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Is Carbon Tax Truly More Salient? Evidence from Fuel Tourism at the France-Germany Border

Abstract

This paper exploits the introduction of the German carbon tax in 2021 as well as excise tax rebates on fuel in both France and Germany, consecutive to the 2022 oil crisis, to infer how fuel tourism responds to changes in relative prices. Based on French high-frequency transaction-level data issued from individual banking accounts, we find substantial displacement between foreign and domestic consumption. When relative prices increase by 1%, the relative cross-border demand decreases by 7.7%. In border areas, the elasticity of tax revenue with respect to foreign prices is as high as 0.5. Moreover, there is no substantial difference in demand response to either carbon or excise tax. Such empirical evidence illustrates the importance of coordinating tax policy within EU.

JEL-Codes: H200, H230, H770, R480.

Keywords: commodity taxation, tax coordination, carbon pricing, fuel tourism, transaction-level data.

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1 Introduction

Fuel is typically a good for which taxes account for a substantial share of the transaction price (about 60% in France, namely 40% corresponding to excise taxes and the remaining 20% to VAT). Tax competition across neighboring countries then generates price differentials: for instance, fuel is cheaper in Germany than in France. In turn, this should impact cross-border shopping; the importance of fuel tourism is yet an empirical issue, though. In the context of reducing greenhouse gas (GHG) emissions being a primary worldwide objective due to global warming, carbon taxation is a natural instrument at the disposal of policy makers (Andersson, 2019), despite redistributive concerns (Douenne, 2020) that can only be partly mitigated (Sallee, 2019). Optimally designing tax schemes, be they for environmental purpose or not, may require a better coordination within EU; it is at least necessary to improve our knowledge of displacement effects induced by commodity taxation.

Our empirical analysis leverages a most appropriate research design, namely policy-driven price changes consecutive to the introduction of a carbon tax in Germany in 2021, but also tax rebates implemented both in France and Germany, consecutive to the 2022 oil crisis. We view these events as quasi-natural experiments which provide us with a clear source of identifying variability for relative fuel prices between these countries. To take the best advantage of such exogenous variations, we resort to high-frequency transaction-level data issued from individual bank accounts of a major French bank. We estimate that cross-border shopping in the three French *départements*[1] (Moselle, Bas-Rhin, and Haut-Rhin) that are located at the border with Germany is very responsive to relative prices. Based on a log-log estimating equation, we leverage a 'macro' approach combined with an instrumental variable (IV) strategy that relies on sharp policy-induced price variations as instruments, we find that fuel tourism is quite sensitive to a change in the foreign-to-domestic price ratio (relative prices, hereafter). A 1% increase in relative prices turns out to diminish the relative demand by 7.7%. The elasticity of tax revenue with respect to foreign prices amounts to slightly less than 0.5 in border *départements*. Comparing the reactions that followed the introduction of the sole carbon tax to those consecutive to

[1] An administrative division of France, somehow intermediate between a state and a county in the U.S. Mainland France, i.e. France at the exclusion of Corsica and overseas, is divided into 94 *départements*. Metropolitan France includes the two Corsican *départements*.

excise tax rebates suggests that those responses look quite similar: from that viewpoint, those results do not point out to carbon taxation being more salient. We then perform counterfactual simulations in order to evaluate the causal impact of the German carbon tax on fuel tourism in France. According to our simulations, it resulted in a 3pp relative drop of the German market share with respect to the French market share in border zones: from 11% to 8% in Moselle and Bas-Rhin, from 10% to 7% in Haut-Rhin. Those results shed light on the necessity of coordinating tax policy within the EU, especially environmental taxation.

Literature This paper intersects two strands of the literature: a first one devoted to (carbon) tax salience, and a second one dedicated to both tax coordination (theoretically) and cross-border shopping (empirically).

As regards tax salience, in a seminal contribution based on both experimental and non-experimental price variation, Chetty et al. (2009) showed that it can be at the source of substantially heterogeneous demand responses. From a field experiment in which they manipulate the sales tax in a grocery store in Northern California, they estimate that a 10 percent increase in that less salient tax has the same effect as a 3.5 percent increase in prices. Focusing then on actual beer consumption, they found that a 10% increase in the non-salient sales tax induced the same demand reaction as a 0.6% increase in the salient excise tax. A more recent literature has wondered whether green taxes are more salient. In the Canadian province of British Columbia, Rivers and Schaufele (2015) show that carbon taxation caused a decline in short-run gasoline demand that is significantly greater than would be expected from an equivalent increase in the market price of gasoline. According to Andersson (2019) who examines the case of the Swedish carbon taxation based on aggregated data, individuals would be three times more averse to a carbon tax than to a corresponding price increase. However, there is no consensus on that topic: when studying the gasoline taxation that prevails in the US, including both state and federal taxes, Li et al. (2014) provide evidence that consumers respond more strongly to gasoline price changes driven by the tax component than to those driven by the pre-tax component, but Kilian and Zhou (2023) find that they are equally responsive to both. In our case, fuel tourists located near the France-Germany border respond quite similarly to both carbon tax and excise tax changes. To the best of our knowledge, this is the first empirical evidence based on clean, large-scale quasi-experimental research design and on high-frequency transaction-level data that does not support the idea that carbon taxation is more salient than other taxes.

