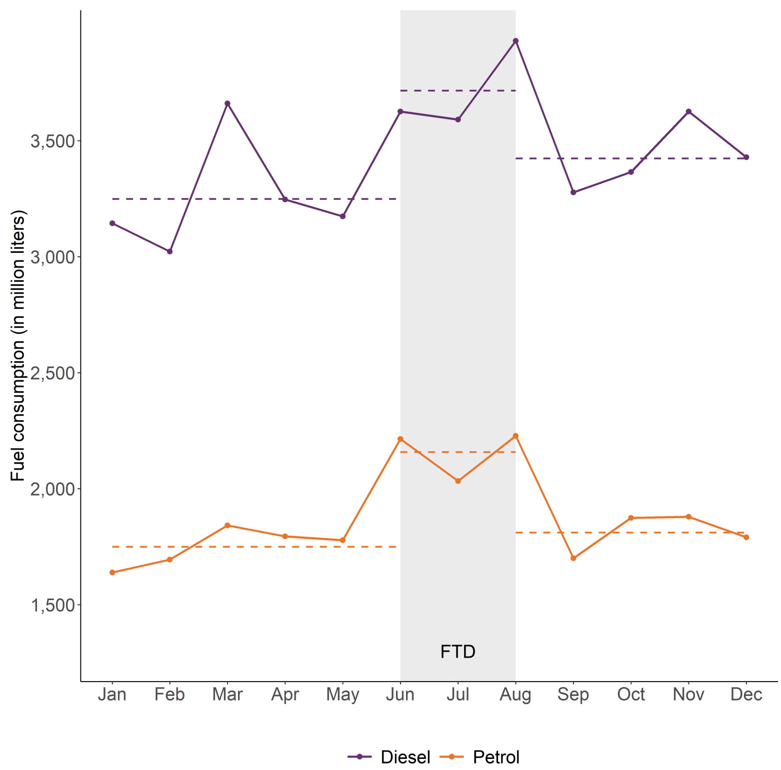
Identifying the beneficiaries of the discount-induced cost savings at the pump requires information on the distribution of (1) the pass-through rate and (2) the volume of fuel consumption. While the analysis of the preceding section shows that pass-through

Table 4: Additional Energy and Value-Added Tax Revenues due to the Discount-induced Higher Fuel Consumption in June, July and August 2022

Months	Fuel consumption (in million liters)		Difference in consumption (in million liters)		Additional tax revenues (in million euros)	
	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
April & May	3,209.9	1,786.2	–	–	–	–
June	3,625.6	2,213.8	415.7	427.6	141.1	153.5
July	3,591.2	2,033.2	381.3	247.0	125.8	88.7
August	3,930.4	2,227.1	720.5	440.9	237.8	85.4
Total	11,147.2	6,474.0	1,517.5	1,115.5	504.7	327.5
Total energy tax revenues in million euros:					832.3	

increases with decreases in purchasing power, indicating a progressive effect, these financial benefits may be offset by lower fuel consumption among poorer households. To glean further insight, we reference household fuel consumption figures from the MOP, separating households into two groups according to whether they earn above or below the median income.

Figure 10: Monthly Petrol and Diesel Consumption in 2022 in Million Liters



Note: The dashed lines represent the average fuel consumption in the respective periods.

Calculating the average fuel consumption for petrol and diesel cars for each income group, we multiply these figures by the total number of diesel and petrol cars among households below and above the median income level, as recorded in the RWI-GEO-GRID data. This yields estimates of total fuel consumption by income level and fuel type, presented in the first two columns of Table 5. Households below the median income consume roughly 37% of fuel by volume, with households above the median consuming the remaining 63%.[11]

Table 5: Purchasing Power and Gains of the Fuel Tax Discount

Purchasing power group	Fuel consumption (in million liters)		Gains from FTD based on estimation (in million Euros)	
	Diesel	Petrol	Diesel	Petrol
Below median	1,477.3	2,344.5	248.3	726.6
	(37.0%)	(37.8%)	(39.4%)	(39.0%)
Above median	2,515.6	3,853.1	381.9	1,138.6
	(63.0%)	(62.2%)	(60.6%)	(61.0%)
Total	3,992.9	6,197.6	630.2	1,865.2
	(100%)	(100%)	(100%)	(100%)
			Total household gains:	2,495.4

Note: The gains based on the pass-through estimation consider the difference between purchasing power groups and rely on the estimated FTD effect of 16.8 Cents for diesel and 31.0 Cents for petrol for below-median levels and 15.2 Cents for diesel and 29.5 Cents for petrol for above-median levels.

