Local Pass-Through and the Regressivity of Taxes: Evidence from Automotive Fuel Markets

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Abstract

The regressivity of taxation is conventionally determined by examining relative quantities – i.e., whether poorer households devote more of their budget to the taxed good than richer ones. However, relative *price* impacts matter as well, and ignoring heterogeneous tax pass-through can lead to mistaken conclusions about distributional impacts. I show this empirically by estimating pass-through of retail diesel taxes in the Spanish market for automotive fuel. A government informational mandate provides access to a national, station-daily panel of retail diesel prices and characteristics; state-specific diesel taxes in Spain vary over time. Pass-through in my sample (2007-2013) is, on average, approximately 94 percent, but at the station level it varies from approximately 70 to 115 percent as a function of local characteristics. Market power appears to raise pass-through: refiner-branding, local brand concentration, and spatial isolation are all associated with higher rates. Observed pass-through patterns are consistent with imperfect competition and convex demand. Pass-through also rises consistently in municipal average house prices, a proxy for wealth. An estimate of the Spanish diesel tax's distributional burden that relies only on relative quantities implies a distributionally neutral policy; an estimate that accounts for heterogeneous pass-through shows a strong progressive trend.

Keywords: Incidence, Pass-Through, Energy, Market Power

JEL Codes: H22, L13, Q41

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1 Introduction

The distributional welfare impacts of taxation are a fundamental consideration in policy design and analysis. For instance, the U.S. government tasks the Treasury Department's Office of Tax Analysis with distributional analysis of tax burdens, which provide policy makers guidance on the "fairness" of proposed changes in tax law (Cronin 1999). Retail taxes on items as disparate as food, cigarettes, and energy are commonly thought to be regressive, which is generally seen as unattractive from a social welfare standpoint. Why are such taxes labeled regressive? The answer is that poorer households have frequently been found to devote a greater proportion of their budget to these goods than their richer counterparts. Yet it is not just relative quantities that dictate regressivity; it is also relative *price* impacts. The first-order approximation of a tax's effect on consumer surplus is a function of both consumption *and* price changes, but distributional calculations in academia and government alike tend to exclusively focus on the former (e.g., Horowitz et al. 2017; Bento et al. 2009; Gruber and Koszegi 2004). Accounting for the empirical relationship between tax pass-through and wealth has the potential to change the answer to "who bears the burden?" questions about taxes.

Pass-through has long been a valuable tool in economic analysis (Jenkin 1872). In public finance, pass-through is used to assess the incidence of taxes on consumers versus producers (Poterba 1996; Besley and Rosen 1999). In industrial organization, it is used to examine the impact of market structure and design on pricing (Bonnet et al. 2013; Fabra and Reguant 2014). In international economics, it has been the focus of studies of exchange-rate fluctuation (Berman, Martin, and Mayer 2012; Amiti, Itskhoki, and Konings 2014). An emerging, cross-field literature on pass-through clarifies its determinants in imperfectly competitive markets (Weyl and Fabinger 2013) and uses pass-through as a sort of sufficient statistic (Chetty 2009) to reveal underlying demand, supply, and policy parameters of interest (Jaffe and Weyl 2013; Atkin and Donaldson 2015; Ganapati, Shapiro, and Walker 2017).

In this paper, I estimate pass-through patterns in an imperfectly competitive market and document their implications for distributional welfare. The empirical setting is the Spanish market for retail automotive fuel – a large, localized, and imperfectly competitive market. I collect daily prices of automotive fuel at nearly 10,000 retail stations in Spain, made available through an informational mandate unveiled in January 2007 by Spain's Ministry of Energy. I combine these data with panel-varying fuel taxes, station attributes, and socioeconomic indicators to estimate average pass-through as well as local pass-through conditional on firm and market characteristics. I then match pass-through rates to fuel consumption by wealth bracket, in order to shed light on the distributional welfare implications of fuel taxation in Spain.

Multiple features of this empirical setting make it attractive for research on “local” pass-through. First, dozens of countries currently employ retail automotive fuel taxes, and hundreds of millions of drivers are more generally affected by the pass-through of cost shocks in the automotive fuel sector. Second, markets for automotive fuel are inherently local, due to spatial and brand differentiation. Third, there is existing evidence that the elasticity of demand for automotive fuel varies with wealth (West and Williams 2004; Houde 2012), which suggests that pass-through may do so as well. Fourth, the availability of daily, station-specific prices makes it possible to identify not just the timing of the pass-through response but also the predictive impact of high-resolution characteristics.

I begin my empirical analysis by conducting an event study of Spanish tax hikes, which provides a sense of how prices evolve in the run-up to and aftermath of these events. I find strong evidence of parallel trends: prices vary very little in the run-up to a tax hike. The pass-through response begins the week of the tax hike and stabilizes three weeks later. The difference-in-differences point estimate of average pass-through rate ranges from 92-95 percent, depending on the specification. These results follow a long literature on the price impacts of automotive fuel taxes, which generally points to full or very nearly full pass-through (Alm, Sennoga, and Skidmore 2009; Marion and Muehlegger 2011).

The average pass-through rate masks significant heterogeneity at the local level. In the full national sample, refiner-branded and wholesaler-branded stations both pass-through an additional 7-8 percentage points of a tax than unbranded ones, an effect which appears to be driven by stations in rural areas. In addition, spatial isolation (from other stations) and the market share of one’s own brand are associated with a higher pass-through rate. In urban areas where average house prices per unit area are available, pass-through rises in consistently in this variable. Rural areas, meanwhile, experience average pass-through rates on par with the lowest quartile of house prices. Using all observable attributes of stations and their surroundings, I predict station-specific pass-through rates that range from 70 to 115 percent.