Second, our paper contributes to a theoretical literature on tax coordination and an empirical literature on cross-border shopping. From the theoretical side, Kanbur and Keen (1993) develop a stylized two-country, single good model of spatial competition, and show that tax competition between countries of similar sizes is inefficient. This analysis is particularly relevant in our framework since France and Germany are comparable in size, and their results suggest therefore that some tax coordination on fuel between those countries is desirable to prevent any wedge between commodity taxes. According to their model, though, coordination would rather imply imposing minimum tax rates (i.e., lower bounds) than a common tax rate. Extensions of their approach include: Nielsen (2001) who considers an even simpler conceptual framework, though reaching similar conclusions; Wang (1999) who allows one country to be a leader in the sense of Stackelberg; and Agrawal (2015) who considers both multiple jurisdictions and levels of government. From the empirical side, cross-border shopping has been the object of researchers' attention at least since Asplund et al. (2007) who estimated that the elasticity of (overall) Swedish demand for alcohol with respect to the foreign price was about 0.3. We build upon their paper by relying on exogenous price shocks: our analysis rests on an IV strategy that exploits quasi-experimental, policy-driven price variation. Following this paper, several studies including Banfi et al. (2005), Gopinath et al. (2011) and Friberg et al. (2022) have focused on the role played by the distance to the border. More recently, Burstein et al. (2023) exploit both the border closure in Switzerland consecutive to the COVID-19 pandemics, and the appreciation of the CHF franc, viewed as quasi-experimental sources of variation in relative prices. Our approach complements previous articles since we rely on a tax differential between two leaders of EU, Germany and France, based on the introduction of a green tax; on top of that, our high-frequency dataset provides a very granular picture of variations in cross-border shopping. Interestingly, Jansen and Jonker (2018) find limited fuel tourism in Netherlands for people living close to either German or Belgian border, which they relate to the low level of cross-border commuting by Dutch workers. By contrast, a substantial share of French residents located near the German border buy fuel in Germany: the German market share is slightly higher than 10% of the French market share, and the relative demand turns out to be quite responsive to changes in relative prices.

The rest of the paper is organized as follows. Section 2 presents our data and the institutional background. Our empirical analysis is exposed in Section 3. Section 4 concludes.

2 Data and context

Our empirical analysis relies on de-identified bank account data. Our database is issued from the *Crédit Mutuel Alliance Fédérale*, a French group of banks with about 30 million customers, either firms or households. The construction of key variables follows a recent strand of literature exploiting such data including, e.g., Baker (2018), Ganong and Noel (2019) and Andersen et al. (2023). We dispose of transaction-level data on credit and debit card payments,[2] paper checks, cash withdrawals, cash deposits, bank transfers, and direct debits. We observe the amount of each transaction, in euros; such information is timestamped, hence available at a high frequency. We nevertheless base our analysis on a daily aggregation. On top of that, balance sheets are available each month. The statistical unit of observation is a household; the data contains various socio-demographics on households' members like age, sex, *département*, family status, occupation, and the type of location (in 3 categories: urban, rural, and semiurban areas).

Working sample Our estimation period runs from September 2021 to February 2023. Our initial raw data is a sample of about 300,000 households who primarily bank at *Crédit Mutuel-Alliance Fédérale*, this sample being stratified by *départements* of metropolitan France and by 5-year age dummies. To alleviate concerns about representativeness, we proceed to calibration weighting using the method proposed by Deville and Särndal (1992) (see Adam et al. (2023) for details): we weight our estimating equations using calibration weights. We further restrict our attention to households with the same number of adults (aged at least 18) over the period. We focus on customers who spend at least €150 during three rolling months, either by card or in cash. Moreover, we impose that customers be present and meet previous criteria all over the period, which leaves us with about 194,000 active customers primarily banking at *Crédit Mutuel-Alliance Fédérale*. We last restrict our attention to 11,865 individuals living in 3 *départements* (57: Moselle, 67: Bas-Rhin, 68: Haut-Rhin) that are located on the France-Germany border. Together, these *départements* account for 5% of fuel purchases nationwide.

[2] In France, the use of credit cards is scarce: it accounts for less than 10% of bank cards.

Fuel spending Our bank account data provide the Merchant Category Code (MCC) classification. Based on that taxonomy, we consider that spending categorized with codes 5541 and 5542 corresponds to fuel spending as Andersen et al. (2023) and Gelman et al. (2023) do. Importantly, for any car payment, we dispose of a variable that contains information on the merchant's country, which allows us to know whether fuel has been purchased, in France, in Germany, or elsewhere. Last, we obtain fuel quantity, in liters, as the ratio of fuel spending over the fuel price index; we now explain how we compute the latter.

Prices Timestamped and geolocated fuel prices in France and Germany are disclosed online at the gas station level.[3] Such data has already been used by researchers: see, e.g., Montag et al. (2021) or Gautier et al. (2023). It contains information on each and any price change for different kinds of fuel (diesel and different types of gasoline: super unleaded petrol (SP95), super unleaded petrol (SP95-E10), super unleaded petrol (SP98), etc.). In the subsequent analysis, we focus on two types of fuel: diesel and standard gasoline, which we confound with SP95-E10, given that the latter exhibits similar variations over time as both SP95 and SP98. On top of that, the data provides with an identifier and the location of each retailer.

As detailed in Appendix A of Gautier et al. (2023), the first step consists in mapping raw data to a daily panel dataset at the (retailer, type of gasoline) level. Since different price changes may occur within the same day, we consider the price that prevails at 5pm as Montag et al. (2021) do. In a second step, we remove inactive stations, which we define as stations that have not experienced any price change since at least 30 days, following Gautier et al. (2023); note that a station may be active for, say, diesel, but inactive for gasoline. We then trim outliers by deleting top and bottom 1% of price observations for each (*département*, type of fuel, day).[4] Admittedly, transaction prices are measured with error since we ignore the exact location of purchase: we only know the country of purchase and the *département* of residence of the customers. Hence we approximate prices of fuel bought in France with the daily average in the *département* where lives the customer and

[3] https://www.prix-carburants.gouv.fr/rubrique/opendata/ for French prices and https://dev.azure.com/tankerkoenig/_git/tankerkoenig-data for German prices.

