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Spatial competition and pass-through of fuel taxes: Evidence from a quasi-natural experiment in Germany

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Spatial Competition and Pass-Through of Fuel Taxes - Evidence from a quasi-natural Experiment in Germany

Frederik von Waldow *[†]

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May, 2024

Abstract

This paper analyses the pass-through rates and their determinants of the temporary German fuel discount in 2022 at its start and its termination. Based on a unique dataset of fuel station characteristics and prices, we employ a Regression Discontinuity in Time (RDiT) methodology to estimate heterogeneous pass-through rates. Our main contribution is to identify the impact of horizontal and vertical market structures on the extent to which taxes are passed on to consumers. While competitive pressure is positively associated with the response of prices to tax changes, we estimate lower pass-through predominantly for more isolated stations with fewer competitors. Furthermore, our results indicate that independence from upstream markets is accompanied by a reduced pass-through of tax changes suggesting the existence of double marginalization.

JEL Classification: Q48, H22, L13

Keywords: gasoline prices, local competition, tax pass-through, regression discontinuity in time

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1 Background and Motivation

Rising demand for energy due to the economic recovery after the COVID-19 pandemic and supply shortages caused by the EU sanctions against Russia in late February 2022 led to a sharp increase of retail gasoline prices in spring 2022. To mitigate the burden falling on private households, the German parliament approved an extensive relief package in May 2022. Amongst others, it contained two measures for the transport sector: the so-called "Tankrabatt", a temporary decrease of fuel taxes, to the extent permitted by European law during June, July, and August 2022, and the 9-Euro Ticket for public transport, allowing unlimited second-class travel throughout Germany. While the 9-Euro Ticket affected prices directly, policymakers had less control regarding the effectiveness and efficiency of the fuel tax discount. Since energy taxes follow the principle of indirect taxation, the overall pass-through of the tax decrease/ increase to consumers is inherently shaped by demand and supply elasticities (Jenkin, 1872) and is affected by further market characteristics such as competition on the retailing level and vertical market structures (Anderson et al., 2001; Weyl and Fabinger, 2013).

Indeed, station prices fell significantly at the beginning of June 2022 after the introduction of the fuel tax discount (figure 1), but the subsequent price increase raised concerns about potentially expanded profit margins of oil companies (Bach, 2022; Duso, 2022; Fratzscher, 2022). Shortly after the fuel tax discount came into force, Fuest et al. (2022) and Freitas and Syga (2022) estimated average pass-through rates between 80% and up to 100% for gasoline and diesel, respectively, suggesting that on average the policy intervention did not lead to extra profits of oil companies. Evidence provided by later studies (Seiler and Stöckmann, 2023; Drolsbach et al., 2023; Schmerer and Hansen, 2023) confirm these early findings. All of them, neglect heterogeneous pass-through as a consequence of spatially varying numbers of stations and different degrees of market concentration, vertical integration, and competition.¹ In addition, these studies solely focus on the introduction of the fuel tax discount but do not study the pass-through after the discount expired at the end of August 2022.

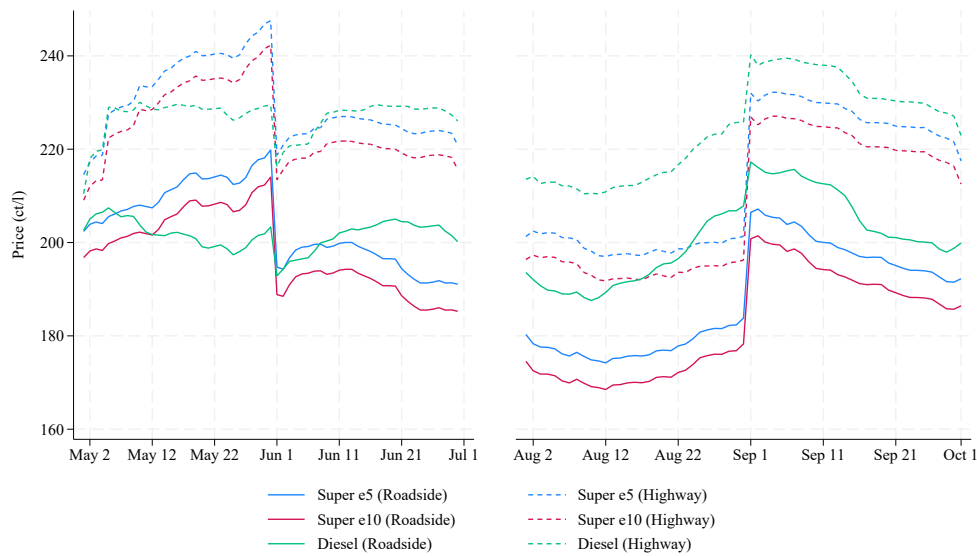
The temporary fuel tax discount provides a unique quasi-natural experiment with two policy interventions: a tax reduction in June 2022 and a subsequent tax increase at the end of August 2022 by the same amount. Against the research gaps indicated above, our paper aims to track the impact of local competition on the retail level in the short-run incidence of fuel and gasoline taxation during both tax interventions. Based on a comprehensive panel dataset with daily prices of 15,142 retailing stations across Germany covering the full year of 2022, and with various variables for horizontal and vertical market structures, we use a Regression Discontinuity Design in Time (RDiT) approach to estimate pass-through rates.

Our analysis focuses on two research questions: First, we are interested in identifying the

¹To the best of our knowledge, Frondel et al. (2024) are the first to exploit pass-through variation both temporally and spatially.

extent to which the two tax interventions were passed through to consumers and to evaluate the effectiveness of this policy. The relevance of this policy question is reinforced by the fact that the total loss of revenue for the public budget was estimated at a total of around 3.15 billion, exceeding the cost of 2.5 billion for the 9-Euro Ticket during the same period. Second, we aim to identify the impact of local competition in the retail gasoline market and vertical integration on tax pass-through. With these two research questions we contribute i) to the literature on tax pass-through, and ii) to the research on the role of spatial determinants and market forms on gasoline retail prices.

Figure 1: Daily Fuel prices from May to September 2022 in Germany at roadside and at highway stations



Note: Graphical representation of daily prices for Super e5, Super e10, and Diesel for roadside and highway stations during the months of May and June, and August and September 2022. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

The remainder of this paper is structured as follows. Section 2 reviews the related literature, followed by an overview of the German gasoline retail market and the settings of the temporary fuel tax discount from June to August in section 3. Section 4 discusses the theoretical framework of tax pass-through under market power and introduces the econometric approach of the Regression Discontinuity in Time (RDiT). Section 5 describes the data used for estimation. This is followed by the presentation and discussion of estimation results in section 6 and both policy conclusions and issues for further research in section 7.

2 Related Literature

The literature on the relationship between gasoline prices and market structure goes back at least to the nineties and has largely focused on retail markets in the U.S. and Canada, however with an increasing stream of studies for Europe since the end of the 20th century. Our review of related

literature follows loosely the categorization of studies from Eckert (2013), starting with studies on the relationship between the market power of firms and price differentials across stations including the effect of mergers, followed by research on the effect of independent retailers versus delegated stations (e.g. the issue of vertical integration) and studies on tacit collusion. Finally, as this is of major interest for our own analysis, we summarize findings from studies dealing with tax pass-through. The extensive literature on edgeworth cycles in gasoline markets is out of scope for our analysis and therefore not reviewed here.

To start with the relationship between market power and prices, most of the studies find substantial price differentials between gas stations and identify a relationship between price discrimination and local market power exercised by stations. Examples include Borenstein and Shepard (2002) who analyze New York Mercantile Exchange (NYMEX) prices for futures contracts for New York harbor delivery of light sweet crude oil and unleaded regular gasoline, finding that firms with market power adjust prices more slowly than competitive firms. Barron et al. (2000) show for gasoline prices from the Los Angeles Basin area that the price difference–cost margins between high- and low-quality gasoline (unleaded and leaded) depends positively on consumers' average valuation for incremental increases in quality and positively on the distance to each competitor's closest rival. Haucap et al. (2015) find for Germany that the type of local competition is more relevant than the number of competitors, with lower prices when the group of branded stations is more heterogeneous in an observed area. Kvasnička et al. (2018) provide evidence for Czechia indicating that an increase in the density of stations has a negative effect on prices, which declines with distance. Clemenz and Gugler (2009) confirm this for Austria and show that market concentration reduces the density of stations, however, they identify as the main effect of concentration the decisions on entry rather than on pricing. Finally, Netz and Taylor (2002) study the location choice of gas stations in the Los Angeles area, providing evidence that firms locate their stations in an attempt to spatially differentiate their product as market competition increases. They argue that this is presumably due to the nature of price competition where stations are required to post prices so that consumers can easily observe prices of nearby stations. Simpson and Taylor (2008) and Houde (2012) study the effect of mergers on station prices in Quebec City, both concluding that mergers induce higher prices.

Most studies on the impact of independent retailers and delegated stations in the U.S., Canada, and various European countries observe that prices charged by independent retailers are lower than those charged by other types of retailers. Examples include Shepard (1993) who compared gasoline prices among contracts and company units in Massachusetts, discovering evidence that the price charged at lease dealerships for certain products are higher. Slade (1998) provides evidence for Vancouver that delegation occurs when the strategic benefits exceed the agency costs which are determined by station characteristics. Hastings (2004) analyses the effects of vertical relationships and competition in retail gasoline markets in California and finds that independent competitors decrease prices through increased price competition. Van Meerbeeck (2003) finds for Belgium where a maximum price agreement between the government and the oil industry is in

force, that stations on sufficiently competitive local markets charge prices below the maximum price in contrast to stations located along a highway. Furthermore, rather than the number of local competitors it is the presence of independent gasoline retailers that has a large impact on retail gasoline prices. Pennerstorfer (2009) confirms this for stations in Lower Austria but argues that independent retailers also reduce price competition for branded stations since consumers might consider gasoline sold at unbranded stations to be inferior.

A related stream of research deals with tacit collusion. Eckert and West (2004) study price rigidity and uniformity in the cities of Ottawa and Vancouver, based on firm and station-specific data. They find evidence for tacitly collusive behavior in one city and the presence of maverick retailers that prevent tacit collusion in the other. Apart from this, they show that the degree of local competition is responsible for the observed differences in pricing patterns in the two cities. Byrne (2010) derives from a spatial econometrics approach that retail gas stations in the Houston metropolitan area engage in strategic interaction with neighboring stations when setting prices. Bergantino et al. (2018) confirm for the city of Rome both the direct price-lowering effect of competition in the market and the existence of spatial price interaction across stations and spillover effects.

Finally, tax pass-through and its heterogeneity have been studied in different settings and approaches regarding tax changes in gasoline markets. Based on monthly price data for all 50 U.S. states over 15 years, Alm et al. (2009) find strong evidence for fully shifting gasoline excise taxes to final customers but with significant differences in pass-through dependent on the level of urbanicity, with high-urban states fully passing through and more rural areas shifting marginally less than full. Doyle Jr and Samphantharak (2008) studied the effect of temporary suspension, and subsequent reinstatement, of the gasoline sales tax in Illinois and Indiana in 2000. Under a simple difference-in-difference approach, utilizing neighboring states as control group, and under several specifications including controls for wholesale costs and demographic variables, they show that 70% of the reduction and 80% to 100% of the increase were passed on quickly. By using day- and station-specific retail prices, they find that market concentration reduces the level of pass-through, especially in the case of tax increases. Jametti et al. (2013) rely on monthly average prices of 10 Canadian cities. They find robust results for undershifting of taxes but with significant variations due to market concentration. While the authors cannot reject that taxes are fully passed on to consumer prices in the least concentrated markets, this result is inverted for highly concentrated markets where taxes might be fully absorbed by producers. Genakos and Pagliero (2022) and Dimitrakopoulou et al. (2023) address the effect of different Greek tax policies and show that pass-through differs in isolated markets, in their case those on small Greek islands. Both studies support evidence that pass-through increases non-linearly with competition. Additionally, they show a positive correlation between competition on islands and the speed of price adjustment. Stolper (2016) breaks important new ground in the fuel tax incidence literature, as he assesses how fuel tax incidence varies across measures of local competition and wealth distribution regarding the Spanish gasoline market. As prices rise nearly one-for-one with taxes on average,

market power measured by spatial isolation and brand concentration is strongly associated with higher pass-through. Among others, Stolper (2016) identifies the geographic extent of markets by utilizing precise information on the location of each gas station. Concentration measures and the distance to the nearest competitors serve as indicators of market pressure. Comparable methodologies to identify heterogeneous gasoline tax incidence are employed by Lade and Bushnell (2019) and Chang (2023). Kihm et al. (2014) study deviations from cost-based pricing, identified by differential effects of the Brent oil price across stations in Germany. Using a panel of daily price data collected over a year from 2012 to 2013, they find that the pass-through of crude oil price increases varies by brand and shows significant heterogeneity. Furthermore, the influence of the Brent price on the gasoline price is stronger as the degree of local competition increases, measured by variation in market concentration, the density of competing stations, and spatial isolation from competing stations. Bello and Contin-Pilart (2012) find for the Spanish gasoline market a full shifting of taxes and a more than proportional pass-through of gas spot prices to retail prices.