One of the advantages of reduced-form methods of pass-through estimation is that, relative to structural methods, they require fewer functional form assumptions, which can predetermine pass-through (Miller, Osborne, and Sheu 2016). Inverting this logic, reduced-form pass-through estimates can shed light on underlying economic primitives. My findings – in particular, that pass-through rises in a variety of metrics of market power and exceeds 100 percent at some stations – are inconsistent with perfect competition, which bounds pass-through between 0 and 100 percent. They also resolve theoretical ambiguity in the shape of demand (Bulow and Pfleiderer 1983). Market power need not raise pass-through, nor must it necessarily produce overfull pass-through.[1] The fact that each of these conditions holds empirically implies that demand is highly convex (Seade 1985).

Since property values are a proxy for wealth, the empirical relationship between pass-through and property values has a first-order bearing on the regressivity of taxation. In my context, pass-through itself is "progressive". How does this affect the ultimate distribution of lost consumer surplus due to the Spanish diesel tax? To answer this question, I examine fuel consumption by expenditure decile in the Spanish Household Budget Survey. The traditional method employed in distributional analyses of taxation – in both government and academic work – is to calculate, for each wealth bracket, the average expenditure on the taxed good as a proportion of household budget (Poterba 1999). If pass-through is uniform, then it does not affect the distributional calculation, and proportional fuel expenditure provides an accurate first-order approximation of *relative* changes in consumer surplus induced by the tax. Rather than being uniform, however, Spanish diesel tax pass-through rises monotonically with wealth. To account for this fact, I multiply proportional fuel expenditure in each wealth decile by the pass-through rate predicted for that decile of the house-price distribution. The traditional procedure, which ignores pass-through heterogeneity, suggests that the Spanish diesel tax has roughly equal incidence across the wealth distribution. In stark contrast, the augmented procedure that accounts for local pass-through suggests that the tax is strongly progressive.

The sizeable dispersion in observed price impacts of fuel taxation begs the question: are the rest of retail automotive fuel costs passed through in the same way? To answer this question, I estimate how pass-through of crude oil shocks varies locally. While crude price pass-through does rise in house prices, the magnitude of the predictive effect is less than one-fifth that of tax pass-through. Competition effects on crude price pass-through are also weaker. These discrepancies could be explained, for example, by the relative persistence or salience of taxes (Li, Linn, and Muehlegger 2014), and they show how the effect of local pass-through on regressivity is, ultimately, an empirical question. Wherever pass-through is progressive, taxes on those products and in those locales become correspondingly more attractive from a distributional standpoint.

[1] Consider, for example, a monopolist facing linear demand; pass-through is identically 50%.

2 Pass-Through and Distributional Welfare

The term “pass-through” refers to what Alfred Marshall (1890) described as “the diffusion throughout the community of economic changes which primarily affect some particular branch of production or consumption.” Most commonly, these economic changes are costs, physically imposed on one part of a supply chain, and passed through to others. A positive cost shock elicits a direct change in consumer surplus through two channels: (a) the additional cost of consumption maintained in the face of rising prices; and (b) the utility lost from reduced consumption.[2] Pass-through physically measures the former (per unit consumption), which is the first-order approximation to the welfare impact of a marginal tax change. It is thus an integral part of distributional welfare analysis, which generally focuses on estimating changes in surplus among different segments of society (e.g., consumers vs. producers, and richer vs. poorer). If the price impacts of rising taxes vary across geographic regions, firms, or individuals, then distributional welfare varies accordingly.

What determines pass-through rates? In perfect competition, pass-through is entirely a function of elasticities of supply and demand. Equation 1 provides the mathematical definition (see Appendix A for the derivation):

$$\frac{dp_c}{dc} = \frac{\epsilon_S}{\epsilon_S - \epsilon_D} = \frac{1}{1 - \frac{\epsilon_D}{\epsilon_S}} \tag{1}$$

Pass-through of cost c to retail price p_c rises in the supply elasticity (ϵ_S) and falls in the absolute demand elasticity (ϵ_D). In the polar cases of either perfectly elastic supply ($\epsilon_S \to +\infty$) or perfectly *in*elastic demand ($\epsilon_D \to 0$), pass-through rates are identically 100%.

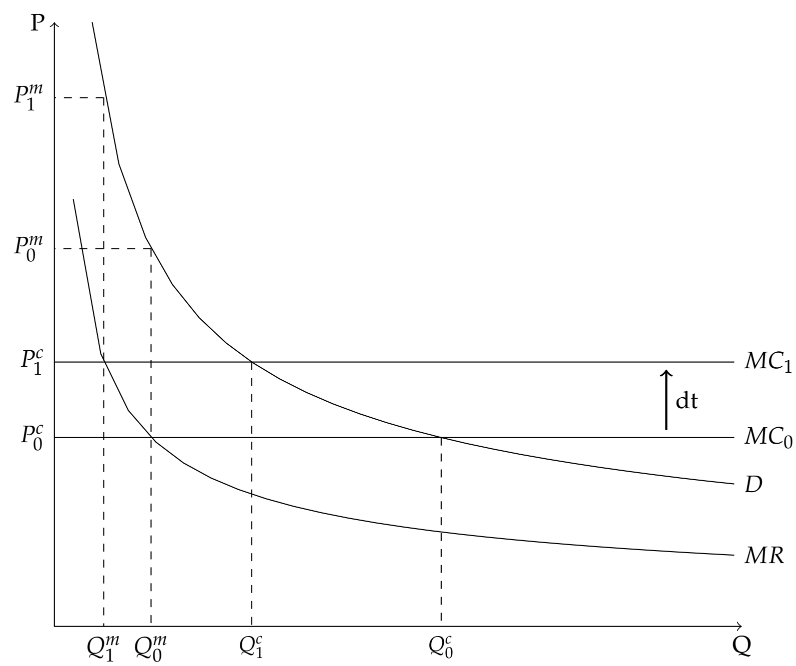
In *im*perfect competition, pass-through varies with not just the first derivative (elasticity), but also the second (convexity). Consider the formula for pass-through in monopoly with constant marginal costs c:

$$\frac{dp_m}{dc} = \frac{\frac{\partial p(q_m)}{\partial q_m}}{2\frac{\partial p(q_m)}{\partial q_m} + q_m \frac{\partial^2 p(q_m)}{\partial q_m^2}} \tag{2}$$

[2] Individual welfare is also determined by (a) ownership of supply-side capital; (b) externalities (such as pollution, traffic, and vehicular safety in the context of energy use); (c) other goods’ prices that are affected in general equilibrium; and (d) the use of government revenues obtained through taxation. In this paper, however, I focus only on the utility derived directly from the purchase and consumption of energy. See Sterner (2012) for a fuller discussion of the various channels through which a tax affects welfare.