[4] As regards German prices, they are equal to their daily averages over the whole set of German gas station, and we thank Felix Montag for pointing that information out to us. Source: German Federal Ministry of the Economy (https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Berichte/Evaluierungsbericht_MTS-K_.pdf?__blob=publicationFile&v=3).

we approximate prices of fuel bought in Germany with the daily average in the *Länder* located on the France-Germany border.

As another limitation of our data, we lack information about the type of fuel actually purchased, diesel or gasoline. This is yet unimportant provided that those prices similarly covary, which is empirically the case. Their Pearson coefficient is higher than 0.95 over the period in the *départements* and *Länder* located on the France-Germany border, even though diesel and gasoline prices sometimes experience different short-run variations due to specific conditions affecting the oil market, for instance. We therefore build a fuel price index that weighs diesel and gasoline prices according to their share using the French survey *Enquête Mobilité*.

Context: Carbon tax in Germany, invasion of Ukraine, 2022 oil price surge, and policy responses (temporary excise tax rebates on fuel) In cross-border *départements*, the ratio of German over both French and German fuel purchases exceeds 6%, while it is almost always lower than 1% in the rest of France. The importance of fuel tourism seems to go beyond the sole share of cross-border workers, about 1% in the Grand-Est region (about 48,000 individuals among 5,5 million inhabitants in 2019).

In December 2020, namely before the introduction of the German carbon tax, the French diesel was 14% more expensive than the German one which amounted to €1.15 per liter; the corresponding differential was 7% as regards gasoline. Figure 1 depicts the evolution of relative prices, namely the ratio of foreign (German) over domestic (French) fuel prices from July 2020 to February 2023. This ratio rose sharply at the beginning of year 2021 due to two distinct reasons: the introduction of a carbon tax and the end of a temporary VAT cut in Germany. Germany has introduced a €25 per ton of CO_2 carbon tax for each firm that was not already subject to the European Union Emissions Trading System (EU ETS). This public policy results from an agreement between the Bundesrat and the German government on the Fuel Emissions Trading Act (BEHG) that dates back to December 2019; the corresponding bill was passed on October 2020. The application of that tax scheme to the road transportation consisted in further taxing the price of the diesel (resp. gasoline) by €0.067 (resp. €0.06) per liter from January 1st, 2021 onwards. At the same time, the standard VAT rate was reduced from 19% to 16% during six months from July to December 2020 as part of a fiscal stimulus package designed to mitigate the impact of the Covid-19 pandemics.

In 2022, fuel prices have experienced substantial variations, partly due to the oil price surge consecutive to the invasion of Ukraine starting on 02-24-2022. The world then faced a pervasive oil crisis: for the first time since the Great Recession, the price of a barrel exceeded the symbolic $120 threshold, in nominal terms. In France, the government decided to intervene by directly subsidizing prices at the pump. On 03-12-2022, Prime Minister Castex made an official announcement to explain that the before-tax gasoline price would be diminished by €0.15 per liter from April 1st onwards (about €0.18 per liter including VAT, with some minor geographic variations due to *département*-specific VAT rates). While this first public intervention was bound to last until the end of Summer 2022, the Parliament decided to extend it to the beginning of October, consecutive to the energy crisis. As announced by Prime Minister Borne at the end of July 2022, a rebate of €0.3 per liter, i.e., an extra €0.12 rebate for each liter purchased, has been effective on the after-tax price from 09-01-2022 to 11-15-2022, which was then reduced to €0.1 only before being completely removed by the end of the year. Meanwhile, in Germany, a similar temporary excise tax cut on fuel was adopted from June 1st to September 1st, 2022, which amounted to -€0.34 per liter on gasoline, and to -€0.17 per liter on diesel.

3 Empirical analysis

3.1 Identification

We rely on previous policy-driven fuel price changes in both France and Germany, viewed as quasi-natural experiments, which provide us with convincing sources of identifying variability for the sensitivity of cross-border demand to relative prices. More precisely, our inference of the price sensitivity rests on four shocks: (i) the German carbon tax in January 2021, (ii) the French rebate in April 2022, (iii) the German rebate in June 2022, and (iv) the removal of that temporary rebate combined with the second rebate in France in September 2022. In France, per unit excise taxes represent roughly 40% of fuel prices, and *ad valorem* VAT about 20%; Germany has nearly the same amount of tax, per liter, but the before-tax price is slightly lower there. In both cases, when announcing discounts at the pump, governments *de facto* offer tax rebates. These policies were publicly disclosed, hence salient to consumers. Note also that the September 2022 shock is the strongest, in nominal terms, and that it resulted in a nearly €0.42 per liter price differential as the combination of two shocks pointing in the same direction: French prices falling by €0.12 per liter at the onset of the month, consecutive to the second fuel price rebate, and German prices concomitantly increasing by roughly €0.30, due to the end of the temporary excise tax rebate there. Figure 1 suggests that cross-border demand is quite responsive to those sharp variations in relative prices. We thus adopt an IV strategy based on previous tax changes as instruments for relative prices. Such an approach also addresses any concern about measurement error, simultaneity, and imperfect pass-through (see Montag et al. (2021) as well as Appendix A for more details on that topic). Montag et al. (2021) provide suggestive evidence that, in Germany, not all consumers are perfectly informed about prices, especially because there is a lot of within-day variation: in a given gas station, prices may change up to 15 times per day, which renders them less predictable, unless consumers dispose of the appropriate app on their smartphone.Under imperfect compliance to the instrument then, the estimated price coefficient would not correspond to the price-sensitivity of perfectly informed consumers, but should rather be interpreted as an average reaction to prices by heterogeneous consumers differing in their level of information. This caveat does not imply that our estimated parameter β (see below) is not policy-relevant, though.[5]