We close this review of related literature with a summary of studies dealing explicitly with the pass-through of the German fuel tax discount in 2022. Fuest et al. (2022) find evidence of full pass-through for diesel and 82% to 85% for gasoline, based on a difference-in-difference approach with average daily prices for Germany and France, covering the first couple of weeks after the tax reduction. Freitas and Syga (2022) even find a pass-through of nearly 100% for both diesel and gasoline, though with diminishing rates in the period after the tax change, based on a dynamic difference-in-difference methodology with weekly prices from Austria, Belgium, Germany, Netherlands, Poland, and Sweden. Drolsbach et al. (2023) yield full- or even over-shifting of temporary tax cuts in Italy, France, and Germany by using a staggered difference-in-difference methodology. In contrast to the mentioned studies which use periods of up to three weeks after the policy implementation, Dovern et al. (2022) use a synthetic control method and weekly price data for the entire period of three months after the implementation of the fuel tax discount ("Tankrabatt"). Finding evidence of full pass-through, they argue that it took about two weeks to pass on the entire tax subsidy to consumers. Kahl (2023) also determines nearly full pass-through in Germany but with widely varying rates over time. Using the augmented synthetic control method (ASCM) to construct the counterfactual, Seiler and Stöckmann (2023) provide quantitative evidence for pass-through rates of about 85% for gasoline and 65% for diesel, without significant signs of excessive price increases in anticipation of the fuel discount. Schmerer and Hansen (2023) compared the German tax cut to the time trend in Austria, discovering 100% pass-through for both diesel and gasoline during the first tax intervention. Interestingly, the reverse effect at the end of the temporary fuel discount amounts to about 70% for Super E5. The first study to analyze the heterogeneous pass-through rates of the initial taxation intervention, conducted by Frondel et al. (2024), revealed a high degree of spatial and temporal heterogeneity. By estimating an event study model with France as a control, the researchers discover lower rates in high-income regions and regions with a low degree of competition. In contrast to all other studies on the German fuel tax discount, they find higher pass-through rates for diesel than for gasoline.

This review of related studies leads to three insights: First, the average pass-through of the initial intervention (fuel tax decrease) was relatively high, ranging from 80% to 100%. Second, all studies except Seiler and Stöckmann (2023) and Kahl (2023) find lower pass-through rates for gasoline as compared with those for diesel. Third, all recent studies analyzing the average tax incidence of the German tax reduction reveal indications of heterogeneous effects (especially in the speed of adjustment), though not specifically at the local level.

3 The German Gasoline Market and the Fuel Tax Discount in 2022

Gasoline markets are in general characterized by certain simplicities such as a high degree of product homogeneity, price-conscious consumers, high market transparency (at least in most developed countries), low search costs, and a rather low rule of product innovation. These characteristics hold for the German gasoline market and would lead to the assumption of a perfectly competitive market. However, some degree of complexity is introduced by product differentiation such as selling gasoline at branded versus non-branded stations, selling by-products such as car wash, shops, etc., and by spatial differentiation. In addition, vertical integration of the market and the fact that gasoline can be sold to stations directly by the refineries or independent distributors, contribute to complexity.

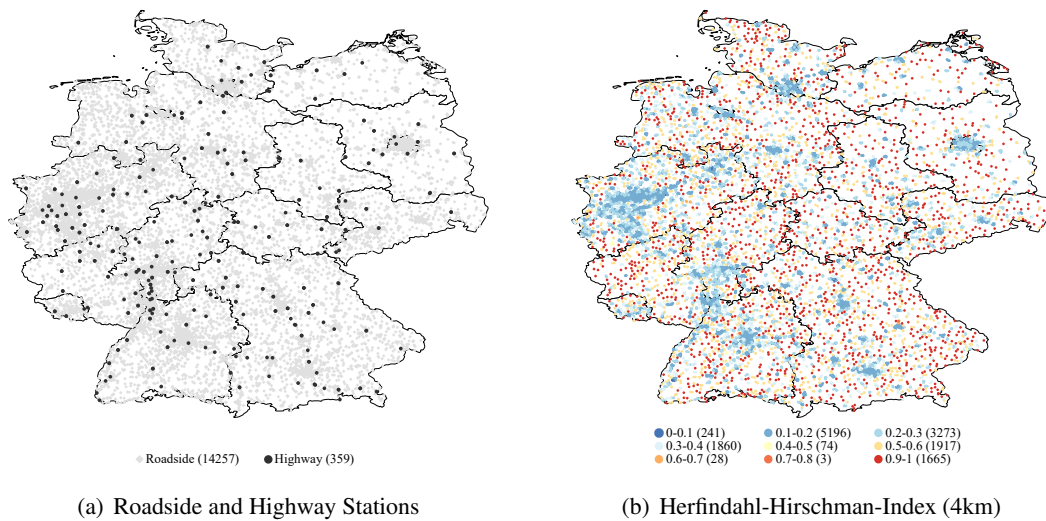
In Germany, the most common fuel types are two gasoline products (Super E5 with a minimum research octane number RON of 95 and up to 5% of ethanol, and Super E10 with 95 RON and 10% ethanol which are close substitutes for most engines) and diesel.² While domestic oil production is negligible, Germany has with 13 refineries one of the largest refining capacities within Europe. At the retail level, in 2022 fuel was sold to final consumers by 14,460 stations, with 359 stations located at highways and the remaining 14,093 stations at roads.³ The distribution of fuel stations throughout Germany is characterized by a high density of roadside stations in metropolitan areas and considerable market concentration in rural regions (figure 2). The gasoline retailing market is dominated by an oligopoly of five companies, including Aral (BP), Shell, Total Energies, Esso, and Jet), which combine a market share of 51%. Apart from these major companies, stations are operated either by other integrated oil companies without or with limited access to refinery capacity in Germany, or by a large number of small to medium-sized retailers (Independents) many of which cooperate under associations such as bft.⁴

²Apart from "Super E5" and "Super E10", "Super Plus" with RON 98 is used by some high-performance vehicles at a considerably higher price. Established brands provide additional gasoline sorts (e.g. Shell V-Power Racing, Aral Ultimate 102, etc.) which differ in their chemical composition, but only account for a small proportion of total sales.

³Stations at highways (so-called Autobahn stations which are located in highway service areas) operate in a different competitive environment compared to ordinary road stations since the responsibility for constructing, operating and leasing of Autobahn stations has been almost exclusively assigned to "Tank & Rast GmbH", a quasi-monopolist owned by Allianz Capital Partners, MEAG (a daughter company of Münchener-Rück), the Abu Dhabi Investment Authority and the Canadian infrastructure funds Borealis Infrastructure. The rights of selling fuel at Autobahn stations are subject to auctions and operators lease the station with its facilities usually within four years contracts. Fuel prices at Autobahn stations are considerably higher than at ordinary road stations.

⁴Bundesverband Freier Tankstellen und Unabhängiger Deutscher Mineralölhändler e.V. (bft).

Figure 2: Observed Gas Stations across Germany 2022



Note: Visual representation of (a) all roadside and highway stations and (b) Herfindahl-Hirschman-Index (HHI) of roadside stations during the months of May and June. The HHI is based on a 4 kilometer radius market delineation. Own calculations are based on Tankerkönig data ([https://creativecommons.tankerkoenig.de.](https://creativecommons.tankerkoenig.de/)).

Station ownership and brand affiliation are not necessarily congruent and the major players also supply fuels to other than their own retail stations, implying that their influence on prices is higher than reflected by the sheer number of branded retail stations. Multiple brand partner agreements concerning dealer or oil company ownership and brand affiliation lead to various operating forms such as coco (company-owned, company-operated), codo (company-owned, dealer operated), and dodo (dealer-owned, dealer-operated). As a response to the suspected market collusion of the major companies, the German competition authority established in 2013 the market transparency unit (MTU) aimed at increasing transparency in the market. Since then, gas stations have been obliged to report price changes in real-time to the MTU. Privately operated websites and mobile apps have been given access to the MTU database to report information to consumers. Apart from the required reporting of price changes, station operators are free in their price setting and there is no other price regulation. However, they have to meet minimum sales targets for "Super E10".

Retail prices of gasoline are primarily influenced by international crude oil prices. However, the largest share of consumer prices in Germany consists of taxes (table 1): A per unit energy tax is levied on diesel and gasoline at 47.04 cents and 65.45 cents per liter, respectively. Refineries are obliged to account for a CO₂ tax and additional fees (i.e. Erdölbereitungsverband fees).⁵ Finally, a 19% value-added tax is levied on net prices, including previously mentioned taxes and fees. Not least due to the high share of taxes in the retail prices, the second relief package to

⁵The CO₂ tax amounts to around 8.4 and 9.5 cents per liter for gasoline and diesel, respectively (ADAC, 2023). The contribution to the fees for the oil reserve (Erdölbereitungsverband) amounts to 0.27 (gasoline) and 0.30 cents per liter (diesel) (EBV, 2012).

mitigate the financial burden of consumers caused by the increased energy costs due to the war in Ukraine, contained amongst others a temporary fuel tax discount. From June to August, parallel to the 9Euro ticket, tax rates for gasoline and diesel were reduced to the minimum rate permitted by European law. Tax rates decreased by 29.55 cents per liter from 65.45 cents per liter for gasoline and 14.04 cents per liter from 47.04 cents per liter for diesel, respectively (Bundesgesetzblatt, 2022). Since the 19% value-added tax is levied on prices including energy tax, the effective tax discount amounted to 35.16 cents per liter for gasoline and 16.71 cents per liter for diesel.

Table 1: Fuel Taxes and Fees in Germany 2022

	Gasoline (e5 & e10)		Diesel	
	Before	After	Before	After
Energy tax (ct/l)	65.45	35.90	47.04	33.00
CO ₂ (ct/l) tax		8.40		9.50
Fees to the oil reserve (ct/l)		0.27		0.30
Σ (ct/l)	74.12	44.57	56.84	42.80
VAT		19%		19%

Note: The After period includes the months of June, July, and August of 2022.

4 Methodology

4.1 Conceptual Framework

The extent to which consumers and producers bear the change of a consumption tax depends integrally on the nature of competition at the retail level. Existing literature mainly focuses on the equilibrium rate of tax pass-through to retail prices, as this provides a full characterization of tax incidence under certain assumptions. Our analysis is based on the theoretical framework of standard tax incidence (Jenkin, 1872; Buchanan, 1969; Bulow and Pfleiderer, 1983; Weyl and Fabinger, 2013). In the following, we derive pass-through levels under i) symmetric imperfect competition and provide implications for ii) perfect competition and iii) monopoly.

In a market with n firms, the demand and supply functions, respectively represented by D and S , are determined as a function of price p and tax τ . Denote further the quantity traded with q , the inverse demand function with $p(q)$, and the marginal cost excluding taxes as $mc(q)$. In perfectly competitive markets, sellers have full information and a symmetric cost structure, are offering a homogeneous good, and are located in different locations, with price as the primary decision variable. Under imperfect competition with a finite number of n symmetrically differentiated firms, pass-through of a per-unit tax can be derived by using the conduct parameter specified in Weyl and Fabinger (2013). Rather than specifying a model of firm interactions, the elasticity-adjusted Lerner index $(p - mc(q)/p) \times \varepsilon_D$ defines the conduct or market power parameter θ (Bresnahan, 1989; Genesove and Mullin, 1998). θ describes the intensity of competition among firms: As $p = mc$ in perfectly competitive markets, the absence of market power is indicated by $\theta = 0$. Oligopolists

and monopolies, however, charge prices greater than marginal cost ($p > mc$), with a range of θ between 0 and 1 up to a pure monopoly case, indicated by $\theta = 1$.⁶ Pass-through under symmetric imperfect competition ρ_I can be expressed as:

$$\rho_I = \frac{d\rho}{d\tau} = \frac{1}{1 + \frac{\theta}{\varepsilon_\theta} + \frac{\varepsilon_D - \theta}{\varepsilon_S} + \frac{\theta}{\varepsilon_{ms}}} \quad (1)$$

where $\varepsilon_D = -D'p/Q$ and $\varepsilon_S = S'p/Q$ are the demand and supply elasticities. Holding other parameters constant, pass-through depends on the relative elasticities of supply and demand and the tax burden falls mostly upon the side that is least responsive to prices (Jenkin, 1872). $\varepsilon_{ms} = ms/ms'q$ is the price elasticity of marginal surplus; it measures the curvature of the logarithm of demand and can be positive or negative (Fabinger and Weyl, 2012). If demand is linear, then $\varepsilon_{ms} = 1$, if concave, then $\varepsilon_{ms} < 1$, and if convex $\varepsilon_{ms} > 1$. Therefore, depending on the functional form of demand, pass-through under market power is ambiguous, i.e. it can be higher or lower than under perfect competition (Bulow and Pfleiderer, 1983). Tax pass-through ρ_I is essentially driven by the conduct parameter θ and the elasticity of conduct with respect to quantity $\varepsilon_\theta = \theta/q \times d\theta/dq$.⁷ Due to non-linear interactions with multiple elasticities, an increase in the conduct parameter can have either a positive or negative effect on pass-through. Without further assumptions, the sign and magnitude of the pass-through are generally ambiguous.

In the specific case of gasoline retailing, marginal costs are assumed to be constant because the main cost driver is the purchase of gasoline. This implies that $\varepsilon_S \rightarrow +\infty$, an assumption that seems reasonable in the short run. Therefore, the term $\varepsilon_D - \theta/\varepsilon_S$ in the denominator of equation (1) converges to zero and diminishes. A constant conduct parameter θ without restricting its magnitude seems reasonable at least in the short run (Genakos & Pagliero, 2022). Hence, $d\theta/dp = 0$ which results in diminishing $\theta/\varepsilon_\theta$. We rely on a linear functional form of demand ($\varepsilon_{ms} = 1$), with the understanding that this assumption is quite restrictive (Mrázová and Neary, 2017).⁸ Under these premises, the pass-through of a tax change to retail prices is defined as $d\rho/d\tau = 1/(1+\theta)$. Increasing competitive pressure, indicated by a decrease in the conduct parameter, leads to higher pass-through rates. Conversely, market imperfections result in lower pass-through rates. Moreover, estimating pass-through can provide insight into market characteristics, as the relationship between pass-through and competition intensity can be inverted.