Equation 2 shows that monopoly pass-through can, in principle, be higher or lower than perfectly competitive pass-through – it depends on the convexity parameter $\frac{\partial^2 p(q_m)}{\partial q_m^2}$ (Seade 1985).[3] Under perfect competition, constant marginal costs (i.e., perfectly elastic supply) guarantees fully 100 percent pass-through. With linear demand, $\frac{\partial^2 p(q_m)}{\partial q_m^2} = 0$ and monopoly pass-through simplifies to a constant 50 percent. If $\frac{\partial^2 p(q_m)}{\partial q_m^2} > 0$, then market power increases pass-through. If $\frac{\partial^2 p(q_m)}{\partial q_m^2}$ is positive and sufficiently large,[4] then pass-through can exceed 100 percent. Figure 1 depicts such a situation graphically, using an isoelastic demand curve. The price change under perfect competition ($P_1^c - P_0^c$) is exactly equal to the tax change; under monopoly ($P_1^m - P_0^m$), it is much larger.

Figure 1: *Pass-Through with Isoelastic Demand*



Notes: Subscripts indicate pre-tax (0) and post-tax (1) values. Superscripts denote perfect competition (c) and monopoly (m). The gray-filled area is the consumer surplus (CS) lost due to the tax hike (dt) under perfect competition; the pattern-filled area is the lost CS under a monopoly.

Empirically, pass-through has been shown to vary with market power (Doyle and Samphantharak 2008; Scharfstein and Sunderam 2016), supply elasticity (Marion and Muehlegger 2011), and cost structure (Ashenfelter et al. 1998; Stolper and Sweeney 2017). However, there is a disconnect between

[3]The main difference between monopoly and oligopoly pass-through is that the latter depends on both own- *and* cross-price terms; see Appendix A).

[4]The mathematical condition is $\frac{\partial^2 p(q_m)}{\partial q_m^2} > -\frac{\partial p(q_m)}{\partial q_m}\frac{1}{q_m}$.

the literatures on empirical pass-through estimation and distributional welfare analysis. Studies which focus on how progressive or regressive a cost change is uniformly rely only on inspection of relative consumption – i.e., quantities and not prices. The researcher does not allow for heterogeneous markup adjustment by firms, instead choosing a single pass-through rate to apply throughout the analysis. This practice is especially prevalent in the energy tax literature (Metcalf 1999; West 2004; Bento et al. 2009; Mathur and Morris 2012) but is also employed in studies of the U.S. sales tax (Caspersen and Metcalf 1994) and cigarette taxes (Gruber and Koszegi 2004).

To date, there is a lack of evidence on the relationship between pass-through and wealth.[5] However, widespread evidence on the link between demand elasticity and income implies that pass-through may vary with wealth. In industrial organization, demand estimation commonly includes a parameter for disutility of price times income; the parameter estimate is almost always negative (as in Houde 2012, in Quebec City's retail gasoline market), which implies that wealth lowers one's demand elasticity. Moreover, several studies have directly estimated demand elasticities as a function of wealth (West 2004; West and Williams 2004; Gruber and Koszegi 2004; Hughes, Knittel, and Sperling 2008). Gruber and Koszegi (2004) and West and Williams (2004) both note that a negative relationship between (absolute) demand elasticity and wealth makes taxes more progressive, but the channel that they focus on is reduced consumption. They do not extend their logic to the first-order welfare effect – pass-through.

3 Background on Spain's Oil Markets

The Spanish retail automotive fuel market appears highly imperfectly competitive.[6] Three companies (Repsol, Cepsa, and BP) own the nine oil refineries operating in Spain (imports account for only 10% of refined diesel), and together they own a majority stake in the national pipeline distribution network. Most importantly, they are heavily forward-integrated into the retail market: 61% of retail gas stations in Spain bear the brand of a refiner. Not surprisingly, these companies face significant scrutiny from government and popular media alike, on the grounds of alleged collusion and some of the highest estimated retail margins in all of Europe (see, for example, El País 2015).

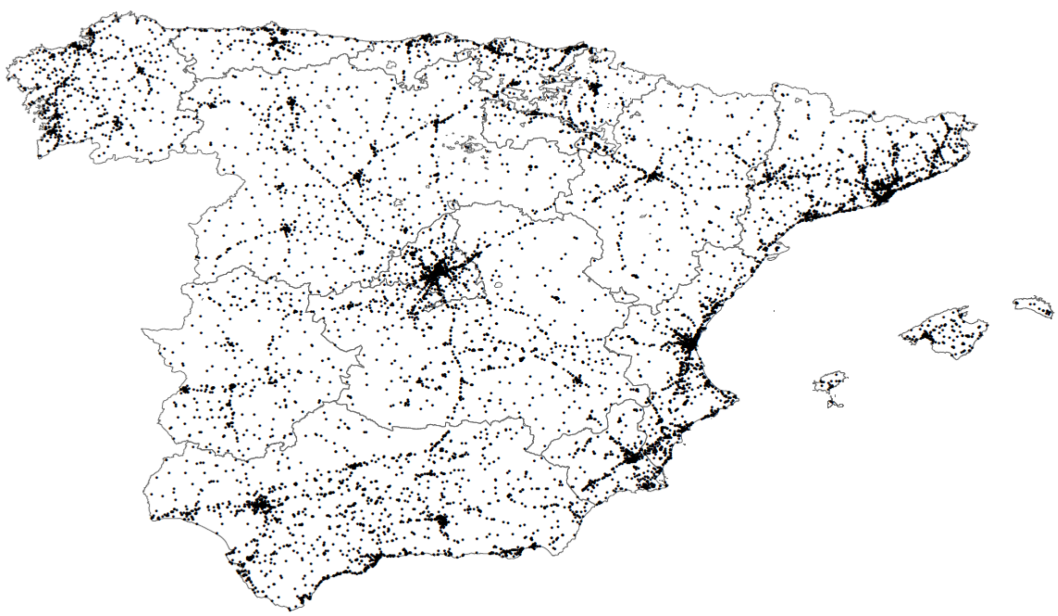
One result of such scrutiny has been very close monitoring of pricing by gas stations. A govern-

[5] Harding, Leibtag, and Lovenheim (2012) find different point estimates of cigarette tax pass-through by income tercile, but the difference does not appear to be significant.