3.2 Econometric specification

Our goal is to quantify by how much fuel cross-border shopping depends on relative prices, i.e. on the foreign-to-domestic price ratio. We thus resort to a tractable method to address that issue: we adopt a 'macro' approach, which could be derived from the French government's reasoning at the national level, and we estimate a log-log demand equation which does not include any dyadic-level determinant of station choice. To nonetheless be able to perform counterfactual simulations, we provide below a stylized micro-foundation for such an equation at the *département* d level.

We assume that consumer i living in *département* d receives the utility:

$$U_{iFdt} = \alpha_{Fd} + \beta \log(p_{Ft}) + \xi_{Fdt} + \varepsilon_{iFdt} \equiv \delta_{Fdt} + \varepsilon_{iFdt} \tag{1}$$

[5] Montag et al. (2021) further document substantial heterogeneity among consumers as regards their degree of information as regards prices, more informed consumers being diesel drivers and those buying at the minimum (as opposed to average) price within some geographical area. In Adam et al. (2023), a companion paper, we instrument prices by the sole tax changes on diesel prices, and doing that leaves our results essentially unaltered. Besides, we partly address this heterogeneity issue by relying on a price index that depends on households' characteristics, a proxy for the level of information.

when purchasing foreign (F) on day t, and the utility:

$$U_{iDdt} = \alpha_{Dd} + \beta \log(p_{Dt}) + \xi_{Ddt} + \varepsilon_{iDdt} \equiv \delta_{Ddt} + \varepsilon_{iDdt} \tag{2}$$

when purchasing domestic (D). It is worth pointing out that this model does not contain any outside option: in other words, it is conditional on purchasing. Empirically our estimation is performed on car drivers who do purchase fuel, either in France or in Germany, abstracting from any other consideration which might include: domestic purchases in another *département*, foreign purchases in Belgium, Luxembourg, Switzerland, Spain, Italy, or Andorra, not to omit reducing or postponing fuel consumption. As a result, the parameter β governs the sole allocation between foreign and domestic consumption, keeping total consumption (the sum of foreign and domestic consumption) unchanged. By contrast, a price-elasticity coefficient would indicate by how much total consumption would respond to price changes, taking thus the possibility of no purchase into account.[6] The specification we adopt emphasizes the trade-off between price and distance, whereby the distance of each and any consumer to the border is approximated by the *département* where she lives, the actual distance between consumer residence and the gas station where the transaction occurred being unavailable in the data.

Assuming further that the idiosyncratic terms ε_{idt} are i.i.d. according to some EV(1) distribution, the domestic market shares writes:

$$s_{Ddt} = \frac{e^{\delta_{Ddt}}}{e^{\delta_{Ddt}} + e^{\delta_{Fdt}}} \tag{3}$$

One can normalize $\alpha_{Dd} = 0$ without loss of generality since $(\alpha_{Dd}, \alpha_{Fd})$ and $(0, \alpha_{Fd} - \alpha_{Dd})$ are observationally equivalent. A similar reasoning prevails when normalizing $\xi_{Ddt} = 0$. As shown by Berry (1994), an estimating equation is:

$$\log \frac{s_{Fdt}}{s_{Ddt}} = \alpha_{Fd} + \beta \log \frac{p_{Ft}}{p_{Dt}} + \xi_{Fdt}. \tag{4}$$

In our econometric specification, we posit that $\xi_{Fdt} = \nu_{Fds(t)} + \eta_{Fdt}$ where $\nu_{Fds(t)}$ captures seasonal effects (day-in-the-year, day-of-the-week, and bank holidays) while η_{Fdt} corresponds to unexplained error terms. In practice, we replace the left-hand side of equa-

[6] In Adam et al. (2023), we estimate that this price elasticity amounts to -0.3, on average.

tion (4) with the ratio of foreign-to-domestic purchases $\frac{q_{Fdt}}{q_{Ddt}}$, in logarithm: again, due to the absence of any outside option, the market size plays no role here.

To alleviate endogeneity issues due to, e.g., measurement error, simultaneity or imperfect pass-through, we instrument for relative prices, based on quasi-experimental price shocks described above. Standard errors are clustered by block bootstrap at the individual level.

To investigate whether carbon tax is more salient than excise taxes, we perform separate estimations where we either rely on the sole price shock from January 2021 consecutive to the introduction of the German carbon tax, or on subsequent excise tax rebates. To gain statistical power, we in fact consider a unique estimating equation while allowing for the price coefficient β to correspondingly vary over time. To ease interpretation, any change in that relative price-sensitivity over time would suggest that consumers differently value relative price increases of similar magnitude, depending on whether they result from a carbon tax or an excise tax; such heterogeneity would be consistent with behavioral effects related to tax salience.