4.2 Estimation Strategy

While the majority of available research on short-term tax incidence in gasoline retailing is based on difference-in-difference approaches (Eckert, 2013), our study belongs to the emerging

⁶For Cournot competition with N symmetric firms, the conduct parameter equals to $1/N$.

⁷Under perfect competition ($\theta = 0$) equation (1) yields the standard tax incidence formula: $\rho_C = 1/(1+\varepsilon_D/\varepsilon_S)$. In this case, pass-through is limited to a range of 0% to 100% and primarily affects the side of the market that is least responsive to changes in price.

⁸By regressing logged distance driven on logged fuel prices under various functional forms, Frondel et al. (2024) find no evidence of convexity, thus supporting the credibility of the assumed linearity in demand.

body of empirical work that employs a Regression Discontinuity in Time (RDiT) framework. This methodological choice results from the setting of the two policy interventions (June 1st and September 1st, 2022) which affected all gas stations and their customers equally, implying serious difficulties in defining a feasible control group.⁹

In the potential outcomes framework, formalized by the Neyman-Rubin (1974) model causality of a treatment is inferred based on the estimation of an average treatment effect (ATE). Given the fact that it is not possible to observe an individual unit in more than one state at once, the individual treatment effect is fundamentally unknown (Holland, 1986). It is thus not possible to compare an outcome under both treatment status $Y_i(1)$ and control status $Y_i(0)$, but these binary treatment indicators can be used to derive the average treatment effect (ATE) by comparing the average outcomes of those individuals who received treatment to that of individuals without treatment as $\tau = \mathbb{E}[Y_i(1) - Y_i(0)]$ (Rubin, 1974). However, for non-randomized processes, a simple comparison of the observed outcome of the treatment group and a control group can lead to selection bias.

In absence of randomized treatment assignment, the use of a sharp RD may be considered. In the standard cross-sectional regression discontinuity (RD) framework, the treatment status is determined relative to the value of a continuous variable, the so-called forcing variable X_i being on either side of a threshold c .¹⁰ However, in this methodological setting, the researcher only observes the outcome under control $Y_i(0)$ for units whose score is below the threshold c and the outcome under treatment $Y_i(1)$ for units whose score is above c (Lee and Lemieux, 2010). If the values of the average potential outcomes at c are not substantially different from their values at points near c , then units with $X_i = c$ and $X_i = c - \varepsilon$ would be very similar except for their treatment status. Under a sharp RD, the average treatment effect (ATE) can be represented by $\tau_{ATE} = \mathbb{E}[Y_i(1) - Y_i(0)|X_i = c] = \lim_{x \downarrow c} \mathbb{E}[Y_i|X_i = x] - \lim_{x \uparrow c} \mathbb{E}[Y_i|X_i = x]$ by assuming $\mathbb{E}[Y_i(1)|X_i = x]$ and $\mathbb{E}[Y_i(0)|X_i = x]$ are continuous in x (Hahn et al., 2001).¹¹ To ensure internal validity, several mild assumptions must be satisfied: First, to guarantee quasi-random assignment of treatment around the threshold, there must be randomness in the forcing variable and the units considered cannot perfectly manipulate their treatment status. Second, observed and unobserved characteristics other than treatment status must be continuous at the threshold.

Recent empirical research in several economic fields, particularly environmental and energy fields, has adopted the RD methodology to applications where the forcing variable is time and treatment begins at a particular threshold time. Under such a Regression Discontinuity in Time

⁹Other studies (e.g. Fuest et al., 2022; Freitas and Syga, 2022; Drolsbach et al., 2023; Frondel et al., 2024) employ the difference-in-difference approach, utilizing (to varying degrees) one or more neighboring European countries as control groups. Given the substantial heterogeneity across countries in price developments, market characteristics, and regulatory policies, the results may depend on the particular choice of the counterfactual.

¹⁰For a comprehensive review of the methodological literature on the analysis and interpretation of regression discontinuity designs, see Cattaneo and Titiunik (2022).

¹¹Lee and Lemieux (2010) provide a mathematical proof that when the treatment effect varies across units, the estimate of τ is a weighted average of the individual treatment effects.

(RDiT) setting, the ATE is defined as the difference in intercept at the start of the intervention: $\tau_{ATE} = \lim_{t \downarrow T_0} \mathbb{E}[Y_i | T_i = t] - \lim_{t \uparrow T_0} \mathbb{E}[Y_i | T_i = t]$. As the identifying variation in RDiT is similar to that in interrupted time series or event studies (Anderson-Cook, 2005), several features of an RDiT differ from those of a conventional RDD, accompanied by different challenges (Hausman and Rapson, 2018). For instance, while a cross-sectional RD can be viewed as a random trial locally around a threshold (Lee, 2008), time as a forcing variable in an RDiT cannot be regarded as randomly assigned within the proximity of the threshold and RDiT only corresponds to the discontinuity at a threshold characterization (Hahn et al., 2001). Furthermore, in RDiT settings treatment is inevitable for all units and therefore, the characterization of RDiT is conceptually distinct from RD. While a standard RD is determined over the cross-section, e.g. the N dimension, RDiT is identified in the time dimension T . Since time is uniformly distributed among units, density tests (e.g. McCrary, 2008) which check for sorting or anticipating behavior around the threshold are not feasible. A further consequence relates to the role of covariates: In contrast to the standard RD where baseline covariates are included to increase the precision by reducing sampling variability (Lee and Lemieux, 2010), RDiT is more vulnerable to unobservables that may be correlated with the forcing variable T . Since they may have discontinuous impacts on the potential outcome, covariates need to be included as controls to prevent bias, rather than alone to improve precision (Hausman and Rapson, 2018). In addition, the time series character of a RDiT setting might also cause autocorrelation problems both in the outcome variable and in the residuals which need to be checked.

With two times of intervention (introduction on June 1st and termination on September 1st, 2022), the German fuel tax discount is conceptually consistent with the RDiT approach using the time of tax change as the threshold of the forcing variable, time. We estimate two models for each fuel type (E5, E10, and diesel) to determine the pass-through for the tax decrease and its subsequent increase for gasoline blends and diesel, respectively. We do not impose a particular structure to recover the mechanisms behind pass-through, as we can observe a large fraction of costs. Therefore, we utilize a reduced-form approach in line with the growing literature (e.g. Vita, 2000; Chouinard and Perloff, 2004) and estimate the following equation to determine average pass-through levels:

$$p_{ict} = \alpha + \beta TR_t + \gamma_1 f(date_t) + \gamma_2 TR_t \times f(date_t) + \delta X_{ct} + \mu_i + \epsilon_{ict} \quad (2)$$

where p_{ict} displays daily average prices in cents per liter at station i in county c on day t ; $TR_t = \begin{cases} 1, & t \geq T_0 \\ 0, & t < T_0 \end{cases}$ is an indicator variable that takes the value of one from the implementation date of the tax change T_0 ; and $date_t$ is the forcing variable that is normalized to T_0 and determines the number of days before and after the tax change; $f(\cdot)$ is a second-order polynomial.¹² To account for different time trends and price fluctuations on both sides of the threshold, we include an interaction term $TR_t \times f(date_t)$ in the model. The main coefficient of interest is β ,

¹²Section 6.1 provides further robustness checks for different n th order polynomials.

which captures the population ATE where $t = T_0$. Considering the definition of pass-through, $\rho = dp/d\tau$, the pass-through rate $\hat{\rho}$ is given by $\hat{\rho}_{gasoline} = |\hat{\beta}_{gasoline}|/35.16$ in the case of E5 and E10 and $\hat{\rho}_{diesel} = |\hat{\beta}_{diesel}|/16.71$. The matrix X_{ct} accounts for the time-varying differences between 401 German counties c in terms of supply and demand conditions. Specifically, we account for demand-side effects by controlling for school and public holidays, the day before holidays, and weather conditions such as temperature and precipitation measures. Based on the extensive literature on the response of retail prices to upstream costs (e.g. Borenstein et al., 1997; Frondel et al., 2016), we control for input cost fluctuations by lagged Brent crude oil prices and US dollar to euro exchange rates. Given that gasoline prices tend to exhibit intra-week price cycles, with potential peaks on Sunday and Monday (Noel, 2007; Foros and Steen, 2013), we include indicator variables for these particular days. Along with various studies examining station-specific price dispersion (Lewis, 2008; Hosken et al., 2008; Kihm et al., 2014), μ_i denotes the unknown individual-specific term that accounts for time-invariant endogeneity.¹³ By allowing for variable intercepts per station, we aim at capturing constant upstream cost levels that may depend on operating forms, partner agreements, or supply costs. Furthermore, as the location is a constant determinant of gas stations and indicates proximity to traffic junctions, commuting routes, or the next refinery, fixed effects can capture the impact of constant differences in demand levels and delivery costs, respectively. To conclude the specification, ε_{ict} denotes the idiosyncratic error term that varies over stations and time. Since it is assumed that the variance is not equal across observations, heteroskedasticity-consistent (HC) standard errors are implemented.

For the main specification, we consider a bandwidth of two weeks before and after treatment, so the polynomial fit only includes observations with $X_i \in [T_0 - 14, T_0 + 14]$. Bandwidth choice is a crucial aspect of RD as it balances bias and precision of estimates (Lee and Lemieux, 2010). Simultaneously, we must account for possible seasonality effects due to fluctuating prices during the day and week. Since we can avoid the former issue by computing daily prices, we must utilize a suitable time frame to absorb price fluctuations on certain days of the week. We provide further robustness checks with additional bandwidth sizes in section 6.1

5 Data and Descriptive Analysis

5.1 Station-Level Prices and Characteristics

For our study, we had access to high-frequency retail prices of around 14.500 retailing stations across Germany covering the full year of 2022. Tankerkönig, an authorized consumer information service kindly provided us with a rich database of historical price changes and station characteristics.¹⁴ As part of the data processing, we compute daily average prices for each station by

¹³A Hausman-Test favors the fixed effect specification, as the null hypothesis is highly rejected for all fuel types and tax interventions.

¹⁴The data obtained from Tankerkönig is available under the Creative-Commons-License (CC BY 4.0) at <https://creativecommons.tankerkoenig.de>.

weighting all price fluctuations throughout a day by the time difference between a price change and the previous price change.¹⁵ Further characteristics provided by Tankerkönig, such as station name, brand affiliation, address, and coordinates, allow us to localize each station precisely.¹⁶ Various spellings and misspellings have been taken into account to standardize the brand affiliation. As highway stations constitute a distinct business segment and operate in different competitive environments than the majority of roadside stations (Haucap et al., 2015; Kleineberg, 2020), we differentiate between roadside stations (n=14,257) and highway stations (n=358) based on station name and address. Table 2 displays descriptive statistics of the average prices for the 14-day period preceding and following each tax change. Besides higher price levels for highway stations, we observe continuously higher standard errors. We observe a mean difference in prices for the initial and subsequent interventions, with the magnitude of this difference varying across fuel and station types. Figure 1 presents a graphical representation of the nationwide time series data, disaggregated by fuel type and station category, during both policy interventions. In addition to the observation of pronounced price fluctuations, a preliminary assessment indicates that there have been notable price responses across all types of fuel. Furthermore, highway stations charge on average approximately 25 cents per liter more for fuel of all types. Due to the differing pricing strategies and business segments, we focus solely on the local market structure of roadside stations in the following analysis. According to Stolper (2016) and Kahl (2020), cross-border effects are common in gasoline markets and price and tax differentials at state borders may result in extensive fuel tourism (Rietveld et al., 2001; Banfi et al., 2005). As we are unable to observe prices and approximate market structures in neighboring countries, we exclude observations within a 10 kilometer geodetic distance from the German border for our main analysis.

5.2 Approximation of Local Market Structures

Comparable to measures that are commonly employed in the retail gasoline markets literature (e.g. Lade and Bushnell, 2019; Stolper, 2016; Chang, 2023), we construct a variety of indicators to study the effects of local competition on pass-through. We consider market dynamics resulting from market entries and exits by calculating separate indicators for each period around the first and second tax intervention. Given the highly localized nature of fuel station markets, we employ detailed geographic information to calculate linear distances between competing stations in their immediate vicinity.¹⁷

The mean distance to the closest stations operated by a competing brand is approximately 1.7 kilometers with a range from virtually 0 kilometers up to 17.2 kilometers (table 3). As one moves

¹⁵We assume 24/7 opening hours to calculate daily averages. If a station does not report any price changes a day, the last price of the day prior is used to reflect the current price.

¹⁶Implausible geo-coordinates have been corrected by forward geocoding through the OpenCage API (see <https://opencagedata.com>).

¹⁷Geodetic distances are calculated using the Vincenty (1975) equation, which takes into account the elliptical curvature of the Earth.