[6] For background on the evolution of Spain's oil markets, see Contín-Pilart, Correljé, and Palacios (2009) and Perdiguero and Borrell (2007).

ment mandate which went into effect in January 2007 requires all stations across the country (more than 10,000 today) to send in their fuel prices to the Ministry of Energy whenever they change, and weekly regardless of any changes. These prices are then posted by the Ministry to a web page - called the *Geoportal* - that is streamlined for consumer use (see Appendix Figure 7). I obtain daily price data for retail diesel (which has a 67% share of the retail automotive fuel market), as well as the location, amenities, brand, and wholesale contract type at all Spanish gas stations from January 2007 to June 2013.[7]

Figure 2: *Station Geography*



Notes: Dots are Spanish retail gasoline stations.
Source: Ministries of Industry, Energy and Tourism (stations); National Statistical Institute (state boundaries).

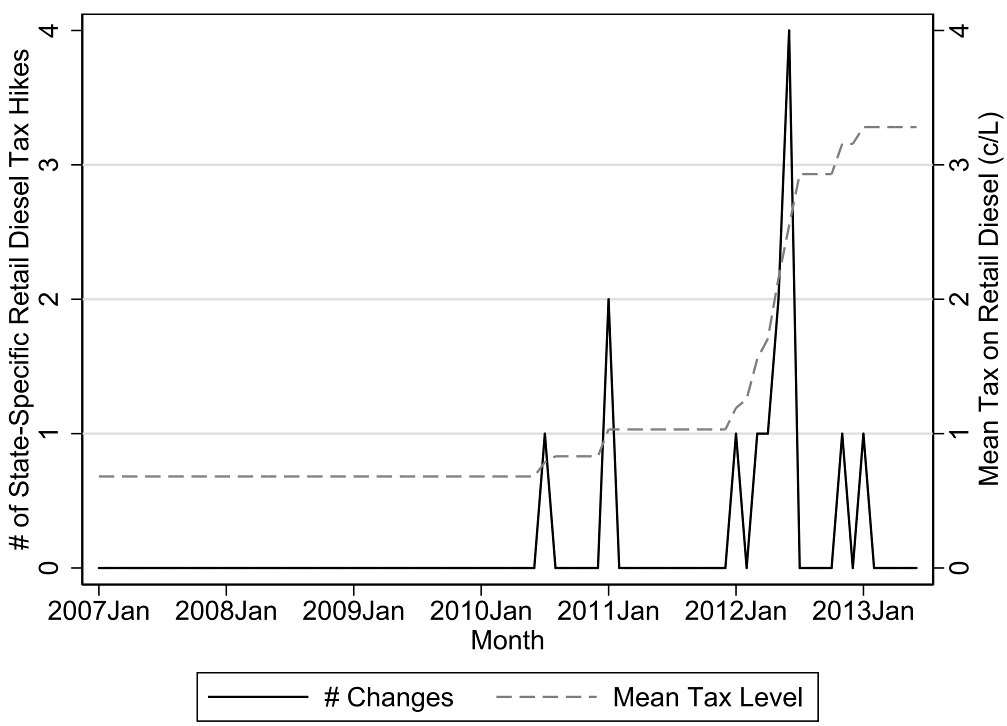
For each individual station, I calculate two proxies for market power, both using . The first is a count of open stations within a 10-minute distance radius, weighted by $\frac{1}{1+d}$, where d is the travel distance (in minutes) between a pair of stations. This proxy thus captures the degree of spatial isolation, or differentiation, from competitors. The second is the proportion of stations within a 10-minute radius that share one's brand; this measure captures the degree of brand concentration in local markets. Both of these competition proxies vary cross-sectionally and over time due to entry and exit of stations. The final characteristics I add to the station-level dataset are municipality-year

[7] Corresponding quantity (consumption) data are unavailable: the Ministry of Energy collects station-year total sale volume, but these data cannot be reliably matched to the Geoportal price data.

population density and municipal-quarter average house prices per unit area. The latter variable is only available for municipalities with greater than 25,000 residents, to which I refer as the "urban" sample.

There are four taxes applicable to retail diesel in Spain, but only one of them exhibits panel variation. This tax, colloquially known as the 'centimo sanitario' ("public health" tax), has as its stated purpose the generation of revenues to be used for public health improvements. In my sample time period, it varies from 0 to 4.8 Eurocents/liter (c/l) across states and discretely rises 14 times over my seven-year time period. This variation is plotted in Figure 3. The first tax change occurs in early 2010, and each month thereafter has 0-4 state-specific tax changes – all rises. The tax *changes* are marginal; their average size is 2.8 c/L, which is about 2.3 percent of retail prices.[8] However, two national excise taxes on retail diesel push the total excise tax burden to an average of 32 c/l, or 32.5 percent of retail price.

Figure 3: *Tax Variation*



Note: The solid line plots state-specific tax hikes. The dashed line plots the national mean level of the tax.

[8]There is a national sales tax of 21% that applies to retail diesel sales. I remove the contribution of this tax from retail prices in all analyses.