In a final step, we multiply these figures by the pass-through rates for diesel and petrol, using a model specification that differentiates estimates by median income. As reported in the final two columns of Table 5, about 61% of the gains accrue to households earning above the median income both for diesel and petrol fuel. Thus, notwithstanding the higher pass-through rate among low-income households, the overall effect of the FTD appears to be regressive, a consequence of the higher fuel consumption among high-income households.

[11]Our estimate of about 6.2 billion liters of total petrol consumption in Table 5 aligns tightly with the figure of 6.5 billion liters, published by the association of oil-producing companies (en2x, 2023). Our diesel estimate of about 4 billion liters is lower than the official estimate of about 11 billion liters, which owes to the fact that our calculations do not include goods transportation by truck.

8 Conclusion

Around the world, many governments, including those of France, Germany, Poland, the UK, and several states in the US, have introduced temporary tax discounts to mitigate hardship when fuel prices spike. Given this objective, it is important to assess the extent to which the tax relief reaches consumers, as well as the distribution of beneficiaries. Using both difference-in-differences and event-study approaches, this paper has investigated the pass-through of Germany's fuel tax discount (FTD), implemented from July through August of 2022. Expanding on the related literature on fuel tax incidence, our analysis considered both demand- and supply-side channels through which the pass-through rate may be moderated. To this end, we explored the roles of purchasing power and competition, additionally allowing for variation in the magnitude of the pass-through rate over time.

Three key results emerge. First, we find that pass-though estimates are subject to a high degree of spatial and temporal heterogeneity. In the case of diesel, estimates vary between 48 and 144 percent, while they vary between 46 and 102 percent for petrol. Second, the results indicate that some part of this heterogeneity owes to the mediating influences of regional competition and income. Specifically, in theoretical consistency with our identification of not excessively convex demand for mobility, we find that the magnitude of the pass-through rate increases with the intensity of competition. We also find, similar to the study of Harju et al. (2022) for Finland, that pass-through decreases with increases in purchasing power. Last, and most strikingly, our application of an event study approach reveals a pronounced abatement in the magnitude of the pass-through rate over the three months that the discount was in effect. By the final month, the rate was about 50% across fuel types, thereby heavily undermining the political endeavor to mitigate consumers' burden due to energy price shocks. We surmise that this pattern can be ascribed to waning consumer attention, but this is a question that warrants additional investigation.

We completed the analysis by exploring the budgetary costs of the FTD and, using the econometric estimates, the distribution in the incidence of financial relief to households. Over its three month implementation, the costs totaled about €3.1 billion, reaching over a quarter of Germany's annual budget for foreign aid. Our calculations further show that roughly 61% of tax relief accrues to households earning above the median level of purchasing power, suggesting a regressive impact of the FTD.