Table 2: Summary Statistics

	First Intervention				Second Intervention			
	Road		Highway		Road		Highway	
	Before	After	Before	After	Before	After	Before	After
Super e5 (ct/l)	215.00 (5.02)	198.40 (4.16)	242.09 (12.76)	224.46 (12.64)	179.56 (6.85)	202.92 (7.94)	199.47 (11.70)	230.90 (15.66)
Super e10 (ct/l)	209.18 (5.39)	192.66 (4.29)	236.81 (13.25)	219.25 (13.24)	173.99 (7.33)	197.15 (8.12)	194.38 (12.53)	225.78 (16.26)
Diesel (ct/l)	199.85 (4.69)	198.63 (4.95)	228.42 (13.67)	224.13 (12.04)	200.89 (8.50)	213.90 (7.33)	220.07 (11.02)	238.55 (12.63)
Brent (ct/l)	73.83 (2.76)	79.47 (1.29)	73.83 (2.76)	79.47 (1.29)	61.97 (1.35)	57.75 (1.24)	61.97 (1.35)	57.75 (1.24)
€ to US\$ (ct)	106.54 (0.79)	106.50 (1.00)	106.54 (0.79)	106.50 (1.00)	100.15 (0.59)	100.14 (0.78)	100.15 (0.59)	100.14 (0.78)
Temp. (°C)	15.00 (3.49)	16.59 (2.33)	15.15 (3.50)	16.81 (2.32)	19.71 (2.35)	17.28 (2.27)	19.91 (2.30)	17.36 (2.25)
Precip. (mm)	2.20 (3.55)	1.82 (3.86)	2.09 (3.41)	1.70 (3.67)	2.11 (6.39)	3.38 (5.99)	2.07 (6.31)	3.68 (6.19)
Observations	193,682	193,478	5,026	5,026	193,516	194,108	5,026	5,026

Note: Daily averages for roadside and highway stations for the period 14 days before and after June 01 and September 01, respectively. Standard deviations are shown in parentheses.

across the urban-rural continuum, stations become increasingly isolated in rural areas.¹⁸ In order to delineate local markets, we group stations within a particular radius, gauged by linear distance, and consider them as competing firms in the same market. Determining an appropriate threshold is crucial for establishing the geographic extent of gasoline retail markets since the proper market area depends on a variety of factors, including road network, population density, and search costs (Barron et al., 2004; Perdiguero and Borrell, 2019). The existing literature does not provide a clear consensus on the delineation of local gasoline retail markets. Eckert and West (2004) and Haucap et al. (2015) rely on a two-kilometer radius, whereas Kihm et al. (2014) and Kleineberg (2020) use five kilometer distances since driving such a distance would take an average driver five to ten minutes. For our main specification, we assume a uniform delineation of local markets, with a radius of four kilometers for all roadside stations across Germany.¹⁹ According to the given definition of the geographic markets, we observe an average of six competitors associated with approximately five brands (table 3). The structure of local markets undergoes significant spatial variation. A station located in metropolitan areas faces around 11 rivals affiliated with roughly eight brands, whereas rural markets exhibit lower absolute values of brands and competitors. Similar to Doyle Jr and Samphantharak (2008) and Jametti et al. (2013), we compute a station-specific Herfindahl-Hirschman Index (HHI), a widely applied concentration measure in the field of antitrust law to detect dominant market positions of one or more suppliers. The index typically values from $1/N \leq HHI \leq 1$: At $HHI = 1/N$ firms have equal market shares, whereas high values suggest that one or a few firms control large parts of the markets. Markets dominated by a

¹⁸Each gas station was assigned a class along the urban-rural continuum based on the NUTS3 urban-rural classification provided by EUROSTAT (see https://ec.europa.eu/eurostat/cache/RCI/#?vis=urbanrural.urb_typology&lang=en).

¹⁹Sensitivity tests for 3 kilometer and 5 kilometer thresholds were performed and are shown in the appendix.

monopoly exhibit values of 1.²⁰ In contrast to the aforementioned measures, the HHI incorporates both the distribution of brands and market shares, which makes it a reliable proxy for the competitive landscape of local markets. We define market shares as the proportion of stations affiliated with a single brand in a given market. On average, we observe a HHI of 0.34 across local markets. In accordance with the preceding measures, market concentration exhibits a significant increase across urban and rural regions. Usually, market exits and entries impact the structure of local markets. However, market developments over the observation period are of limited consequence and, therefore, can be considered as highly insignificant in light of all employed measures. For a graphical representation, figure 2 displays the spatial heterogeneity of the measure for market concentration for all roadside stations. As expected, there is a relatively high density of stations, especially in conurbations and highly populated regions like the Ruhr area. However, we observe a substantial number of isolated stations that exhibit HHI values as high as one across Germany. Our descriptive findings indicate a significant variation of horizontal market structures at the local level, given a uniform extent of markets. This conclusion is consistent across alternative thresholds for market delineations, as demonstrated in table (A1).

Table 3: Spatial Competition between Roadside Stations in Germany 2022

	full sample		region type					
			urban		intermediate		rural	
dist. next comp. (km)	1.69 (1.93)	1.70 [(1.93)]	1.08 (1.08)	1.08 [(1.08)]	1.82 (1.99)	1.83 [(1.99)]	2.37 (2.50)	2.39 [(2.50)]
brand count	5.34 (3.40)	5.31 [(3.39)]	7.51 (3.24)	7.46 [(3.23)]	4.65 (3.10)	4.65 [(3.11)]	3.35 (2.20)	3.32 [(2.18)]
comp. count	6.47 (6.54)	6.41 [(6.47)]	11.14 (7.48)	11.00 [(7.37)]	4.80 (4.89)	4.79 [(4.91)]	2.64 (2.61)	2.60 [(2.58)]
HHI	0.34 (0.27)	0.35 [(0.27)]	0.22 (0.16)	0.22 [(0.16)]	0.37 (0.28)	0.37 [(0.28)]	0.48 (0.31)	0.48 [(0.31)]
Observations	14,257	[14,200]	4,791	[4,765]	6,451	[6,429]	3,015	[3,006]

Note: Average values for various measures of local competition for the full sample and by region type during May and June. Values for August and September are included in squared brackets. Standard errors are in parentheses. Geographic distances are calculated via the Vincenty (1975) equation. The Herfindahl-Hirschman-Index (HHI) ranges between $1/n$ and 1. The later three parameters are based on a 4 km radius market delineation. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

As the HHI only differentiates brands by market shares, we provide a further overview of the retail market given by brand affiliation. Table 4 summarizes the distribution of stations by vertical integration segments and by selected brands. As we are not able to conduct a direct measure of vertical integrations, we rely on a classification proposed by the German competitive authority (Bundeskartellamt, 2022) that is applied to empirical research by Haucap et al. (2015; 2017). Based on brand affiliation, gas stations are classified as "oligopolistic players", which include Aral (BP), Shell, and TotalEnergies. These stations have a nationwide network and direct

²⁰Station-specific HHI is given by $HHI_r = \sum_{k=1}^N (x_k / \sum_{j=1}^N x_j)^2$, $\forall i$ for roadside station i , brand k , and station j within the market boundaries defined by the radius r around i .

access to refining capacities, resulting in high levels of vertical integration. Esso (ExxonMobil), Jet (ConocoPhillips), Orlen (Star), ENI (Agip), Tamoil/HEM, and OMV make up the group of “other vertically integrated players” and share typically a regional station network. The last group comprises “independents”, which includes smaller brands and joint brands such as Avia, BFT, or Raiffeisen. Top major players and other integrated players dominate the gasoline retail market. Considering the urban-rural divide, vertically integrated brands prevail in urban regions, while the proportion of independent stations increases in rural areas.

Table 4: Brand Affiliation

	full sample	region type		
		urban	intermediate	rural
<i>number of stations by segment</i>				
oligopolistic player	4,621 [4,595]	1,942 [1,930]	1,914 [1,903]	765 [762]
other integrated player	3,352 [3,329]	1,327 [1,314]	1,445 [1,438]	580 [577]
independent player	6,284 [6,276]	1,522 [1,521]	3,092 [3,088]	1,670 [1,667]
<i>number of stations by brand</i>				
ARAL	2,149 [2,133]	910 [904]	901 [892]	338 [337]
SHELL	1,644 [1,638]	709 [706]	682 [681]	253 [251]
ESSO	977 [950]	406 [391]	406 [396]	165 [163]
TOTALEnergies	828 [824]	323 [320]	331 [330]	174 [174]
JET	686 [687]	324 [324]	290 [291]	72 [72]
Observations	14,257 [14,200]	4,791 [4,765]	6,451 [6,429]	3,015 [3,006]

Note: Frequency of roadside stations for each brand segment and the top five brands for the total sample and by region type during May and June. Frequencies for August and September are included in squared brackets. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

5.3 Other Covariates

In order to account for the drivers of fluctuations in gasoline prices, we include price-influencing factors from a variety of sources. Fluctuations in input costs are mainly influenced by international crude oil prices. We use data from the U.S. Energy Information Administration (EIA) to obtain daily closing spot prices for Brent crude oil, Europe’s most important crude oil grade.²¹ Additionally, international trade in crude oil and refined products requires to account for exchange rates. We use daily exchange rates between the US dollar and the euro from the European Central Bank.²²

On the demand side, the main drivers of fuel prices are seasonality and weather effects. Böcker et al. (2013) and Tsapakis et al. (2013) provide evidence for weather impacts, with favorable weather conditions promoting active transportation modes such as walking or cycling, and unfavorable weather conditions, in particular precipitation (both rain and snow), cause commuters to switch to motorized modes with higher fuel consumption. To consider these impacts, we assign

²¹ See <https://www.eia.gov/dnav/pet/hist/rbrteD.htm>

²² See https://www.ecb.europa.eu/stats/policy_and_exchange_rates/html/index.en.html

day- and county-specific weather information to each gas station by using data from the Climate Data Center of the German Weather Service.²³ Temperature and precipitation measurements of 5,558 and 493 stations, respectively, between May and September 2022, are geo-localized and aggregated into daily averages at the NUTS-3 level to correspond to our station sample.²⁴ Table 2 provides descriptive statistics for supply and demand shifters before and after the fuel tax reduction and subsequent increase, respectively. As for additional seasonality impacts, public and school holidays are commonly assumed to affect fuel prices due to different traffic patterns and volumes than on normal days. We control for these effects by adding state-specific school and holiday dummies derived from the Standing Conference of Ministers of Education and Cultural Affairs (KMK).²⁵ To capture possible anticipation effects of high seasons where gas stations adopt different pricing strategies (Hall et al., 2007; Erutku, 2007), we include an indicator for the day before each holiday.

6 Estimation Results

In this section, we focus on the estimation results for gasoline E5 and diesel. Appendix B contains the corresponding estimation results for gasoline E10 which are very close in all levels to those for E5 and therefore not further discussed here.

6.1 Average Tax Pass-Through

Figure 3 shows the RDiT plots for the first and second interventions, with daily average prices of 13,359 and 13,398 roadside gas stations, respectively, in a window of 14 days before and after each treatment.²⁶ Based on a quadratic time trend before and after each intervention, the visual representation indicates a sharp decrease in average prices after the first intervention of approximately 26 cents per liter for E5 and 12 cents per liter for diesel, and a price increase of 21 cents per liter for E5 and 7 cents per liter for diesel after the second intervention. Table 5 provides regression discontinuity estimates for the initial tax intervention on June 1st, as calculated by equation (2) and successively including controls, for E5 (columns (1) – (4)) and diesel (columns (5) – (8)). The coefficients including Z quantify the price trends around the tax interventions and depict similar algebraic signs across fuel types for each intervention. Pass-through rates, given by $\hat{\rho}_{gasoline} = |\hat{\beta}_{gasoline}|/35.16$ and $\hat{\rho}_{diesel} = |\hat{\beta}_{diesel}|/16.71$, range from 77.8% to 71.0% for E5 and diesel, respectively. To control whether the tax change response is affected by underlying supply and demand conditions, the subsequent columns add controls successively, until columns (4) and (8) provide the full inclusion of the covariate matrix X_{ct} . By accounting for underlying factors, the

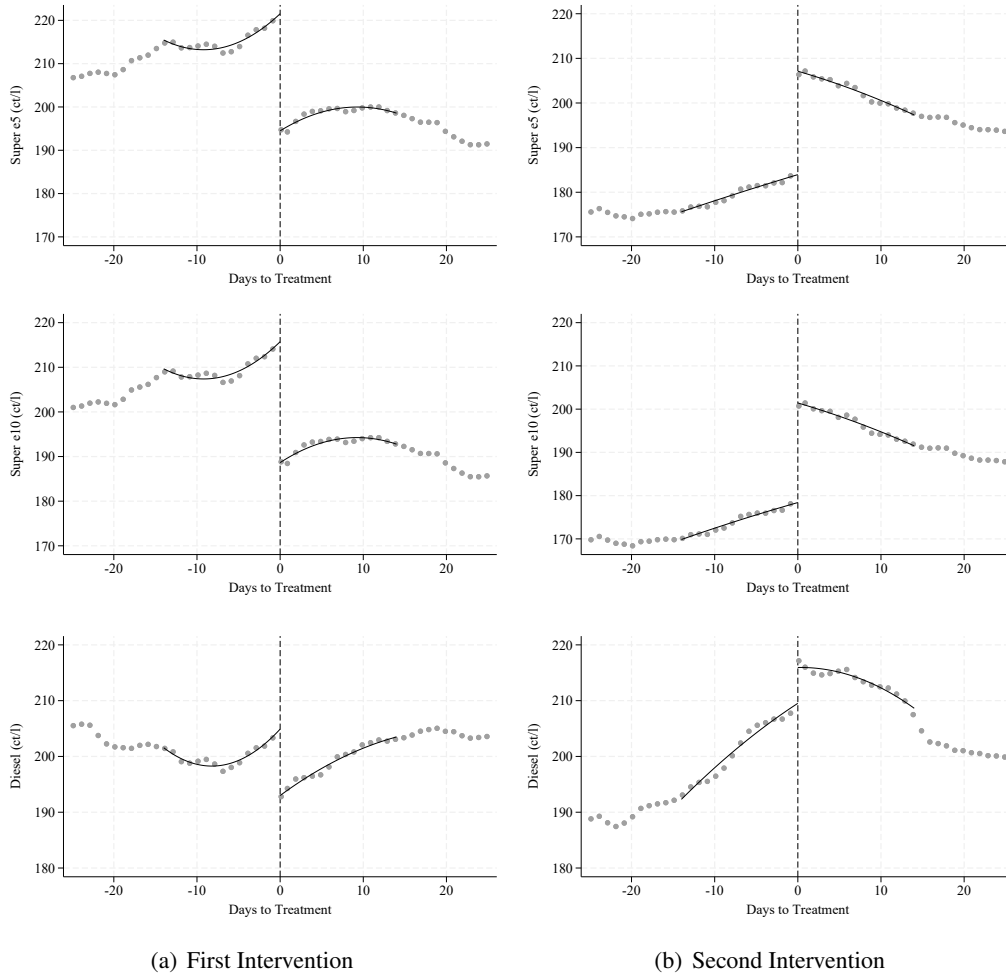
²³See <https://cdc.dwd.de/portal/>

²⁴Counties without valid observations are assigned measurements from the nearest weather stations.