Table 1: *Summary Statistics*

	Rural	Urban	National
	(1)	(2)	(3)
After-tax retail price (c/l)	98.34	98.74	98.49
	(5.647)	(5.022)	(5.420)
Mean tax level (c/l)	1.733	1.796	1.757
	(1.116)	(0.971)	(1.063)
Brand			
Refiner (0/1)	0.587	0.642	0.608
	(0.492)	(0.479)	(0.488)
Wholesaler (0/1)	0.126	0.155	0.137
	(0.332)	(0.362)	(0.344)
Unbranded (0/1)	0.287	0.203	0.255
	(0.452)	(0.402)	(0.436)
# of rivals (distance-weighted)	0.910	1.720	1.219
	(1.038)	(1.380)	(1.244)
Local brand market share ([0,1])	0.308	0.248	0.286
	(0.365)	(0.276)	(0.335)
Municipal population density (1000s/km2)	0.258	2.363	1.060
	(0.737)	(3.472)	(2.445)
Municipal average house price (1000s of Euros/m2)	.	1.872	1.872
	(.)	(0.630)	(0.630)
N	5,852	3,605	9,457

Notes: All statistics are calculated from station-level observations. Brand dummies are cross-sectional from the time of entry into Geoportal. All other variables vary over time and are first collapsed to station-specific means. "Urban" refers to stations in municipalities with greater than 25,000 residents; house price data are only available for urban stations. Summary statistics for other variables are displayed in Appendix Table 1.
Source: Author's calculation using data from the Spanish Ministries of Industry, Energy, and Tourism.

The raw *Geoportal* data contain 9,911 stations as of June 2013 (the end of my sample period). The total drops to 9,457 when I remove stations from the three areas with unknown tax levels: the state of Canary Islands and the territories Ceuta and Melilla. The urban sample contain 3,605 stations; the rural sample contains the remaining 5,852. Table 1 presents summary statistics for the main analysis variables nationally as well as in the rural and urban samples separately.[9] The national average retail price is 98.49 c/l, and urban and rural averages are within 0.25 c/l of this number.[10] However, other characteristics differ substantially between urban and rural areas. Urban stations are more likely to be branded but have lower own-brand shares of markets. This lower share is, in part, a function of spatial competition: the average urban station has 1.72 distance-weighted rivals, compared to only 0.91 at the average rural one. Nationally, the maximum weighted number of rivals observed is 11.27.

4 Estimation of Average and Local Pass-Through

I begin my empirical analysis by studying *average* diesel tax pass-through. I use event study to investigate price trends in the temporal vicinity of tax changes. Tax changes are not random; according to correspondence with the Ministry of Industry, Energy, and Tourism, the state-level taxes in question have been raised in order to collect more revenue. States and times in which the need for revenue is relatively greater may be different along other relevant dimensions. Event study thus serves to assess endogeneity concerns.

I estimate the following model:

$$P_{it} = \alpha + \sum_{j=a}^{b} \pi^j D_{it}^j + \delta \mathbf{X}_{it} + \lambda_i + \sigma_t + \varepsilon_{it} \tag{3}$$

P_{it} is the after-tax (but gross of sales tax) price of retail diesel at station i and week t. The superscript j denotes a time period *relative* to the tax hike; D_{it}^j is thus a binary variable equalling one if an observation is both (a) in a state experiencing a tax hike and (b) j periods after (or before) that tax hike, where $j \in [a, b]$. X_{it} is a vector of observable demand and supply shifters. λ_i and σ_t are station and week fixed effects, respectively, and ε_{it} is a pricing residual that captures unobservable demand and cost conditions. Equation 3 is a conventional event study model, allowing prices to respond to an event flexibly over time. If prices respond either prematurely or with a lag relative to a tax hike,

[9] Station amenities and ownership structure are tabulated in Appendix Table 1.
[10] 98.49 c/l corresponds to 4.70 US$/gallon at the end-of-sample exchange rate.

that response will be captured by the coefficients π^j.

Several implementation details should be noted. First, and as suggested earlier, I choose the station-week as my baseline observation. Taxes themselves vary only at the state level; however, competition is a much more local phenomenon in retail automotive fuel markets. Meanwhile, the week level balances high resolution of analysis with computational tractability. Second, I choose $[a, b]$ to be equal to $[-12, 12]$, which is an observation window of 6 months, and omit the term $\pi^{-12}D_{it}^{-12}$ so that the price impact twelve weeks before the tax hike is normalized to zero. Third, I use all weeks from January 2007 through June 2013, regardless of their temporal proximity to tax hikes; this helps pin down my time fixed effects but necessitates the creation and inclusion of two dummy variables: one for an observation being from a period $j < -12$, and one for an observation being from a period $j > 12$. Fourth, I use all states, regardless of whether they are "treated" (with a tax hike) or "untreated".[11] Fifth, and finally, I cluster standard errors at the province (i.e., "county") level.

Figure 4 plots the estimated event study coefficients. On average, prices remain flat throughout the three months preceding a tax hike. They begin rising in the week of the tax hike itself and restabilize three weeks later, after which they remain flat out to the three-month mark. There is no evidence of differential pre-trends in "treated" and "control" stations. The average tax hike is 2.8 c/l, and the post-event price level is about 2.5 c/l higher than the baseline level estimated twelve weeks prior to an event.

To obtain a point estimate of diesel tax pass-through, I estimate the following difference-in-differences (DD) model:

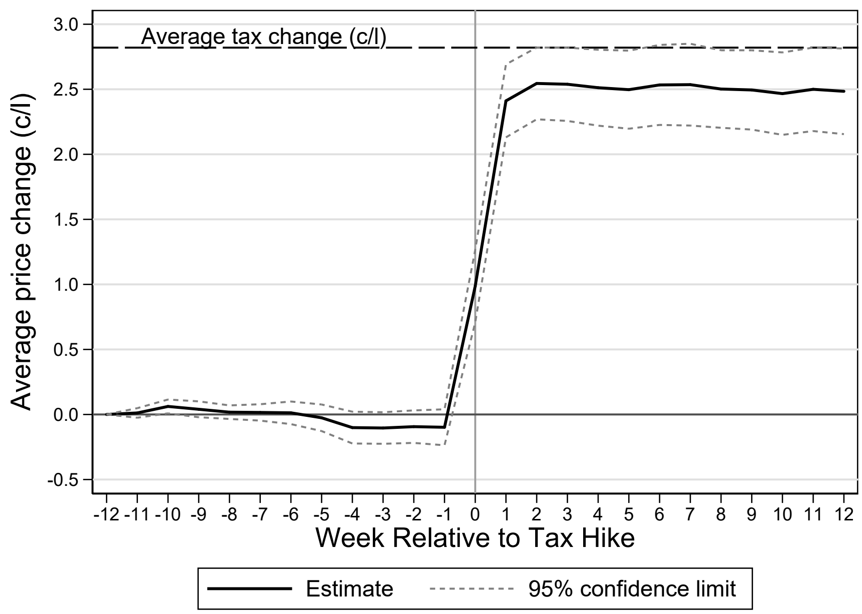
$$P_{it} = \alpha + \beta Tax_{it} + \delta \mathbf{X}_{it} + \lambda_i + \sigma_t + \varepsilon_{it} \tag{4}$$