3.3 Estimation results

In practice, we estimate the previous model with Germany (resp. France) being the foreign (resp. domestic) country. Table 1 displays our results issued from both OLS and IV approaches. Column IV contains our favorite point estimate corresponding to the IV specification with seasonal controls. A +1 log-point relative price increase causes relative fuel purchases to fall by $\hat{\beta} \approx -8.1$ log-point; put differently, when relative prices increase by +1%, the relative demand falls by about 7.7%. Both marginal own- and cross-price effects, in absolute, are given by: $\frac{\partial s_c}{\partial p_c} = \hat{\beta} \frac{s_c(1-s_c)}{p_c}, \forall c = D, F$, omitting unnecessary indices here. In the three border *départements* (Moselle, Bas-Rhin, Haut-Rhin), the conditional German share amounts to 7-8%, on average. Hence the effect of German prices increasing by $\Delta p_F = 10$ cents on German share is about $\Delta s_F \approx -5.1$pp, i.e., a reduction by more than one half of it. This figure already illustrates the need for tax coordination: in practice, a price differential of a few cents seems sufficient to almost ban competition by excluding the foreign country from the domestic market.

We address salience issues in Table 2 where we allow for the coefficient β to vary over time, separating what happened consecutive to the introduction of the carbon tax in

Germany from what is related to excise tax rebates. As a robustness check, we also split our sample and provide separate estimations before and after September 1st, 2021. From a purely statistical point of view, one cannot reject the null hypothesis of homogeneity of that coefficient over the whole period, in the specification where the German lockdown from December 16th, 2020 to 6th, May, 2021 is excluded from the sample. That specification aside, the relative demand responds more strongly to the carbon tax than to excise tax rebates, as would be the case if the carbon tax were more salient than excise taxes. However, there is no substantial difference from an economic point of view: the point estimate we obtain is -8.6 for the carbon tax and -7.6 for excise taxes, which yields close marginal effects.

3.4 Counterfactuals

The main advantage of previous approach is to predict the effect of any change in relative prices on country-specific shares. Denoting fuel purchases in *département* d on year y by $q_{dy} = q_{Ddy} + q_{Fdy}$,[7] the nationwide foreign share in France aggregates local foreign shares:[8]

$$\tilde{s}_y = \sum_d \hat{w}_{dy} \tilde{s}_{dy}, \tag{5}$$

based on *département*-specific weights $\hat{w}_{dy} = \frac{q_{dy}}{\sum_d q_{dy}}$ that account for the importance of *département* d in nationwide fuel consumption. Local foreign shares on that year $\tilde{s}_{dy}$ are given by:

$$\tilde{s}_{dy} = \sum_{t \in y} \hat{w}_{dt} \tilde{s}_{dt}, \tag{6}$$

i.e., summing up over all days in year y with respect to daily weights $\hat{w}_{dt} = \frac{q_{dt}}{q_{dy}} = \frac{q_{dt}}{\sum_{t \in y} q_{dt}}$ that account for the importance of day t in annual fuel consumption. By construction, our counterfactuals rule out any correlation in the choice of the country of fuel purchase and intertemporal substitution or substitution between *départements*. The latter assumptions sound quite fair approximations of actual consumer trade-offs. Relying on those behavioral assumptions enables us to compute the local market shares that would prevail at

[7] Once again, we abstract here from any change in fuel consumption in other countries than France and Germany. We focus on market shares that are conditional on buying either in France or in Germany.

[8] In what follows, we omit the subscript F in s_{Fdt} since the discrete-choice model considered here is binary.

any counterfactual German price $\tilde{p}_{Ft}$, replacing observed price p_{Ft} with the latter in equation (3), based on $(\hat{\alpha}, \hat{\beta}, \hat{\xi})$ estimates obtained under our favorite homogeneous specification in which $\hat{\beta} = -8.1$. In what follows, we focus on a counterfactual scenario with no German carbon tax at the onset of 2021, and simulate the corresponding German fuel share in year $y = 2021$. We also consider what would happen if German fuel prices increased by 20%: this counterfactual illustrates the case of growing political concerns about carbon pricing in that country.

The results are displayed by Table 3, which decomposes behavioural responses in each of the three border *départements*. We first evaluate that the German carbon tax has decreased the German (conditional) share of fuel purchases by 28-29% in Bas-Rhin, in Moselle, and in Haut-Rhin. Overall, it has reduced that (conditional) share by 23% nationwide. Remembering that the carbon tax was about 6 cents per liter only, namely 5% of the German price at the time, that counterfactual simulation is meaningful to get a sense of the magnitude of the relative price sensitivity of fuel purchases to foreign taxes. From these estimations, we can deduce that the German carbon tax increased domestic consumption, hence French fuel tax revenue, by 3.5% in Moselle and in Haut-Rhin, and by 3.0% in Bas-Rhin. In those *départements*, the elasticity of tax revenue with respect to German prices is thus substantial, about 0.5 (remember that the introduction of the carbon tax increased after-tax prices by about 7%), slightly higher than the 0.3 found by Asplund et al. (2007) for instance.

In the same vein, wondering next what would happen if German fuel prices rose by 20%, we find that the German share would shrink in those *départements* by a factor 4, i.e., it would decrease by nearly 75% (from 7.9% to 1.9% in Moselle). Overall, fuel tourism in Germany would almost vanish. We therefore believe that those two examples shed light on the magnitude by which uncoordinated tax policy on fuel affects cross-border purchases.