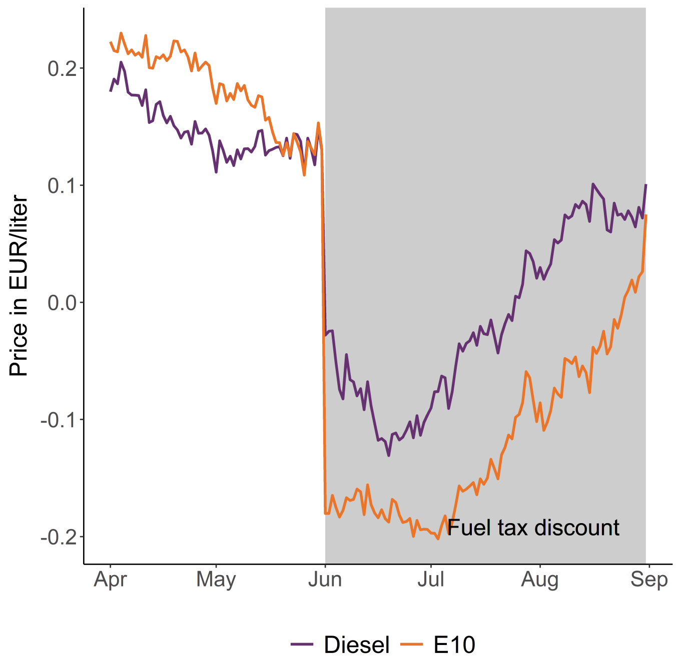
These findings have important policy implications that likely extend beyond Germany to other countries implementing fuel tax discounts. In particular, the spatial and temporal heterogeneity revealed by the econometric estimates point to the importance of assessing local economic conditions in guiding policy decisions on where and when to adjust fuel taxes. Based on the German experience, we conclude that the economic logic of the fuel discount was dubious, amounting to a distortion of market signals that encouraged higher fuel consumption – and primarily among wealthier households – at a time when scarcity induced by the Ukraine war would have instead called for conservation.

Appendix

A Testing Parallel Trends

This section provides additional support for the parallel trend assumption. Figure 1 and Figure A1 provide visual evidence of this assumption by plotting the price trends and price differences for Germany and France over time. These graphs suggest that the parallel trend assumption holds, especially close to the introduction date of the FTD (June 1), as both countries have similar price patterns.

Figure A1: Fuel Price Difference between Germany and France for Diesel and E10.



Note: The grey area marks the period of the German fuel tax discount, which lasted from June 1 to August 31, 2022.

In addition to the visual support for parallel trends in the figures, we provide a more formal check by applying the framework recently outlined by Rambachan and Roth (2023). By imposing restrictions on the model, the authors ask how far the parallel assumption can be violated to still obtain significant estimates that can be interpreted causally. This provides an opportunity to perform a sensitivity analysis of our results.

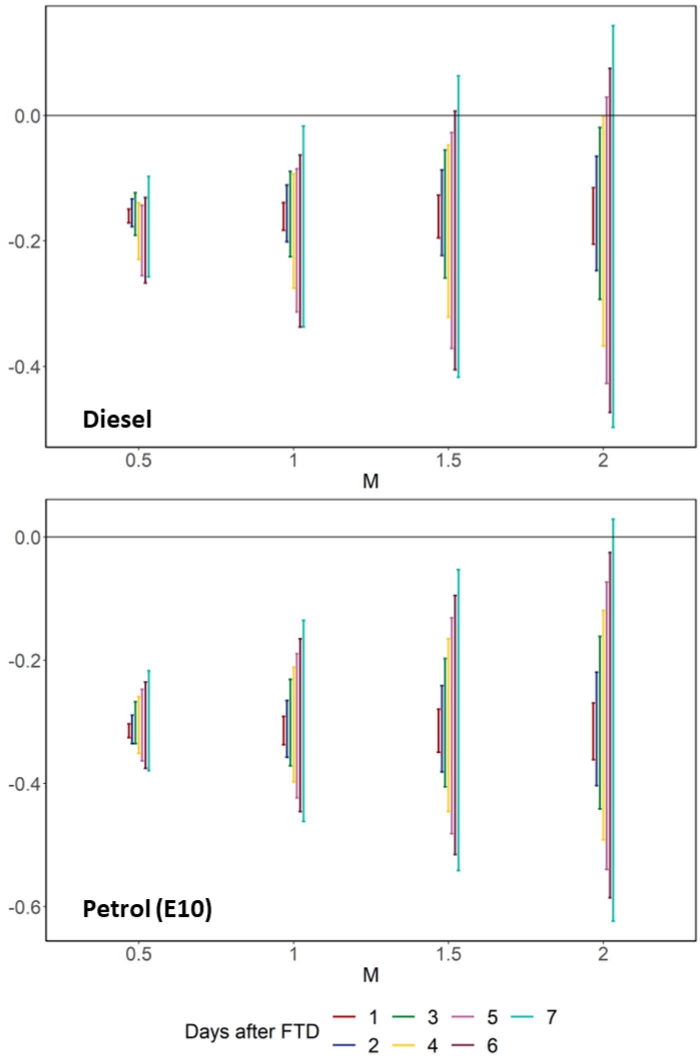
Rambachan and Roth (2023) discuss mainly two restrictions for analyzing the parallel trend patterns - the relative magnitude restriction and the smoothness restriction. Which one to apply depends on the empirical setting. The relative magnitudes restriction, which is also discussed by Manski and Pepper (2018), assumes that the confounding factors that violate the parallel trend assumption are relatively constant between the pre- and post-treatment periods. The smoothness restriction is the appropriate choice when the confounding factors arise from secular trends, i.e., it emphasizes prevailing (long-run) differences between the treated and comparison groups. The first constraint, relative magnitudes, seems more relevant to our setting for two reasons: First, we examine a short period of five months. Even though we include the entire period of the FTD, it is unlikely that France and Germany were put on completely different paths during this limited time. Second, and relatedly, we do not assume that confounding factors, i.e., (unobserved) differences between the two countries, are much stronger in the post-treatment periods than in the pre-treatment periods.