²⁵See <https://www.kmk.org/service/ferien.html>

²⁶As stated in section 5.1, to account for potential effects on the border between Germany and other countries, approximately 800 stations situated in close proximity to the border have been removed from the analysis.

Figure 3: RDiT Plot - Average Nationwide Effect of the Fuel Discount in Germany 2022



Note: Graphical representation of the RDiT during the (a) first and (b) second intervention. Each point illustrates the daily average prices of roadside stations. The function in black represents the quadratic time trend before and after the treatment, each for a period of 14 days. The figure is based on own calculations using Tankerkönig data ([https://creativecommons.tankerkoenig.de.](https://creativecommons.tankerkoenig.de/)).

treatment estimator stabilizes at -27.28 cents per liter and -12.22 cents per liter, indicating an incomplete pass-through for both E5 and diesel at 77.6% and 73.1% , respectively. All coefficients are significantly different from zero at the one percent level. With respect to the control variables, the observed associations are largely in line with expectations. Upon examination of upstream costs, a significant relationship between crude oil prices and exchange rates with retail prices is observed, which remains stable when demand shifters are included. However, there is a distinct bond between each type of fuel, with the algebraic sign being the opposite.²⁷

Economic theory of tax incidence suggests that price responses to taxes are symmetric for both tax increases and tax reductions. As a result, any standard incidence model predicts that if a tax

²⁷The disparate effects of upstream costs can be attributed to some amount to the differences in refining efficiency between gasoline and diesel (EIA, 2023). Furthermore, short-term decoupling of retail and crude oil, given the skyrocketing prices in early 2022, may explain our coefficients (Szafranek and Rubaszek, 2023).

Table 5: Average Pass-Through of the German Fuel Discount - First Intervention

	Super e5				Diesel			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TR	-27.35*** (0.05)	-27.81*** (0.05)	-27.05*** (0.05)	-27.28*** (0.05)	-11.86*** (0.03)	-12.25*** (0.04)	-11.91*** (0.03)	-12.22*** (0.03)
Z	1.95*** (0.01)	1.89*** (0.01)	1.96*** (0.01)	1.84*** (0.01)	1.64*** (0.01)	1.70*** (0.01)	1.56*** (0.01)	1.63*** (0.01)
Z ²	0.11*** (0.00)	0.10*** (0.00)	0.11*** (0.00)	0.10*** (0.00)	0.10*** (0.00)	0.10*** (0.00)	0.09*** (0.00)	0.09*** (0.00)
TR × Z	-0.76*** (0.01)	-0.57*** (0.01)	-0.91*** (0.01)	-0.72*** (0.01)	-0.61*** (0.01)	-0.53*** (0.01)	-0.45*** (0.01)	-0.36*** (0.01)
TR × Z ²	-0.17*** (0.00)	-0.19*** (0.00)	-0.17*** (0.00)	-0.18*** (0.00)	-0.12*** (0.00)	-0.13*** (0.00)	-0.12*** (0.00)	-0.13*** (0.00)
<i>Supply Shifter</i>								
Brent (ct/l)		0.14*** (0.01)		0.21*** (0.01)		-0.03*** (0.00)		-0.04*** (0.00)
€ to US\$ (ct)		-0.77*** (0.01)		-0.56*** (0.01)		-0.48*** (0.01)		-0.44*** (0.01)
<i>Demand Shifter</i>								
Constant	221.83*** (0.03)	293.82*** (0.98)	221.29*** (0.04)	265.18*** (1.09)	204.95*** (0.03)	259.20*** (0.87)	204.45*** (0.03)	255.36*** (0.96)
Observations	352,835	352,814	352,835	352,814	359,863	359,841	359,863	359,841
Adjusted R ²	0.931	0.931	0.933	0.934	0.590	0.592	0.604	0.606

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. TR indicates treatment by the tank rebate, Z represents the amount of days before and after treatment. The bandwidth includes 14 days before and after June 01. All regressions include station fixed effects. Robust Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

rate is reduced and then increased back to its original level, the equilibrium price after the increase should be equivalent to the equilibrium price before the increase. We examine this expectation by estimating pass-through for the subsequent tax increase on September 1st; regression results are reported in table 6. Columns (4) and (8) depict treatment effects of 22.44 cents per liter and 8.21 cents per liter, respectively, corresponding to pass-through rates of 63.8% and 49.1% for E5 and diesel.²⁸ Interestingly, we detect a pronounced asymmetric reaction to the temporary fuel tax discount in Germany, as we detect lower pass-through rates for the tax increase than for the prior tax reduction.²⁹ Table 7 presents the pass-through rates for all fuel types for both the first and second tax interventions, respectively. Furthermore, we have estimated pass-through for the 359 highway stations, which reveal approximately 10%p higher pass-through levels during the first intervention.³⁰ With regard to E5 and E10, the pass-through at highway stations remains relatively symmetrical, with the exception of diesel, which exhibits a lower pass-through for the tax

²⁸In Germany, school holidays typically end around the beginning of September. For this reason, table 6 does not show estimates for the day-before-holiday indicator.

²⁹Equality of response to the tax reduction and the subsequent tax increase can be statistically rejected at all common significance levels for all fuel types.

³⁰Upon request, regression results for highway stations will be provided by the authors.

hike.³¹ Our results are somewhat different from those found in the literature on gasoline markets. Alm et al. (2009) find no evidence of asymmetric responses to excise tax changes. Doyle Jr and Samphantharak (2008) find that tax cuts are shifted forward to a lesser extent than tax increases, but cannot statistically reject the equality of response.³²

Table 6: Average Pass-Through of the German Fuel Discount - Second Intervention

	Super e5				Diesel			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TR	23.21*** (0.05)	22.90*** (0.05)	22.91*** (0.05)	22.44*** (0.05)	7.01*** (0.03)	7.90*** (0.03)	6.89*** (0.03)	8.21*** (0.03)
Z	0.52*** (0.01)	0.63*** (0.01)	0.71*** (0.01)	0.75*** (0.01)	0.81*** (0.01)	0.95*** (0.01)	0.82*** (0.01)	0.77*** (0.01)
Z ²	-0.01*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	0.00*** (0.00)	-0.03*** (0.00)	-0.01*** (0.00)	-0.03*** (0.00)	-0.03*** (0.00)
TR × Z	-1.00*** (0.01)	-1.23*** (0.02)	-1.21*** (0.02)	-1.37*** (0.02)	-0.95*** (0.01)	-0.94*** (0.01)	-0.92*** (0.01)	-0.58*** (0.01)
TR × Z ²	-0.01*** (0.00)	-0.01*** (0.00)	-0.02*** (0.00)	-0.01*** (0.00)	0.01*** (0.00)	-0.01*** (0.00)	0.01*** (0.00)	-0.02*** (0.00)
<i>Supply Shifter</i>								
Brent (ct/l)		-0.05*** (0.00)		-0.13*** (0.01)		0.33*** (0.00)		0.38*** (0.00)
€ to US\$ (ct)		-0.25*** (0.01)		-0.01 (0.01)		-0.38*** (0.01)		-0.17*** (0.01)
<i>Demand Shifter</i>								
Constant	183.83*** (0.03)	212.10*** (1.33)	181.40*** (0.07)	190.13*** (1.20)	209.19*** (0.02)	226.92*** (0.89)	209.09*** (0.06)	202.57*** (0.86)
Observations	353,303	353,229	353,303	353,229	360,425	360,350	360,425	360,350
Adjusted R ²	0.930	0.931	0.931	0.931	0.899	0.900	0.899	0.901

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. TR indicates treatment by the tank rebate, Z represents the amount of days before and after treatment. The bandwidth includes 14 days before and after September 01. All regressions include station fixed effects. Robust Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de/>).

To verify that the models can accurately capture all significant sharp changes at the threshold, figure A1 presents graphical evidence of the primary requirement for the RDiT approach, that is, ε_{ict} does not change discontinuously in time. Across E5, E10, and diesel for both tax changes, we observe a uniform dispersion of predicted residuals over time, with no interruptions on the day of treatment. However, the residual plots of all fuel blends demonstrate a slightly higher variation in residuals during the subsequent period of the second intervention (tax increase).³³ To

³¹ Given that highway stations constitute a discrete business sector and that the market is dominated by vertically integrated players, this subset is likely to drive up coefficients, as evidenced by the findings of the following heterogeneity analysis.

³² For context, Fuest et al. (2024) detect a roughly two times larger price decrease in response to a temporary value-added tax (VAT) reduction for supermarkets than the price increase following a tax rate hike. Benzarti et al. (2020) show that prices respond more to VAT rate hikes for hairdressing than to decreases.

³³ During the latter half of August, Germany experienced a prolonged drought that led to dropping water levels of

assess the credibility of the continuity assumption of the underlying covariates, figure A2 graphs supply shifters such as crude oil (Brent) and exchange rates (€ to US\$) over the period of the temporary fuel discount. While exchange rates exhibit a gradual decline over time, crude oil prices demonstrate a pronounced downward trend accompanied by considerable fluctuations. There is no pronounced discontinuity during either tax intervention, with the exception of a sharp fall in crude oil prices at the end of the fuel discount. However, this decline is a component of fluctuating prices within a longer downward trend.³⁴

Table 7: Pass-Through of the German Fuel Discount per Fuel and Station Type

	First Intervention		Second Intervention	
	Road	Highway	Road	Highway
Super e5	77.6%	87.3%	63.8%	86.8%
Super e10	77.8%	87.3%	63.7%	87.0%
Diesel	73.1%	83.5%	49.1%	77.6%
Stations	13,359	358	13,398	358

Note: Average Pass-Through is given by $\hat{\rho}_{E5,E10} = |\hat{\beta}_{E5,E10}|/35.16$ and $\hat{\rho}_{Diesel} = |\hat{\beta}_{Diesel}|/16.71$. Values for roadside stations are based on RDiT estimates from tables 5 and 6.

Further robustness checks were conducted on the choice of bandwidth and polynomials, which are essential for the approximation of the time trend (Hausman and Rapson, 2018) and to which the RDiT approach is usually sensitive. While larger bandwidths bear the risk including observations that are very different from the threshold, and thus may introduce bias or confounding factors, a small bandwidth results in the loss of statistical power or precision and cannot account for seasonality properly as observations miss variation in the T dimension. Columns (2) to (4) of tables A3 and A4, respectively, display RD estimates for different bandwidths and support the choice of a time window of 14 days before and after treatment. Given the high degree of volatility in gasoline prices and the sensitivity of time trend approximations to outliers, the robustness checks provide strong support for our main specification. Thus, the chosen second-order polynomial is an appropriate specification for adequately capturing time trends without unknowingly extracting some of the residual variation, and for avoiding overfitting.

6.2 Heterogeneous Tax Pass-Through

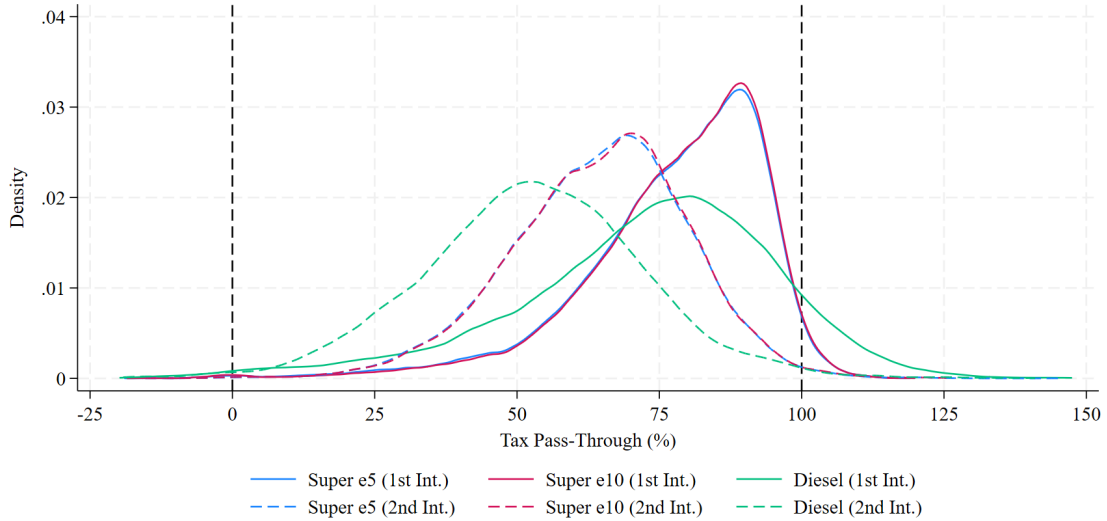
Thus far, we have established convincing evidence of the average incidence of both the tax reduction and increase. It is unclear, however, if these price effects are homogeneous across all roadside stations across Germany. To give insights into the heterogeneity and underlying distribution of pass-through, we estimate an unrestricted model of equation (2). Figure 4 plots the kernel density smoothed distribution of pass-through for both tax interventions, derived from the

the Rhein, a river with a significant transport volume for industrial goods. This may have hindered the supply of gas stations or refineries and, thus, influenced local gas prices.