4 Conclusion

This paper has exploited exogenous, policy-driven price changes (the introduction of German carbon tax in 2021 and excise tax rebates in 2022) to infer the sensitivity of French fuel tourism to relative prices at the France-Germany border. Based on both a convincing research design and high-frequency transaction-level data, we have established that cross-border shopping is quite elastic: the relative demand decreases by 7.7% when relative prices increase by 1%. The elasticity of tax revenue with respect to foreign prices is as high as 0.5 in border *départements*. Moreover, we find similar demand responses to the carbon tax, on the one hand, and to excise tax rebates, on the other hand: though the difference in corresponding estimated price-sensitivity is statistically significant at usual levels, the gap between point estimates is small from an economical viewpoint, and the null hypothesis of equality cannot be rejected in some specifications. We interpret this result as evidence against the carbon tax being more salient than other taxes. Last, we have simulated the removal of the carbon tax in Germany to evaluate its causal impact on the relative German market share: about -3pp, namely a decrease by slightly less than 30% of that share in French border *départements*. Our results thus illustrate the importance of coordinating tax policy, be the tax a green tax or not. To the extent of external validity, they also give a flavor of what could result from imposing a carbon tax at the border. Investigating whether these findings extend to other institutional settings, hence assessing that external validity, sounds like a promising area of further research.

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Figures

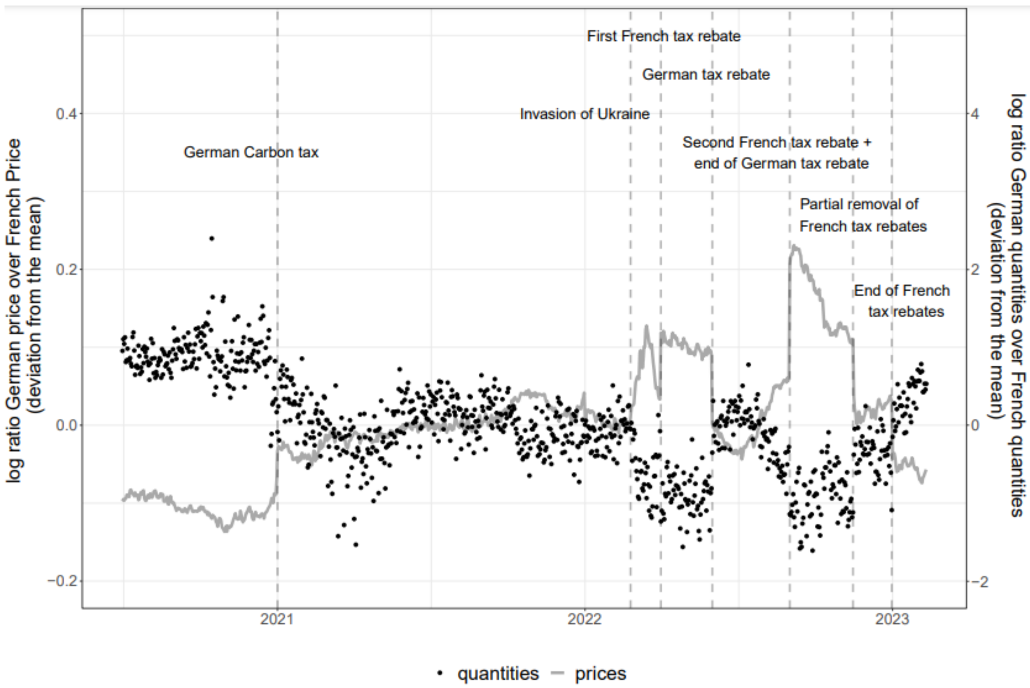


Figure 1: Relative German/French fuel prices and purchases (normalized log ratio)

Notes. Dashed lines correspond to the different price shocks: the invasion of Ukraine and policy interventions (introduction of a carbon tax in Germany on January 1st 2021, tax rebates in France on April 1st 2022, in Germany on June 1st 2022, the removal of the German rebate combined with an additional French rebate on September 1st, the partial removal of the French rebate on November 15th, and the complete removal of French rebates on December 31th).

Sources. Sample of households who primarily bank at *Crédit Mutuel Alliance Fédérale.*

Tables

Table 1: Main estimates

	I	II	III	IV
β	-7.73 (0.20)	-7.57 (0.20)	-8.15 (0.21)	-7.97 (0.22)
Instrumental variables			✓	✓
Seasonal controls		✓		✓
Département FE	✓	✓	✓	✓
# of customers	11,870	11,870	11,870	11,870
# of *départements*	3	3	3	3
# of *days*	955	955	955	955
Adjusted R^2	0.49	0.55	0.48	0.54
Wu-Hausman stat.			41	31
F-test (first stage)			5,050	4,886

Note. This table provides the results of the regression of the log ratio of fuel purchases on the log ratio of prices. Estimation sample: 11,870 customers in 3 *départements* located on the France-Germany border (Moselle, Bas-Rhin and Haut-Rhin). Estimation period: from July 1st, 2020, to February 10th, 2023. Standard errors computed from block bootstrap at the individual level. Columns I and II: OLS estimations. Columns III and IV: IV estimations. All regressions are weighted by age, sex and population in the *département*.
Source. Sample of households who primarily bank at *Crédit Mutuel Alliance Fédérale.*

Table 2: Heterogeneity (by tax salience)

	I	II	III	IV
β	-8.33 (0.19)	-8.02 (0.22)	-9.06 (0.20)	-8.26 (0.21)
$\beta \times$ (Post Carbon Tax)	1.25 (0.24)	0.94 (0.27)	2.13 (0.30)	0.68 (0.37)
Instrumental variables			✓	✓
Seasonal controls		✓		✓
Département FE	✓	✓	✓	✓
# of customers	11,870	11,870	11,870	11,870
# of *départements*	3	3	3	3
# of *days*	955	955	955	955
Adjusted R2	0.49	0.55	0.49	0.55
Wu-Hausman stat.			37	14
F stat first stage (log price ratio)			5,050	4,886
F stat first stage (log price ratio)x(Post)			1,998	1,659

Note. Estimation sample: 11,870 customers in 3 *départements* located on the France-Germany border (Moselle, Bas-Rhin and Haut-Rhin). Estimation period: from July 1st, 2020, to February 10th, 2023. The post-carbon tax period begins from September 1st, 2021. Standard errors computed from block bootstrap at the individual level. Columns I and II: OLS estimations. Columns III and IV: IV estimations. All regressions are weighted by age, sex and population in the *département*.
Source. Sample of households who primarily bank at *Crédit Mutuel Alliance Fédérale*.