The relative magnitude constraint assumes that the maximum violation of parallel trends in the post-treatment periods equals the maximum violation of parallel trends in the pre-treatment periods times some parameter $\bar{M}$. This allows us to perform a sensitivity analysis for a sequence of $\bar{M}$ ranging from 0.5 to 2.[12] Note that $\bar{M} = 0$ represents the originally estimated coefficient, which assumes that there are no parallel trend violations.

Figure A2 shows the implementation of the Rambachan and Roth (2023) framework for the first week following the FTD.The figure shows that for diesel, all periods hold up to a factor of $\bar{M} = 1$. The parameter is even higher for E10, where all periods are robust to parallel trend violations for a factor of $\bar{M} = 1.5$. The wider confidence intervals with increasing $\bar{M}$ follow directly from the framework since increasing $\bar{M}$ implies a stronger violation of parallel trends, which leads to a less precise estimation of the coefficients.

[12]The interpretation of, for example, $\bar{M} = 2$ is that the violations of parallel trends in the post-treatment period cannot be greater than twice the violations in the pre-treatment periods in order to still obtain significant results.

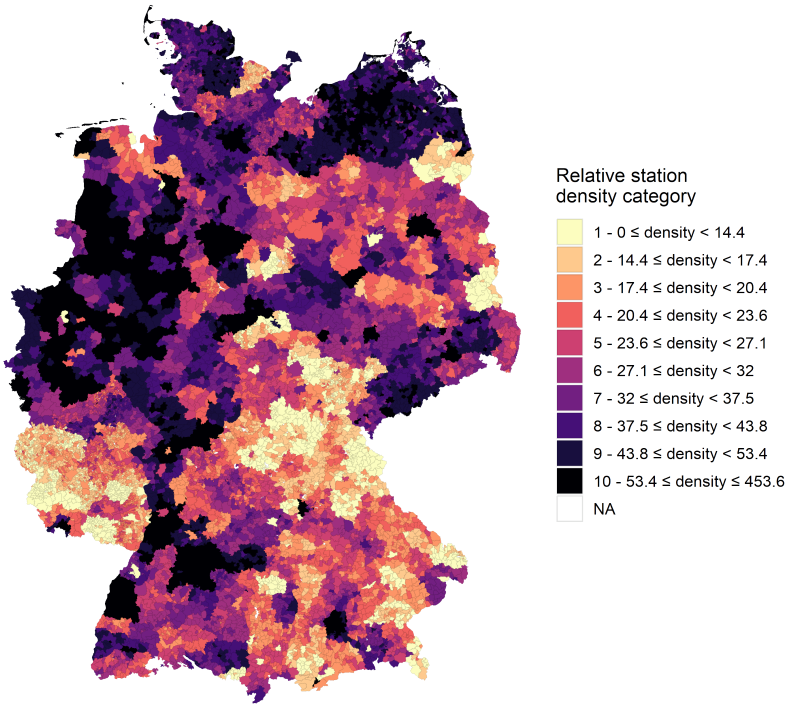
Figure A2: Robust Parallel Trends



Note: The figure shows the outcome of the Honest-DiD (Rambachan & Roth, 2023) approach around the implementation of the FTD.