³⁴Additional robustness checks did not identify significant discontinuities in temperature and precipitation levels.

estimation of policy effect coefficients for 12,482 roadside stations.³⁵ Consistent with our previous results, stations tend to exhibit lower pass-through rates during the tax increase than during the preceding tax reduction. Moreover, the distributions exhibit uni-dimensional characteristics and the observed pass-through rates are relatively widespread, with values ranging from low or negative pass-through up to full and overfull pass-through.

Figure 4: Distribution of Station-Level Pass-Through (%)



Note: The figure displays the smoothed distribution of modified regression discontinuity station estimates. The smoother uses an Epanechnikov kernel. Station level effects are estimated for stations with at least 20 observations within 14 days before and after treatment. Pass-Through is given by $\hat{\rho}_{e5,e10} = |\hat{\beta}_{e5,e10}|/35.16$ and $\hat{\rho}_{diesel} = |\hat{\beta}_{diesel}|/16.71$. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

In order to gain further insights into the drivers behind heterogeneity of pass-through, we introduce an interaction to our main specification (equation 2) that combines the treatment and time variables with a series of indicator variables that proxy for vertical integration, region type, local market structure, and market concentration. To start with, we introduced an indicator variable for vertical integration as an ordinal variable which refers to i) whether a station is affiliated with an oligopolistic player, other vertically integrated, or independent brand. A further ordinal variable indicates whether a station is located in i) predominantly urban regions, ii) intermediate regions, or iii) rural regions. To evaluate the impact of local market structures on pass-through, we considered the distances between a given station and the nearest competitor, and the number of competitors located within defined market boundaries are considered separately. For the latter variable, we classify stations into three categories based on their proximity to the closest rival: less than one kilometer, between one kilometer and three kilometers, and greater than three kilometers. Finally, we consider the effect of market concentration by incorporating distinct quartiles of the station-specific HHI, as detailed in section 5.2. The bottom quartile exhibits an average

³⁵A reliable estimation of pass-through is only possible for stations that satisfy the criterion of reporting prices on all consecutive 14 days before and after policy implementation.

HHI of 0.13, while the mean for the subsequent quartiles is 0.21, 0.39, and 0.93, respectively. As the bottom quartile indicates competitive markets, the top quartile represents highly concentrated markets with mostly one brand and likely one station.³⁶

Table 8: Heterogeneous Pass-Through of the German Fuel Discount - First Intervention

	Super e5					Diesel				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TR	-29.68*** (0.05)	-28.38*** (0.07)	-27.56*** (0.07)	-26.50*** (0.07)	-28.02*** (0.08)	-13.62*** (0.04)	-12.93*** (0.05)	-12.34*** (0.05)	-11.79*** (0.05)	-12.71*** (0.06)
<i>Brand Category</i>										
TR × oth. integr.	2.39*** (0.09)					1.38*** (0.07)				
TR × independ.	4.31*** (0.10)					2.47*** (0.07)				
<i>Regional Typology</i>										
TR × intermed.		1.14*** (0.10)					0.74*** (0.07)			
TR × rural		2.81*** (0.13)					1.80*** (0.09)			
<i>dist. next comp.</i>										
TR × (1 ≤ dist. < 3)			-0.01 (0.10)					-0.03 (0.07)		
TR × (3 ≤ dist.)			1.70*** (0.15)					0.80*** (0.11)		
TR × comp. count				-0.12*** (0.01)					-0.06*** (0.00)	
<i>Herfindahl-Index</i>										
TR × HHI Q ₂					0.33*** (0.11)					0.37*** (0.08)
TR × HHI Q ₃					0.74*** (0.13)					0.58*** (0.09)
TR × HHI Q ₄					2.00*** (0.14)					1.07*** (0.10)
<i>Control Variables</i>										
Constant	265.03*** (1.09)	265.22*** (1.09)	265.18*** (1.09)	265.23*** (1.09)	265.16*** (1.09)	255.40*** (0.96)	255.40*** (0.96)	255.32*** (0.96)	255.30*** (0.96)	255.27*** (0.96)
Observations	352,814	352,814	352,814	352,814	352,814	359,841	359,841	359,841	359,841	359,841
Adjusted R ²	0.936	0.934	0.934	0.934	0.934	0.609	0.611	0.606	0.608	0.607

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. The bandwidth includes 14 days before and after June 01. All regressions include station fixed effects. Competition categories are based on a 4km radius market delineation. Robust Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Table 8 provides heterogeneous pass-through coefficients for the first tax intervention. Considering oligopolistic (highly vertically integrated) players as the reference category in columns (1) and (6) for gasoline (E5) and diesel, respectively, our estimates show that independent fuel stations pass on a significantly smaller proportion of the tax reduction to consumers than oligopolistic players. In numerical terms, mineral oil companies with extensive station networks and remarkable refinery capacities pass on nearly 12%p (15%p) for E5 (diesel) more than independent

³⁶To provide context, the HHI quartiles comprise an average station count of 16.1, 8.9, 3.7, and 1.45, respectively.

companies.³⁷ Table A2 presents additional regression results for selected brands within each category, based on separate regressions. Once again, independent associations such as BFT or AVIA pass on a considerably smaller proportion of the fuel discount than the major five vertically integrated brands. These findings are consistent with those of Bajo-Buenestado and Borrella-Mas (2022), indicating that gas stations exhibit distinct responses to tax changes under varying vertical arrangements.³⁸ Columns (2) and (7) present the effect of the degree of urbanization on tax incidence. While fuel stations located in predominantly urban regions pass through approximately 81% (77%) for E5 (diesel) to consumers, those located in rural regions pass through 8%p (10%p) less. All coefficients are significantly different from zero at the one percent level.³⁹ To provide context, previous research has identified similar causalities (e.g. Alm et al., 2009; Harju et al., 2022). Given the distribution of stations along the urban-rural continuum (table 3), our results may provide a first insight into the effect of competition on pass-through.

Columns (4) and (8) assess the impact of a station's geographic isolation on pass-through (table 8). There is no statistically significant difference in pass-through for E5 and diesel between stations with distances to the nearest competitor of less than one kilometer and between one and three kilometers. However, in contrast to stations located in near proximity of competitors, stations situated at a considerable distance (e.g. more than three kilometers) from a rival pass on 8%p and 11%p less for E5 and diesel, respectively. The remaining columns acknowledge spatial heterogeneity by considering the geographic extent of markets. Similar to Harju et al. (2022) and Chang (2023) we estimate a negative relation between the count of competitors and the pass-through of taxes. Each additional rival is accompanied by an approximately 0.3%p increase in pass-through for both E5 and diesel. Finally, we incorporate the station-level HHI. Columns (5) and (10) present the regression results of the interaction terms, with the excluded category being the bottom HHI quartile as the reference category. The results are remarkably consistent across all fuel types, with the coefficients increasing significantly over each HHI quartile. Higher market concentration (HHI Q_4) is associated with a decrease in pass-through rates of up to 6%p for both E5 and diesel. These findings are consistent with the existing literature on the influence of horizontal market structure on pass-through, which identifies similar patterns of increasing rates with increasing competition intensity (e.g. Genakos and Pagliero, 2022; Harju et al., 2022; Dimitrakopoulou et al., 2023; Chang, 2023; Frondel et al., 2024). Given that the 4-kilometer threshold was artificially selected to delineate markets, we test for pass-through heterogeneity with alternative thresholds. Figure 5 panel (a) illustrates the coefficients for each HHI quartile across market boundaries ranging from three kilometers to five kilometers. The graph illustrates a consistent positive correlation between the quartiles and pass-through coefficients across

³⁷As previously stated in section 5.2, vertical integration is correlated with urbanicity, which results in biased estimates. This point will be further discussed in a subsequent section.

³⁸Lade and Bushnell (2019) identify a lower, but statistically indistinguishable pass-through rate for brands that are affiliated with large and vertically integrated refining companies as few branded stations offer the investigated fuel blend.

³⁹It should be noted, however, that the interpretation of these results must be regarded with some caution, as the distribution of brands across territorial categories is not uniform (table 3) which may lead to omitted variable bias. This issue will be addressed in more detail later on.

Table 9: Heterogeneous Pass-Through of the German Fuel Discount - Second Intervention

	Super e5					Diesel				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TR	23.86*** (0.07)	22.92*** (0.08)	22.75*** (0.07)	21.90*** (0.07)	22.92*** (0.10)	9.10*** (0.04)	8.07*** (0.04)	8.27*** (0.04)	8.09*** (0.04)	8.33*** (0.06)
<i>Brand Category</i>										
TR × oth. integr.	-0.77*** (0.11)					-0.88*** (0.07)				
TR × independ.	-2.90*** (0.10)					-1.56*** (0.06)				
<i>Regional Typology</i>										
TR × intermed.		-0.81*** (0.10)					0.35*** (0.06)			
TR × rural		-0.60*** (0.13)					0.02 (0.08)			
<i>dist. next comp.</i>										
TR × (1≤dist.<3)			-0.36*** (0.10)					-0.05 (0.06)		
TR × (3≤dist.)			-1.11*** (0.13)					-0.20** (0.08)		
TR × comp. count				0.08*** (0.01)					0.02*** (0.00)	
<i>Herfindahl-Index</i>										
TR × HHI Q ₂					-0.24* (0.13)					-0.13* (0.07)
TR × HHI Q ₃					-0.85*** (0.12)					-0.13* (0.08)
TR × HHI Q ₄					-1.06*** (0.16)					-0.25** (0.10)
Control Variables	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Constant	190.15*** (1.20)	190.30*** (1.20)	190.27*** (1.20)	190.37*** (1.20)	190.44*** (1.20)	202.56*** (0.86)	202.56*** (0.86)	202.54*** (0.86)	202.40*** (0.86)	202.47*** (0.86)
Observations	353,229	353,229	353,229	353,229	353,229	360,350	360,350	360,350	360,350	360,350
Adjusted R ²	0.932	0.932	0.931	0.932	0.932	0.902	0.902	0.902	0.902	0.902

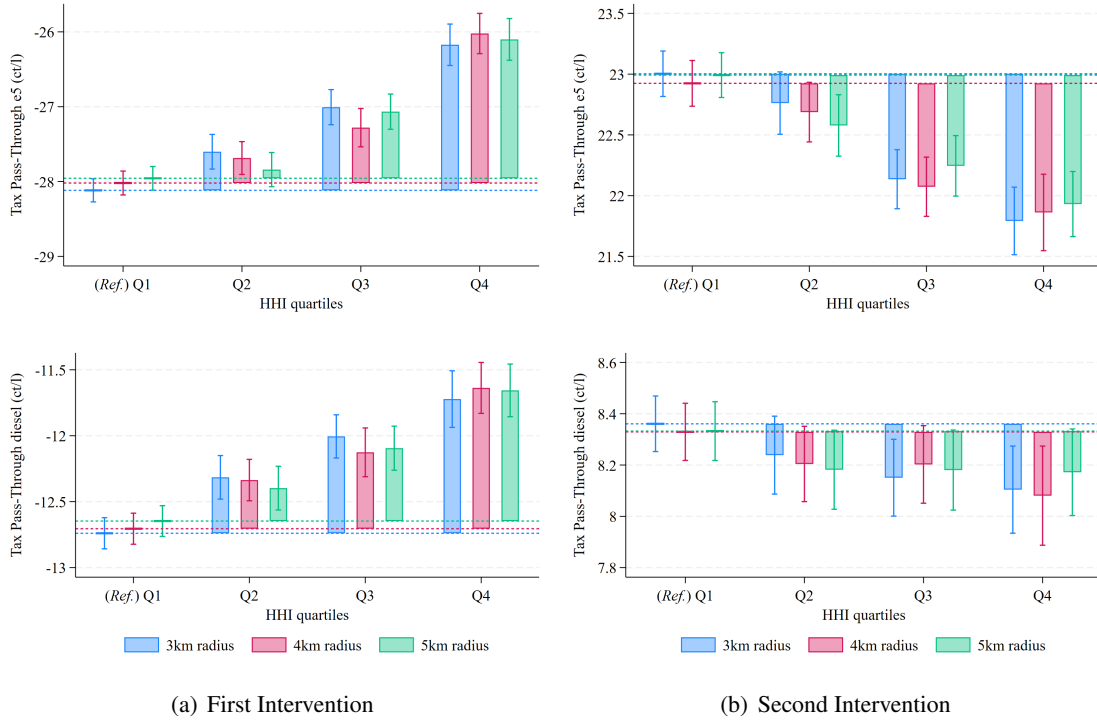
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. The bandwidth includes 14 days before and after September 01. All regressions include station fixed effects. Competition categories are based on a 4km radius market delineation. Robust Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

all defined geographic markets, suggesting robust results regarding geographic market delineation.