Table 3: Counterfactual market shares

	I Observed prices	II No carbon tax in Germany	III German prices increase by 20%
German share in Moselle	7.95 (0.37)	11.05 (0.51)	2.01 (0.13)
German share in Bas-Rhin	6.90 (0.32)	9.63 (0.42)	1.73 (0.12)
German share in Haut-Rhin	7.98 (0.31)	11.06 (0.42)	2.02 (0.12)
German share in the rest of France	0.11 (0.01)	0.11 (0.01)	0.11 (0.01)
German share in France	0.42 (0.01)	0.54 (0.01)	0.18 (0.01)
Seasonal controls	✓	✓	✓
Départment FE	✓	✓	✓

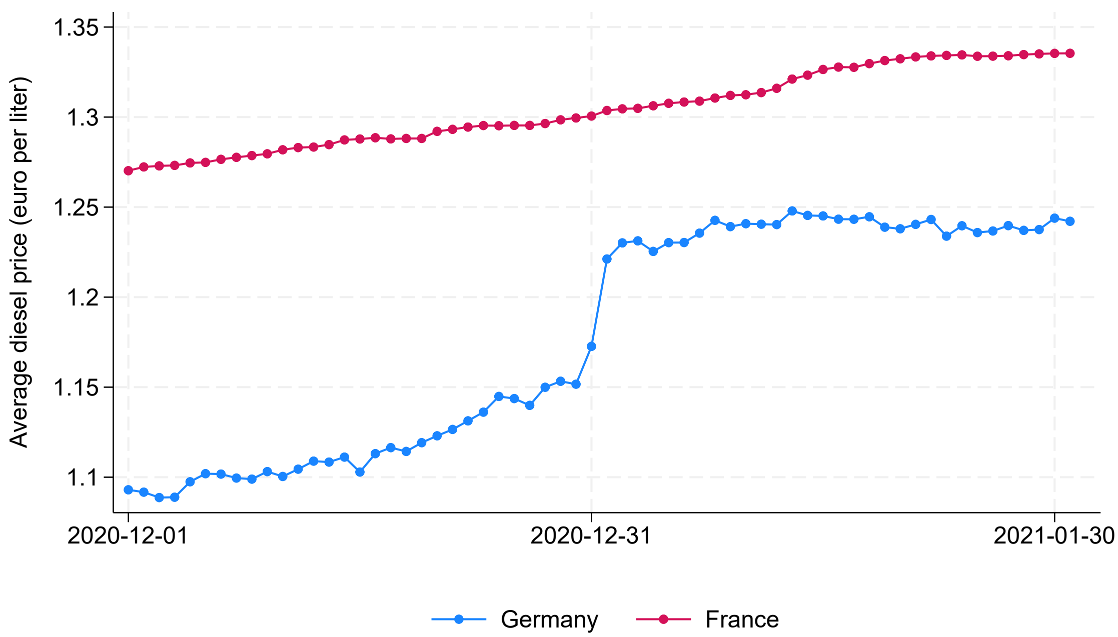
Lecture note. In 2021, the conditional market share of German fuel purchases (i.e., conditional on buying either in France or in Germany) amounted to 8.44%. In the absence of any German carbon tax, that share would have reached 11.45%. All regressions are weighted by age, sex and population in the *département*.
Note. Standard errors computed from block bootstrap at the individual level.
Source. Sample of households who primarily bank at *Crédit Mutuel Alliance Fédérale*.

Appendix

A Pass-through

In this section, we estimate the price pass-through of the German carbon tax. Consecutive to that tax, the price of diesel increased by 6.7 cents per liter before VAT, hence by 8 cents per liter after VAT (the VAT rate decreased from 19% to 16% from July to December 2020). Figure A1 shows the average evolution of diesel prices in both French and German gas stations located near the border.[9]

Figure A1: Mean diesel price in France and Germany around January 1st, 2021



Given prices p^{pre} before the introduction of the carbon tax, and under full pass-through,

[9] In France, this refers to the previous *départements* (57, 67 and 68) while in Germany we consider four first-two postcode areas (66, 76, 77 and 79). All subsequent results are not sensitive to this sample restriction and the estimated pass-through is very homogeneous regardless of the "distance" to the border.

prices p^{post} after that introduction should verify:

$$p^{\text{post}} = \frac{1.19}{1.16} p^b + 0.067 \times 1.19 \approx 1.02586 p^{\text{pre}} + 0.08, \tag{7}$$

where p^b accounts for the before-tax price that prevailed at the end of 2020. Given that average diesel prices in December 2020 were roughly €1.11 per liter, prices at the beginning of 2021 should then amount to nearly €1.21 per liter: the price gap should be about 10 cents per liter.