B Number of Gas Stations per Car per Household

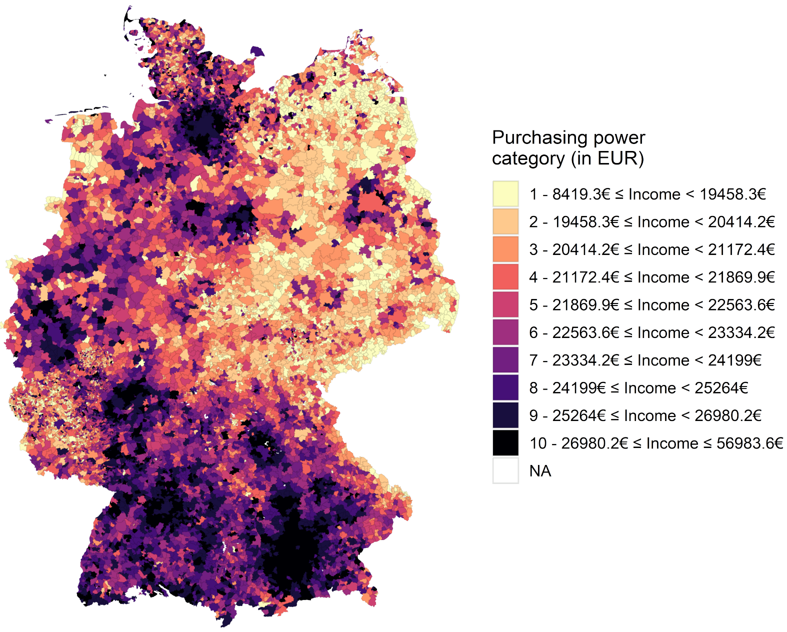
Figure B1: Deciles of the Number of Gas Stations per Car per Household at the Municipality Level



Notes: The map shows the deciles of relative station density at the municipality level, reflecting the number of gas stations per car per household. Some municipalities have missing values as they are not populated.
Source: RWI (2022) provides the raw data on cars per household.

C Purchasing Power Categories

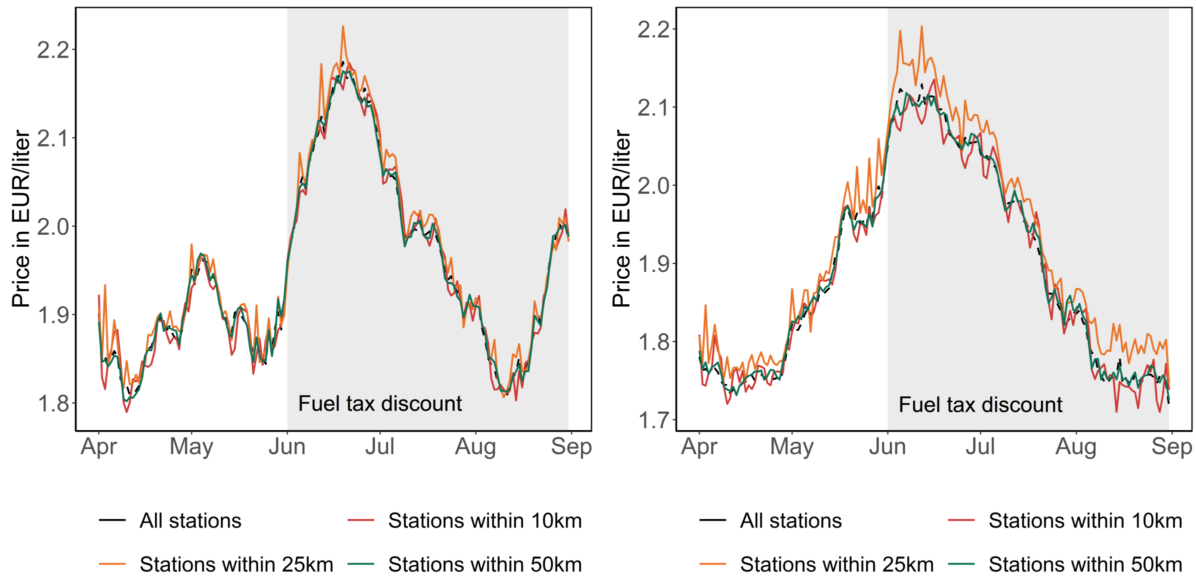
Figure C1: Purchasing Power Categories at the Municipality Level