Our estimations reveal a similar direction of pass-through variation across categories, with a few exceptions for the second tax intervention (table 9). As the average pass-through levels are significantly lower for the subsequent tax increase, the absolute values of the coefficients across groups are also smaller. Our findings indicate that there are notable disparities across brand categories. In contrast, an urban-rural divide in response to the tax change is not as pronounced, and even non-existent in the case of diesel, as it was at the prior tax reduction. Pass-through variation across local competitive environments shows similar relations as for the first intervention, though with a smaller and slightly less significant effect of competitive pressure on tax incidence. While competitive markets (HHI Q_1) pass through approximately 3%p more of the tax increase

Figure 5: Pass-Through (ct/l) by HHI and Market Boundaries



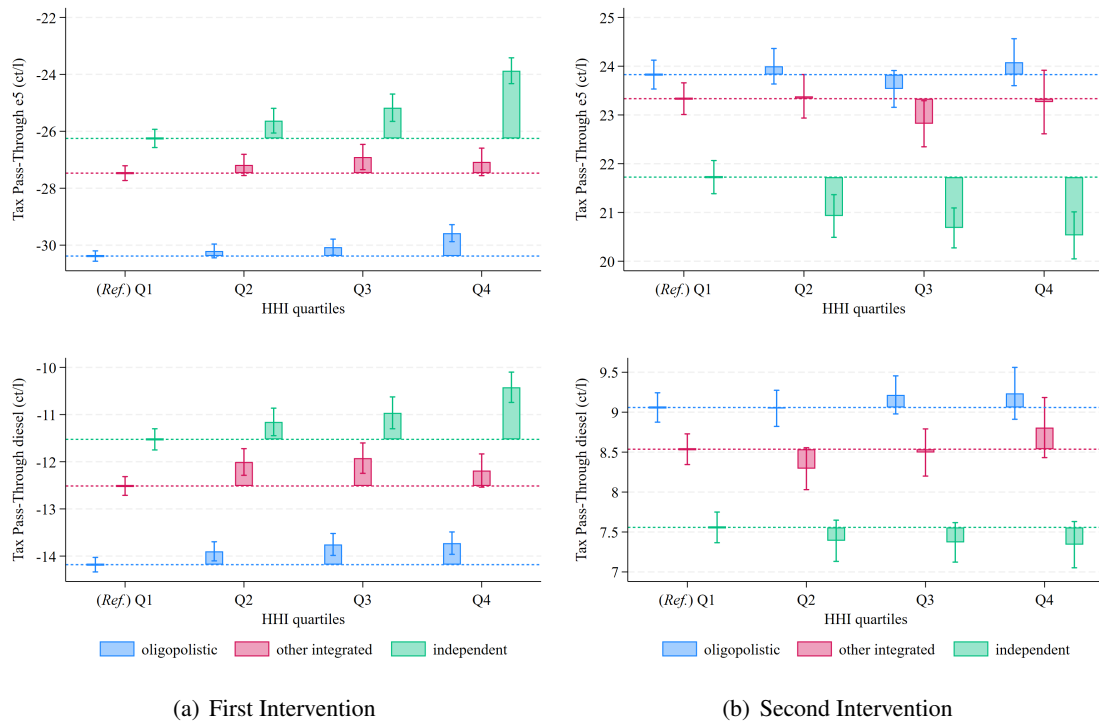
Note: Heterogeneous pass-through levels of the (a) first (b) second intervention by HHI quartiles for different market definitions. Each bar indicates pass-through for each subcategory and its 95% confidence interval. Estimates are provided with varying geographic market boundaries with a linear radius of 3, 4, and 5 kilometers. The HHI is computed using a 4km radius market delineation. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

compared to highly imperfect markets (HHI Q_4) for E5, diesel exhibits a discrepancy of only 1.5%p in pass-through between both market structures. Equivalent to the analysis of the first tax intervention, we test the market concentration results across alternative thresholds. Panel (b) of figure 5 depicts analogous effects for market boundaries based on three and five-kilometer radii. Once more, we observe a low level of pass-through heterogeneity for diesel, with significant levels remaining low for all alternative specifications.

Thus far, our findings suggest that, in accordance with economic theory, market concentration tends to result in a lower response to tax changes than for stations under competitive pressure. However, as our descriptive analysis indicates a higher distribution of independent brands in predominantly rural regions and, simultaneously, a higher market concentration than in metropolitan regions, there might be overlapping effects between the existence of independents (e.g. no vertically integrated stations) which, however, operate at the local level in less competitive markets (e.g. in areas with high market concentration). Consequently, it is possible that both the estimated pass-through differences of the vertical and horizontal markets may be biased and may not accurately reflect the true determinants of heterogeneous tax pass-through. To disentangle the effects of vertical integration from the effects that originate from market concentration at the horizontal

level, we assess columns (5) and (10) from table 8 and 9 by considering the vertical integration of each station. That is, we estimate pass-through across HHI quartiles for oligopolistic, other integrated players, and independents separately (figure 6). Similar to table 8 and 9, panel (a) illustrates the existence of notable discrepancies in pass-through levels depending on the degree of vertical integration.

Figure 6: Pass-Through (ct/l) by Vertical Integration and HHI



Note: Heterogeneous pass-through levels of the (a) first (b) second intervention by HHI quartiles and brand category. Each bar represents the pass-through for each subcategory and its 95% confidence interval in relation to the first quartile of the HHI. The HHI is computed using a 4km radius market delineation. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

The adjusted "competition effect" exhibits differentiated patterns across levels of vertical integration. Since downstream retailers are not dependent on upstream markets, the impact of horizontal markets become more striking. High market concentration (HHI Q_4) is associated with a reduction in pass-throughs for E5 and diesel of up to 7%p for independent retailers. In contrast, highly vertically integrated players exhibit considerably lower pass-through differentials across HHI quartiles, with values of only 2 to 3%p for E5 and diesel, respectively. With regard to the subsequent tax increase in Panel (b), the "competition effect" is ambiguous across vertical markets. While we observe a pronounced competition effect among independents for E5 up to 3.4%p in the top HHI quartile, pass-through differentials across market concentration levels are insignificant and non-existent for vertically integrated stations.⁴⁰ Conversely, the variation in

⁴⁰Other vertically integrated stations demonstrate an outlier with a pass-through differential of 1.5%p at a significance level of 5% for the third HHI quartile.

pass-through across horizontal markets disappears entirely for diesel. As none of the estimates reach significance at all common significance levels, including independent retailers, higher market concentration does not imply lower pass-through rates. Contrary to theoretical expectations, we identify not only overall pass-through asymmetries for the first and second tax intervention, but also a more complex asymmetry of the so-called "competition effect," which differs significantly across fuel types and vertical markets.

7 Conclusion

In order to mitigate the impact of rising energy prices on consumers, the German government introduced a temporary fuel tax discount in 2022. Economic theory suggests, that the ability to pass through taxes is conditioned by market characteristics, which exhibit significant variation at the local level in downstream fuel retailing. The nationwide temporary fuel discount provides a quasi-experimental setting for testing these theoretical predictions, in particular the spatially heterogeneous pass-through of a decrease and increase in energy taxes on retail prices for fuel stations in different competitive environments. Based on a unique dataset that combines station characteristics and retail prices with additional price-influencing variables, we employ a Regression Discontinuity in Time (RDiT) approach. Our estimates from a series of models including various covariates, enable us to draw the following conclusions.

First, our estimates provide evidence for an incomplete pass-through for the tax reduction and the subsequent tax increase: For the first tax intervention, we estimate average pass-through rates of 77.6% and 73.1% for E5 and diesel respectively, while we obtain rates of 63.8% and 49.1% for E5 and diesel, respectively, for the second intervention. Furthermore, our estimates indicate a predominantly asymmetric pass-through for gasoline and diesel, whereby the tax cut was to a higher extent passed on to consumers than the tax increase. Second, we identify significant spatial variation in pass-through rates which is driven by local market power both at the horizontal level and at the vertical level. With highly varying market concentrations on the retail level among the rural-urban continuum, pass-through heterogeneity exhibits similar patterns. In line with economic theory, we find that competitive markets boost the effectiveness of the tax interventions, resulting in up to 6%p higher pass-through rates as compared to imperfect markets. This effect is particularly evident during the first intervention (e.g. the tax reduction), with proportional pass-through differences cutting in half for the following tax increase. This pattern is stable across various geographic extents of markets and fuel types. Third, in addition to market power at the horizontal level, our findings indicate that stations affiliated with vertically integrated brands are able to pass through a significantly higher amount of the tax change. This would suggest that these arrangements are capable of avoiding (or reducing) the double-marginalization phenomenon. In terms of vertical and horizontal markets, by isolating the channels of influence behind tax pass-through, we find that independent retailers are particularly sensitive to the competitive environment. Concurrently, the extent of pass-through differentiation across horizontal

markets is nearly eliminated in the context of the tax increase, once vertical arrangements are taken into account.

The findings of our study indicate that policymakers should consider the degree of competition in highly localized markets when considering tax changes. Market imperfections reduce the effectiveness of tax interventions that have the underlying intention of directing prices. While we focus primarily on horizontal markets, our results on the effects of vertical integration is currently restricted to a rather broad classification of stations. With improved data on the variety of contractual arrangements between refiners, wholesalers and the downstream retailer, these effects could be studied in more detail and could potentially contribute to the literature on double marginalization.

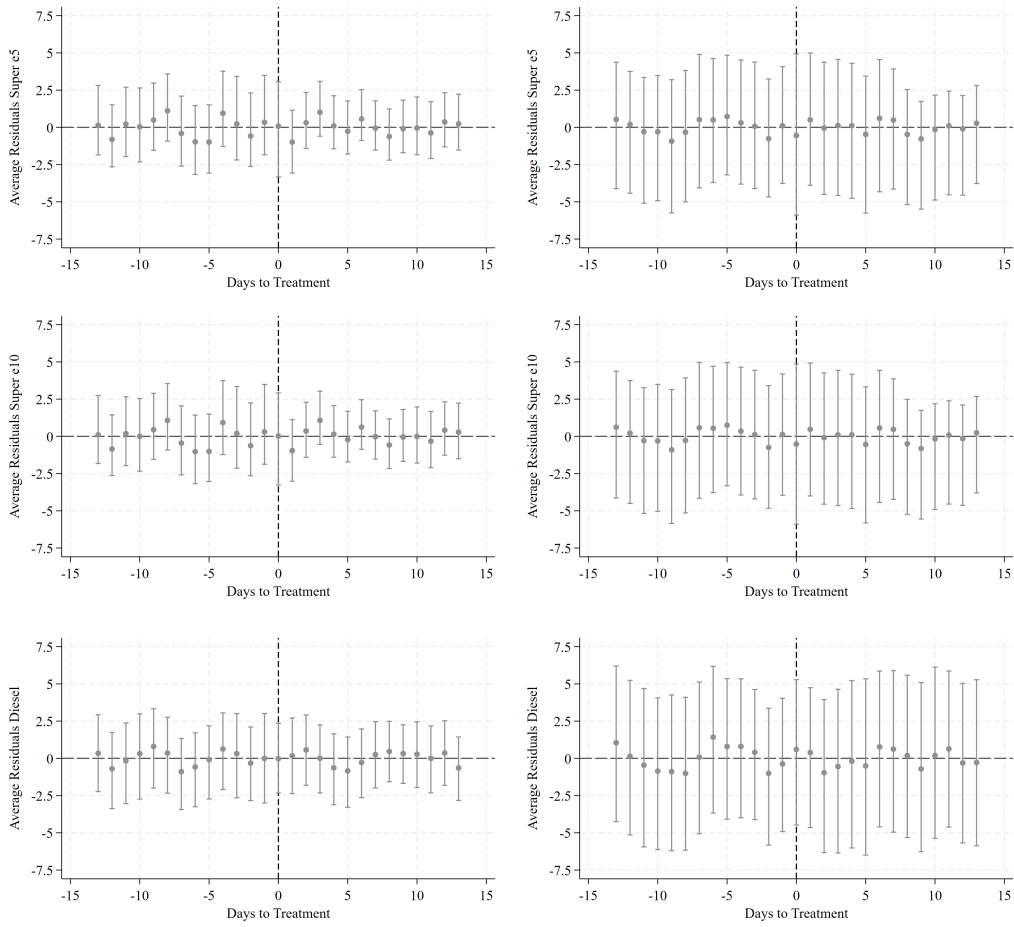
Appendix A

Table A1: Spatial Competition between Roadside Stations in Germany 2022

	full sample	region type		
		urban	intermediate	rural
<i>3km radius</i>				
brand count	4.24 [4.23] (2.74) [(2.72)]	5.74 [5.70] (2.74) [(2.72)]	3.74 [3.74] (2.54) [(2.54)]	2.92 [2.89] (1.96) [(1.93)]
comp. count	4.25 [4.21] (4.27) [(4.22)]	6.85 [6.77] (4.85) [(4.76)]	3.33 [3.32] (3.53) [(3.54)]	2.10 [2.06] (2.24) [(2.20)]
HHI	0.41 [0.41] (0.30) [(0.30)]	0.28 [0.28] (0.21) [(0.21)]	0.45 [0.45] (0.30) [(0.30)]	0.53 [0.54] (0.32) [(0.32)]
<i>5km radius</i>				
brand count	6.41 [6.38] (3.94) [(3.93)]	9.20 [9.13] (3.63) [(3.63)]	5.53 [5.53] (3.50) [(3.51)]	3.86 [3.83] (2.41) [(2.39)]
comp. count	9.05 [8.96] (9.20) [(9.10)]	16.32 [16.13] (10.56) [(10.42)]	6.35 [6.33] (6.15) [(6.17)]	3.28 [3.23] (2.96) [(2.92)]
HHI	0.29 [0.29] (0.24) [(0.24)]	0.19 [0.19] (0.13) [(0.13)]	0.32 [0.32] (0.24) [(0.24)]	0.41 [0.41] (0.28) [(0.28)]
Observations	14,257 [14,200]	4,791 [4,765]	6,451 [6,429]	3,015 [3,006]

Note: Average values for various measures of local competition for the full sample and by region type during May and June. Values for August and September are included in squared brackets. Standard errors are in parentheses. Geographic distances are calculated via the Vincenty (1975) equation. The Herfindahl-Hirschman-Index (HHI) ranges between $1/n$ and 1. Own calculations are based on Tankerkönig data ([https://creativecommons.tankerkoenig.de.](https://creativecommons.tankerkoenig.de/)).