β captures the average pass-through rate of diesel taxes in Spain. Again I cluster standard errors at the province level. While stations set prices in response to both own costs and rival costs, state diesel taxes affect all stations' costs in exactly the same way (except in areas with cross-border competition); thus, β is a measure of what is called industry-cost pass-through, not own- or rival-cost analogs.

Table 2 displays the results of estimating Equation 4. Coefficients are tabulated for three different specifications, first in the national sample, and then in the urban subsample. All specifications

[11]Estimation is also possible using *only* treated states, but this requires an additional parametric assumption (see McCrary 2007).

Figure 4: *Event Study of Tax Hikes: Overall Pass-Through*



Notes: Data points are month-specific coefficients estimated via event study (Equation 3). These coefficients are interpreted as price changes in stations experiencing a tax change, relative to 12 weeks before the tax change.

include station and week fixed effects and province-level clustering of standard errors. Relative to the base specification in columns 1 and 4, the specification in columns 2 and 5 adds time-varying controls (from $\mathbf{X_{it}}$), and the one in columns 3 and 6 additionally includes state-year fixed effects. The pass-through point estimate ranges from 0.924 – 0.944 across these columns, or 92-94 percent, and they are significantly different from 100 percent (or full, or complete, or one-for-one) pass-through.

Table 2: *Overall Pass-Through*

	National sample			Urban subsample		
	(1)	(2)	(3)	(4)	(5)	(6)
Mean tax level (c/l)	0.939***	0.938***	0.924***	0.944***	0.930***	0.933***
	(0.025)	(0.025)	(0.022)	(0.033)	(0.034)	(0.032)
Count of stations w/in 5 min.		-0.158***	-0.122***		-0.185***	-0.166***
		(0.038)	(0.040)		(0.068)	(0.049)
Own-firm proportion		0.038*	0.027		0.079	-0.002
		(0.022)	(0.022)		(0.065)	(0.056)
Population density		-0.596	-0.063		-0.769*	-0.442
		(0.378)	(0.397)		(0.429)	(0.438)
Average house price (Euro/ft2)					0.269	-0.063
					(0.169)	(0.087)
Controls		X	X		X	X
State-year FE			X			X
R-Squared	0.995	0.995	0.995	0.996	0.996	0.996
N	2,645,345	2,644,898	2,644,898	1,025,442	1,025,442	1,025,442

Notes: The dependent variable is after-tax retail diesel price in c/l. An observation is a station-week. All specifications are estimated via OLS with station and week fixed effects. Standard errors, clustered at the province level, are in parentheses.

A pass-through rate exceeding 90 percent is quite common in the automotive fuel tax literature; in fact, Chouinard and Perloff (2004), Alm, Sennoga, and Skidmore (2009), and Marion and Muehlegger (2011) all fail to reject the null hypothesis that state-level automotive fuel tax pass-through is fully 100 percent. The point estimates corresponding to included control variables are also sensible. Additional nearby stations (which implies tougher competition) are associated with lower retail prices, while brand concentration (which implies weaker competition) is associated with higher prices. On the demand side, greater population density (which is likely correlated with public transit supply) is associated with lower prices, while average house prices – a proxy for wealth – are associated with higher ones.

Next, I add interaction terms to the DD model:

$$P_{it} = \alpha + \beta Tax_{it} + \sum_{k=1}^{K} \left(\gamma_k Tax_{it} * X_{it}^k \right) + \delta \mathbf{X}_{it} + \lambda_i + \sigma_t + \varepsilon_{it} \quad (5)$$

γ_k captures the predictive effect on pass-through of a one-unit increase in X_{it}^k. Station and local area characteristics are not randomly assigned in space, so point estimates of γ_k do not have a strict causal interpretation. They nonetheless capture real heterogeneity in pass-through at the local level, and they provide suggestive evidence on the potential causes of such heterogeneity.

Table 3 displays results from estimation of Equation 5. Column 1 corresponds to the national sample. Here we find that branded stations – corresponding to both refiners and wholesalers – pass-through 7.5-8 percentage points more of a tax than unbranded ones, on average. This could be due to market power caused by brand loyalty; or it could be due to brand-specific costs or pricing strategies; or it could be due to endogenous location choices (e.g., brands choosing location based on local demand curves). Average pass-through also drops in weighted number of rivals (i.e, nearby stations) and rises in the market (i.e., station) share of one's brand. All of these relationships are statistically significant. Overall, there appears to be moderate differentiation in the retail market, predicted by various indicators of the toughness of local competition. Three different proxies for market power – branding, spatial isolation, and brand concentration – are positively associated with pass-through.

In the urban subsample, I am able to additionally include an interaction between the tax and average house price. Column 2 of Table 3 shows the results. Neither one's branding nor one's spatial isolation are significant predictors of pass-through; however, brand market share remains predictive, and the effect size doubles. Column 3 provides some contrast: in rural areas, branding has a strong predictive effect, and brand market share has a smaller effect. Strikingly, average house price is strongly, positively correlated with pass-through.