We then resort to an event study around January 1st, 2021 (day 0 in what follows). More specifically, we estimate the following equation:

$$p_{cst} = \beta_t \times \text{Germany}_s + \lambda_t + \alpha_c + \eta_s + \epsilon_{cst}, \tag{8}$$

where countries are indexed by c, gas stations by s and days by t, and *Germany* is a dummy equal to 1 for stations located in Germany.

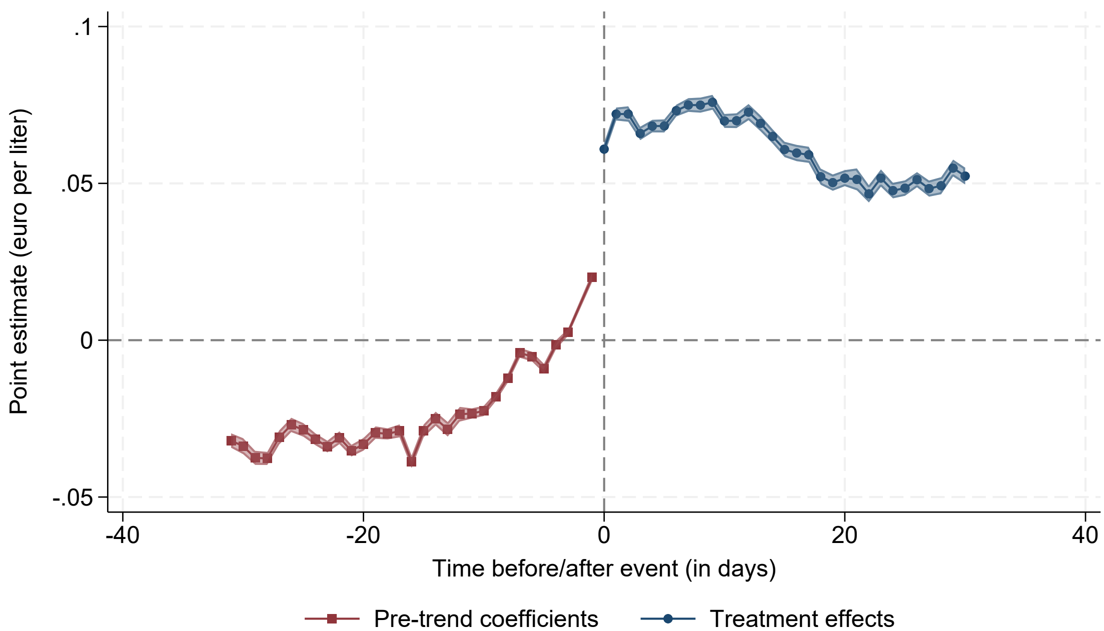


Figure A2: Event study on diesel prices (1 month around 01-01-2021)

The figure provides empirical evidence of immediate and almost full pass-through, in the short run.

In order to get a point estimate of that pass-through, we also estimate a DinD specification based on a 1-month time window before/after the introduction of the carbon tax. We define *Post* as a dummy equal to 1 after January 1st, and we consider the following estimating equation:

$$p_{cst} = (\lambda + \beta \text{Germany}_s)\text{Post}_t + \alpha_c + \eta_s + \epsilon_{cst} \tag{9}$$

Table A1: Pass-through (diesel only, 1 month around 01-01-2021)

	(1)	(2)	(3)	(4)	(5)
	Daily diesel price				
Constant	1.286***	1.186***	1.205***	1.205***	1.205***
	(0.000540)	(0.000195)	(0.000199)	(0.000293)	(0.000961)
German gas station	-0.169***				
	(0.000700)				
Post-January 1st	0.0367***	0.0367***			
	(0.000761)	(0.000434)			
German gas station after Jan-1st (β)	0.0844***	0.0838***	0.0836***	0.0836***	0.0836***
	(0.000989)	(0.000563)	(0.000520)	(0.000995)	(0.00327)
FE		Gas station	Gas station + Day	Gas station + Day	Gas station + Day
Clustering level				Gas station	Gas station + Day
Observations	63,120	63,120	63,120	63,120	63,120

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Our estimate of the pass-through is close to 84%, namely 8.4 cents per liter, to be compared with the expected increase of about 10 cents per liter, and can be interpreted as imperfect, but close to full pass-through. In any case, instrumenting the foreign-to-domestic price ratio in equation (4) should mitigate any concern about imperfect pass-through: from that viewpoint, equation (9) may be interpreted as a first stage, and previous point estimates provide comforting evidence about the strength of our first instrument.

B Data-related acknowledgements (in French)

Data from *Crédit Mutuel Alliance Fédérale*:

Première banque à adopter la qualité d'entreprise à mission, Crédit Mutuel Alliance Fédérale a contribué à cette étude par la fourniture de données de comptes bancaires sur la base de deux échantillons : un échantillon d'entreprises et un échantillon de ménages par tirage aléatoire et construit de telle sorte qu'on ne puisse pas identifier les entreprises (exclusion de sous populations de petite taille) ou les ménages. Toutes les analyses réalisées dans le cadre de cette étude ont été effectuées sur des données strictement anonymisées sur les seuls systèmes d'information sécurisés du Crédit Mutuel en France. Pour Crédit Mutuel Alliance Fédérale, cette démarche s'inscrit dans le cadre des missions qu'il s'est fixées :

- contribuer au bien commun en oeuvrant pour une société plus juste et plus durable : en participant à l'information économique, Crédit Mutuel Alliance Fédérale réaffirme sa volonté de contribuer au débat démocratique ;
- protéger l'intimité numérique et la vie privée de chacun : Crédit Mutuel Alliance Fédérale veille à la protection absolue des données de ses clients.