Notes: The map shows the purchasing power categories (based on deciles) for Germany at the municipality level. Some municipalities have missing values as they are not populated.
Source: RWI (2022) provides the raw data on purchasing power.

D Visual Inspection of Spatial Spillovers close the French Border

Figure D1: Fuel Prices of French Stations Close to the German Border



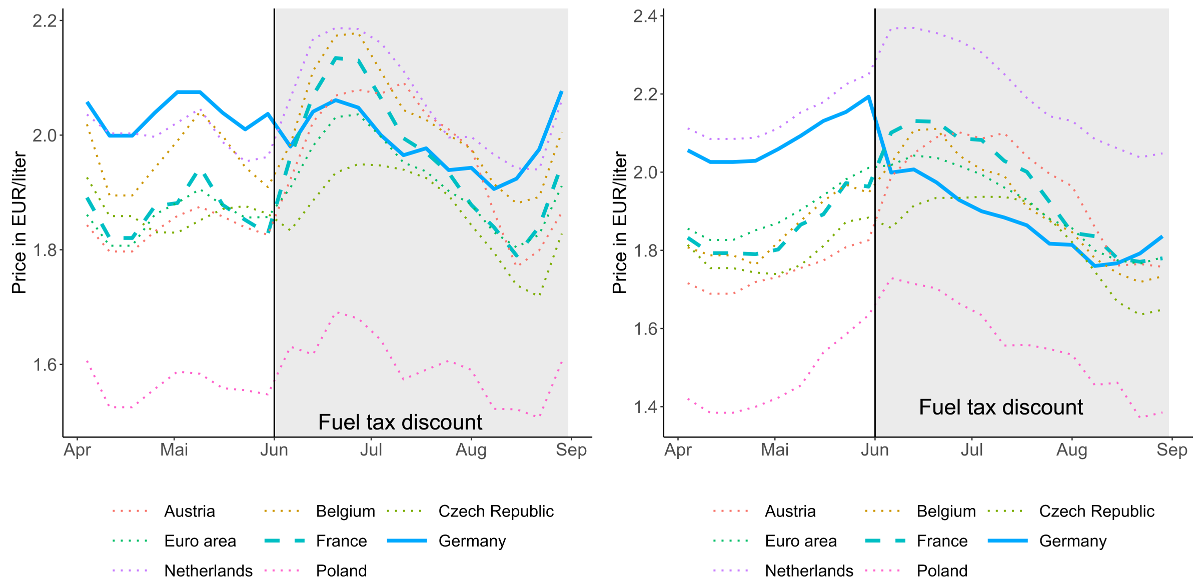
(a) Diesel

(b) Petrol (E10)

Note: French fuel prices for all stations and for stations within 10 km, 25 km, or 50 km from the French-German border.

E Fuel Prices in European Countries

Figure E1: Weekly Diesel and Petrol Prices in selected European Countries, including France and Germany



(a) Diesel

(b) Petrol (E10)

F Fuel Price Discounts in Germany and France

Table G1: Energy Tax Reliefs and VAT in Germany and France

Period in 2022	Country	Tax relief on energy tax (in Cents)		Tax relief VAT on energy tax (in Cents)	
		Diesel	Petrol	Diesel	Petrol
June 1 – August 31	Germany	14.04	29.55	2.67	5.61
April 1 – August 31	France	18		3.6	
September 1 – November 15	France	30		6.0	
November 16 – December 31	France	10		2.0	

Note: VAT amounts to 19% in Germany and 20% in France.

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