Regardless of whether the effects identified in Table 3 have a causal interpretation, they provide strong evidence that pass-through is heterogeneous. This, in turn, implies that distributional analyses which assume uniform pass-through are ignoring a potentially important source of variation in welfare impacts. To investigate how much heterogeneity is missed by assuming uniform pass-through, I use my estimated coefficients to calculate station-specific pass-through rates and plot their distribution.

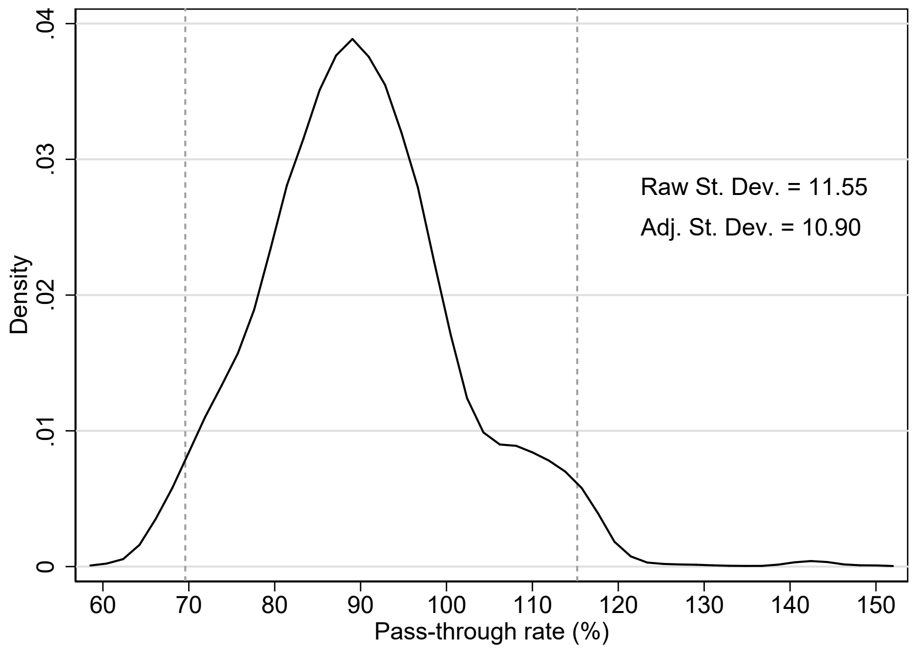
I calculate station-specific price impacts as the linear combination of the predictive effects of

Table 3: *Pass-Through and Local Competition*

	National	Urban	Rural
	(1)	(2)	(3)
Mean tax level (c/l)	0.918***	0.675***	0.895***
	(0.043)	(0.083)	(0.061)
Tax X 1[Refiner]	0.075**	0.048	0.074**
	(0.033)	(0.050)	(0.036)
tax_retail	0.079***	0.021	0.099***
	(0.030)	(0.049)	(0.034)
Tax X # rivals	-0.009*	-0.007	-0.009
	(0.005)	(0.005)	(0.007)
Tax X Brand market share	0.049***	0.090***	0.038***
	(0.011)	(0.024)	(0.012)
Tax X Population Density	0.003	-0.005	-0.005
	(0.005)	(0.003)	(0.016)
Tax X Avg. House price		0.195***	
		(0.040)	
R-Squared	0.995	0.996	0.995
N	2,644,898	1,025,442	1,619,455

Notes: The dependent variable is after-tax retail diesel price in c/l. An observation is a station-week. All specifications are estimated via OLS with station and week fixed effects. Standard errors, clustered at the province level, are in parentheses.

Figure 5: *Empirical Distribution of Pass-Through*



Notes: The plotted curve is a kernel density of pass-through rates at urban stations. Each input data point is a pass-through rate calculated from Equation 5. There is one data point for each station, corresponding to the last day of its observation in the data. Vertical dashed lines denote percentiles 2.5 and 97.5 of the empirical distribution. "Raw" standard deviation pertains to the empirical distribution as predicted by the calibrated regression model. "Adjusted" standard deviation pertains to the 'shrunk' distribution. I calculate the latter as the square root of the sample variance of pass-through rates minus noise, where I estimate noise as the average of the variances of each station-specific pass-through estimate.

all tax terms – $\beta Tax_{it} + \sum_{k=1}^{K} \left(\gamma_k Tax_{it} * X_{it}^{k} \right)$ in Equation 5 above. I divide this value by Tax_{it} to yield an estimate of pass-through $\frac{dp_{it}}{dt_{st}}$ for each station i in week t. In Figure 5, I plot these rates on the last day of observation for each station, using a kernel density estimator. Not surprisingly, the central tendency is 91% pass-through. However, the full range of observed pass-through rates ranges fromunder 60% to over 150%. 95% of these rates fall between 70% and 115%.

It is natural to ask how much of the pass-through distribution's spread is due simply to noise. To answer this question, I calculate the empirical variance of the pass-through rates used in Figure 5 and subtract off an estimate of noise. To estimate noise, I compute the standard error of each station's pass-through estimate, square it, and take the average across all stations. As is indicated on the right side of Figure 5, removing noise drops the standard deviation of the station pass-through rate from a raw value of 11.55 to an adjusted value of 10.9. That change corresponds to a contraction in the 95% confidence range of about 4 percentage points[12].

Pass-through patterns provide indirect insight into the nature of demand for automotive fuel. 24% of retail gas stations pass-through more than 100% of taxes to end consumers; this fact is inconsistent with both perfect competition and linear demand, both of which are common assumptions in the energy tax incidence literature. The most plausible explanation for rates above 100% is a setting of imperfect competition and sufficiently convex demand (like the isoelastic demand curve plotted in Figure 1). Other possible explanations – such as a lack of salience of taxes that drives consumers to under-respond to tax movement (Chetty, Looney, and Kroft 2009) – are less likely to be relevant, given the tax-inclusive nature of posted prices. In sum, both local preferences and competition levels appear to play a significant role in determining rates of energy tax pass-through in the Spanish diesel market. The analysis suggests that, from station to station and from market to market, there can exist large differences in the size of the consumer tax burden.