Figure A1: RDiT Residuals



(a) First Intervention

(b) Second Intervention

Note: Graphical representation of residuals during the (a) first and (b) second intervention. Each dot illustrates daily average residuals of the baseline regression. Capped spikes indicate the range between the bottom and top quartile. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Figure A2: Development of Brent Prices and Exchange Rates from May to October 2022



Note: The figure displays the evolution of daily Brent prices (US\$) and exchange rates (€ to US\$). The figure is based on data obtained from the U.S. Energy Information Administration (<https://www.eia.gov/dnav/pet/hist/rbrteD.htm>) and the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

Table A2: Pass-Through of the German Fuel Discount by Brand Affiliation

	First Intervention			Second Intervention		
	Super e5	Super e10	Diesel	Super e5	Super e10	Diesel
<i>oligopolistic</i>						
ARAL	-30.46*** (0.07)	-30.47*** (0.07)	-14.0*** (0.06)	25.07*** (0.10)	25.07*** (0.10)	10.32*** (0.06)
SHELL	-31.28*** (0.06)	-31.31*** (0.06)	-14.32*** (0.06)	24.27*** (0.12)	24.21*** (0.12)	8.54*** (0.06)
TOTALenergies	-26.84*** (0.14)	-26.84*** (0.14)	-12.73*** (0.11)	19.75*** (0.17)	19.76*** (0.17)	7.21*** (0.10)
<i>other integrated</i>						
ESSO	-29.26*** (0.14)	-29.26*** (0.14)	-13.20*** (0.10)	24.02*** (0.18)	22.93*** (0.18)	8.01*** (0.10)
JET	-24.44*** (0.13)	-24.40*** (0.13)	-10.70*** (0.12)	21.80*** (0.22)	21.80*** (0.22)	8.40*** (0.11)
<i>independent</i>						
BFT	-24.89*** (0.34)	-24.95*** (0.38)	-11.36*** (0.24)	20.09*** (0.30)	20.06*** (0.32)	7.24*** (0.18)
AVIA	-23.25*** (0.22)	-23.25*** (0.22)	-9.62*** (0.15)	21.28*** (0.20)	21.23*** (0.21)	7.85*** (0.12)

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays RDiT estimates by selected brands from separate second order polynomial OLS regressions that include a time trend, interaction terms of the time trend and the treatment dummy. The bandwidth includes 14 days before and after June 01 and September 01, respectively. All regressions include station fixed effects. Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Table A3: Robustness - First Intervention

Polynomial Bandwidth	first		second		third
	14 days	7 days	14 days	21 days	14 days
	(1)	(2)	(3)	(4)	(5)
<i>Super e5</i>					
TR	-22.65*** (0.04)	-29.05*** (0.09)	-27.28*** (0.05)	-23.56*** (0.04)	-28.33*** (0.06)
Constant	159.23*** (0.84)	524.82*** (7.30)	265.18*** (1.09)	199.34*** (0.64)	244.06*** (0.83)
Controls	✓	✓	✓	✓	✓
Observations	352,814	169,865	352,814	535,692	352,814
Adjusted R^2	0.920	0.939	0.934	0.917	0.934
<i>Super e10</i>					
TR	-22.70*** (0.04)	-29.08*** (0.10)	-27.36*** (0.05)	-23.60*** (0.04)	-28.41*** (0.06)
Controls	✓	✓	✓	✓	✓
Constant	152.26*** (0.84)	515.30*** (7.53)	260.69*** (1.12)	193.05*** (0.65)	239.00*** (0.85)
Observations	338,677	163,070	338,677	514,217	338,677
Adjusted R^2	0.917	0.935	0.931	0.915	0.931
<i>Diesel</i>					
TR	-8.72*** (0.03)	-10.47*** (0.07)	-12.22*** (0.03)	-10.18*** (0.03)	-11.89*** (0.04)
Controls	✓	✓	✓	✓	✓
Constant	205.31*** (0.71)	290.86*** (5.60)	255.36*** (0.96)	225.54*** (0.62)	276.91*** (0.95)
Observations	359,841	173,245	359,841	546,317	359,841
Adjusted R^2	0.549	0.702	0.606	0.622	0.609

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays RDiT estimates from a separate OLS regression. Bandwidths range from 7 to 21 days before and after policy implementation and polynomials range from first to third. All regressions include station fixed effects. Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Table A4: Robustness - Second Intervention

Polynomial Bandwidth	first		second		third
	14 days	7 days	14 days	21 days	14 days
	(1)	(2)	(3)	(4)	(5)
<i>Super e5</i>					
TR	22.57*** (0.05)	22.79*** (0.06)	22.44*** (0.05)	22.57*** (0.05)	23.27*** (0.05)
Controls	✓	✓	✓	✓	✓
Constant	190.35*** (1.05)	20.75*** (3.65)	190.13*** (1.20)	222.23*** (0.69)	228.11*** (1.10)
Observations	353,229	170,009	353,229	536,332	353,229
Adjusted R^2	0.931	0.938	0.931	0.930	0.932
<i>Super e10</i>					
TR	22.46*** (0.05)	22.72*** (0.07)	22.38*** (0.05)	22.50*** (0.05)	23.27*** (0.06)
Controls	✓	✓	✓	✓	✓
Constant	186.28*** (1.09)	15.26*** (3.83)	185.45*** (1.26)	218.09*** (0.72)	224.58*** (1.14)
Observations	338,926	163,133	338,926	514,601	338,926
Adjusted R^2	0.928	0.934	0.928	0.928	0.929
<i>Diesel</i>					
TR	7.88*** (0.03)	9.10*** (0.04)	8.21*** (0.03)	7.68*** (0.03)	11.05*** (0.03)
Controls	✓	✓	✓	✓	✓
Constant	269.96*** (0.86)	159.76*** (2.83)	202.57*** (0.86)	159.25*** (0.59)	246.66*** (0.79)
Observations	360,350	173,430	360,350	547,141	360,350
Adjusted R^2	0.900	0.838	0.901	0.908	0.907

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays RDiT estimates from a separate OLS regression. Bandwidths range from 7 to 21 days before and after policy implementation and polynomials range from first to third. All regressions include station fixed effects. Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de/>).

Appendix B

Table B1: Average Pass-Through of the German Fuel Discount - Super e10

	First Intervention				Second Intervention			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TR	-27.44*** (0.05)	-27.91*** (0.06)	-27.13*** (0.05)	-27.36*** (0.05)	23.13*** (0.05)	22.85*** (0.05)	22.82*** (0.05)	22.38*** (0.05)
Z	1.95*** (0.01)	1.91*** (0.01)	1.97*** (0.01)	1.85*** (0.01)	0.50*** (0.01)	0.61*** (0.01)	0.69*** (0.01)	0.74*** (0.01)
Z ²	0.11*** (0.00)	0.10*** (0.00)	0.11*** (0.00)	0.10*** (0.00)	-0.01*** (0.00)	0.00 (0.00)	0.00*** (0.00)	0.00*** (0.00)
TR × Z	-0.75*** (0.01)	-0.56*** (0.01)	-0.91*** (0.01)	-0.71*** (0.01)	-0.99*** (0.02)	-1.24*** (0.02)	-1.21*** (0.02)	-1.37*** (0.02)
TR × Z ²	-0.18*** (0.00)	-0.19*** (0.00)	-0.17*** (0.00)	-0.18*** (0.00)	-0.01*** (0.00)	-0.00*** (0.00)	-0.01*** (0.00)	-0.01*** (0.00)
<i>Supply Shifter</i>								
Brent (ct/l)		0.14*** (0.01)		0.20*** (0.01)		-0.04*** (0.00)		-0.12*** (0.01)
€ to US\$ (ct)		-0.78*** (0.01)		-0.57*** (0.01)		-0.28*** (0.01)		-0.03** (0.01)
<i>Demand Shifter</i>								
Constant	216.07*** (0.04)	289.58*** (1.01)	215.53*** (0.05)	260.69*** (1.12)	178.23*** (0.03)	208.92*** (1.41)	175.66*** (0.08)	185.45*** (1.26)
Observations	338,698	338,677	338,698	338,677	338,998	338,926	338,998	338,926
Adjusted R ²	0.928	0.928	0.930	0.931	0.927	0.927	0.928	0.928

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. TR indicates treatment by the tank rebate, Z represents the amount of days before and after treatment. The bandwidth includes 14 days before and after June 01 and September 01, respectively. All regressions include station fixed effects. Robust Huber-White standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

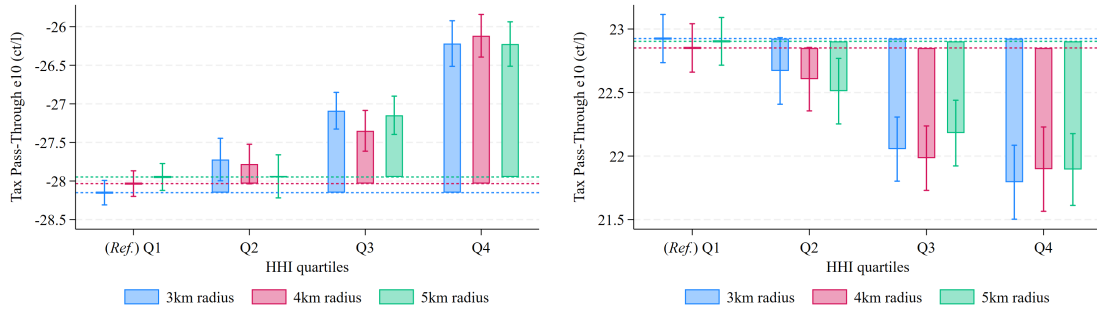
Table B2: Heterogeneous Pass-Through of the German Fuel Discount - Super e10

	First Intervention					Second Intervention				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
TR	-29.71*** (0.05)	-28.39*** (0.07)	-27.67*** (0.07)	-26.61*** (0.08)	-28.03*** (0.08)	23.85*** (0.07)	22.82*** (0.08)	22.64*** (0.07)	21.86*** (0.07)	22.85*** (0.10)
<i>Brand Category</i>										
TR × oth. integr.	2.44*** (0.09)					-1.08*** (0.11)				
TR × independ.	4.27*** (0.11)					-2.93*** (0.11)				
<i>Regional Typology</i>										
TR × intermed.		1.04*** (0.10)					-0.77*** (0.10)			
TR × rural		2.76*** (0.17)					-0.51*** (0.14)			
<i>dist. next comp.</i>										
TR × (1≤dist.<3)			0.06 (0.11)					-0.27** (0.11)		
TR × (3≤dist.)			1.75*** (0.16)					-1.02*** (0.14)		
TR × comp. count.				-0.11*** (0.01)					0.08*** (0.01)	
<i>Herfindahl-Index</i>										
TR × HHI Q ₂					0.25* (0.13)					-0.25* (0.13)
TR × HHI Q ₃					0.68*** (0.13)					-0.87*** (0.13)
TR × HHI Q ₄					1.92*** (0.14)					-0.95*** (0.17)
Control Variables	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Constant	260.69*** (1.11)	260.76*** (1.11)	260.71*** (1.11)	260.76*** (1.11)	260.71*** (1.11)	185.50*** (1.26)	185.61*** (1.26)	185.60*** (1.26)	185.70*** (1.26)	185.77*** (1.26)
Observations	338,677	338,677	338,677	338,677	338,677	338,926	338,926	338,926	338,926	338,926
Adjusted R ²	0.933	0.931	0.931	0.931	0.931	0.929	0.929	0.928	0.928	0.929

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Each column displays estimates from a separate second order polynomial OLS regression, that include a time trend, interaction terms of the time trend and the treatment dummy. The bandwidth includes 14 days before and after June 01 and September 01, respectively. All regressions include station fixed effects. Competition categories are based on a 4km radius market delineation. Robust Huber-White standard standard errors in parentheses. Own calculations are based on Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Figure B1: Pass-Through (ct/l) by HHI and Market Boundaries - Super e10

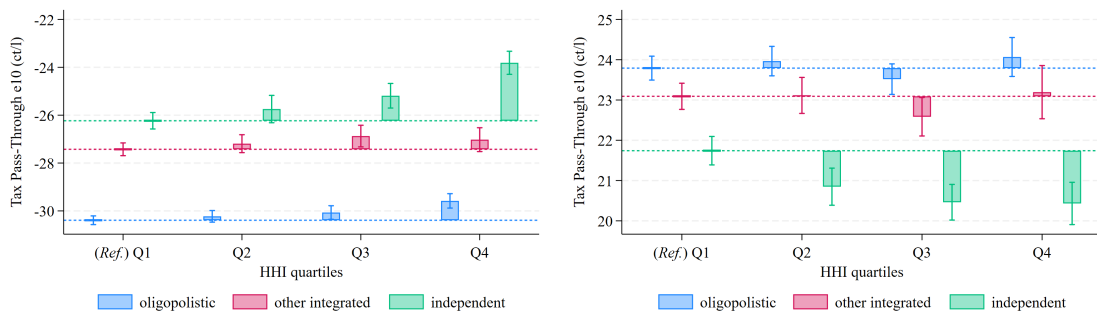


(a) First Intervention

(b) Second Intervention

Note: Heterogeneous pass-through levels of the (a) first (b) second intervention by HHI quartiles for different market definitions. Each bar indicates pass-through for each subcategory and its 95% confidence interval. Estimates are provided with varying geographic market boundaries with a linear radius of 3, 4, and 5 kilometers. The HHI is computed using a 4km radius market delineation. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

Figure B2: Pass-Through (ct/l) by Brand Category and HHI - Super e10



(a) First Intervention

(b) Second Intervention

Note: Heterogeneous pass-through levels of the (a) first (b) second intervention by HHI quartiles and brand category. Each bar represents the pass-through for each subcategory and its 95% confidence interval in relation to the first quartile of the HHI. The HHI is computed using a 4km radius market delineation. The figure is based on own calculations using Tankerkönig data (<https://creativecommons.tankerkoenig.de>).

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