5 The Welfare Impact of Progressive Pass-Through

Average house prices are an especially important predictor of pass-through because they proxy for municipal wealth and thus capture how pass-through varies across the wealth distribution. I zoom in on this relationship in Table 4. I regress price on the tax level, average house price, and an interaction of the two (plus location and time fixed effects). I use municipality-quarter observations, because that is the level of observation of average house prices. Column 1 features results from a linear interaction between tax level and average house price; the coefficient is statistically significant at the 1 percent level, and its magnitude implies a 22.5 percentage-point rise in pass-through for every 1,000 Euros/meter squared increase in average house price. In columns 2 and 3, I interact tax level with house price quartiles. Column 2 shows that pass-through rises monotonically and significantly in quartile. Column 3, meanwhile, shows where rural stations rank; to use these stations in house-price regressions, I include a dummy for having missing house price and then recode missing house prices to zero. Pass-through at rural stations is not significantly different from pass-through in the lowest quartile of observed house prices. This is consistent with the notion that, were house prices available in rural areas, they would fall at the bottom end of the property value distribution.

[12]While there is additional noise coming from the explanatory variables themselves, it is more than counteracted by attenuation of the estimates due to measurement error.

Table 4: *Pass-Through and Local House Prices*

	Urban		National
	(1)	(2)	(3)
Mean tax level (c/l)	0.578***	0.886***	0.906***
	(0.076)	(0.033)	(0.032)
Tax X Avg. house price	0.225***		
	(0.038)		
Tax X 1[Avg. house price in 2nd quartile]		0.085***	0.083***
		(0.028)	(0.027)
Tax X 1[Avg. house price in 3rd quartile]		0.264***	0.259***
		(0.038)	(0.039)
Tax X 1[Avg. house price in 4th quartile]		0.467***	0.457***
		(0.053)	(0.057)
Tax X 1[Avg. house price missing]			-0.005
			(0.023)
R-Squared	0.999	0.999	0.998
N	6,766	6,766	77,371

Notes: The dependent variable is after-tax retail diesel price in c/l. An observation is a municipality-quarter. All specifications are estimated via OLS with municipality and quarter fixed effects. Standard errors, clustered at the province level, are in parentheses.

Pass-through itself thus appears "progressive" in this context. In theory, the distribution of pass-through rates has major implications for the distribution of welfare. As Figure 1 shows, tax changes cause lost surplus through both reduced consumption and higher costs of consumption maintained. With precisely estimated demand and supply curves, one could calculate lost consumer surplus directly. In their absence, the rectangle of area $Q_1 \frac{dp}{dt}$ is the first-order approximation of the lost surplus.[13] Dividing by some proxy for wealth W yields an estimate of the tax burden as a proportion of one's wealth, and one can examine the distribution of this proportional burden across the wealth distribution. If $\frac{\frac{dp}{dt} Q_1}{W}$ rises with wealth, then tax t is progressive; if it falls, then t is regressive.

This kind of calculation is quite common for distributional analysis of tax burdens, except with one simplification: an assumption of full, uniform pass-through. Under this assumption, the proportional burden simplifies to $\frac{Q_1}{W}$, which accurately captures tax *revenues* per unit consumption but is only proportion to tax burden if pass-through is uniform.[14] Examples of this in the context of automotive

[13]Equivalently, it is likely that the first 'cost' on a car owner's mind when a tax is raised is the extra cost paid for all the gasoline that he/she will continue to purchase, rather than the utility lost from reducing purchases.

[14]Moreover, data limitations mean that implementation usually relies on expenditure of energy rather than consumption.

fuel taxation are Poterba (1991) and Fullerton and West (2003). The Treasury Department's Office of Tax Analysis does the same for its own estimates of tax burdens (Fullerton and Metcalf 2002).

To show the effect of systematic variation in pass-through with wealth, I carry out the incidence calculation both with and without the assumption of uniform pass-through, using data from the 2013 Spanish Household Budget Survey. I divide households' fuel consumption Q (in liters) by their overall expenditure E – a smoother proxy for wealth than income (Poterba 1991) – and collapse these values into averages within each decile of overall expenditure. As is, these average values of $\frac{Q}{E}$ can be interpreted as estimates of the government revenues generated by households per unit tax hike, as a proportion of their overall wealth.

I then replicate the calculation while relaxing the assumption of uniform pass-through. This, of course, requires estimates of pass-through corresponding to wealth, of the form

$$\tau = \alpha + \beta Q_E + \varepsilon \tag{6}$$

where τ is pass-through and Q_E is a quantile (decile) of household expenditure. I do not jointly observe (τ, Q_E). Instead, I observe (τ, Q_{HP}), where Q_{HP} is the average house-price decile. The two proxies for wealth are related as follows:

$$Q_E = a + bQ_{HP} + e \tag{7}$$

I estimate pass-through as a function of house prices rather than expenditure, which is equivalent to substitution of Equation 7 into Equation 6. This yields

$$\tau = \alpha + a\beta + \beta b Q_{HP} + \varepsilon + \beta e \tag{8}$$

The coefficient on Q_{HP} underestimates the magnitude of the the rise in pass-through with wealth to the extent that $b < 1$, as would occur due to measurement error.

However, Q_{HP} is unlikely to be a valid instrument for Q_E, because house prices are additionally

fuel expenditure is only proportional to fuel *consumption* if prices are the same for all households, so the calculation relies on an unrealistic assumption of uniform pricing.

correlated with pass-through for unobserved reasons that have little do with income. For instance, some poorer people live in richer neighborhoods, and vice versa. The extent to which poorer individuals are forced to buy automotive fuel in richer areas is likely mitigated to some degree by sorting: some consumers like to price shop, and applications like Gas Buddy in the U.S. and Spain's own *Geoportal* target precisely those consumers. Moreover, demand estimation in the industrial organization literature nearly always finds a lower disutility of price among richer individuals (again, see Houde 2012 for an example). Still, βb may be overestimated on net due to incomplete sorting.

To implement this distributional calculation, I estimate the regression model below, which follows from Equation 8:

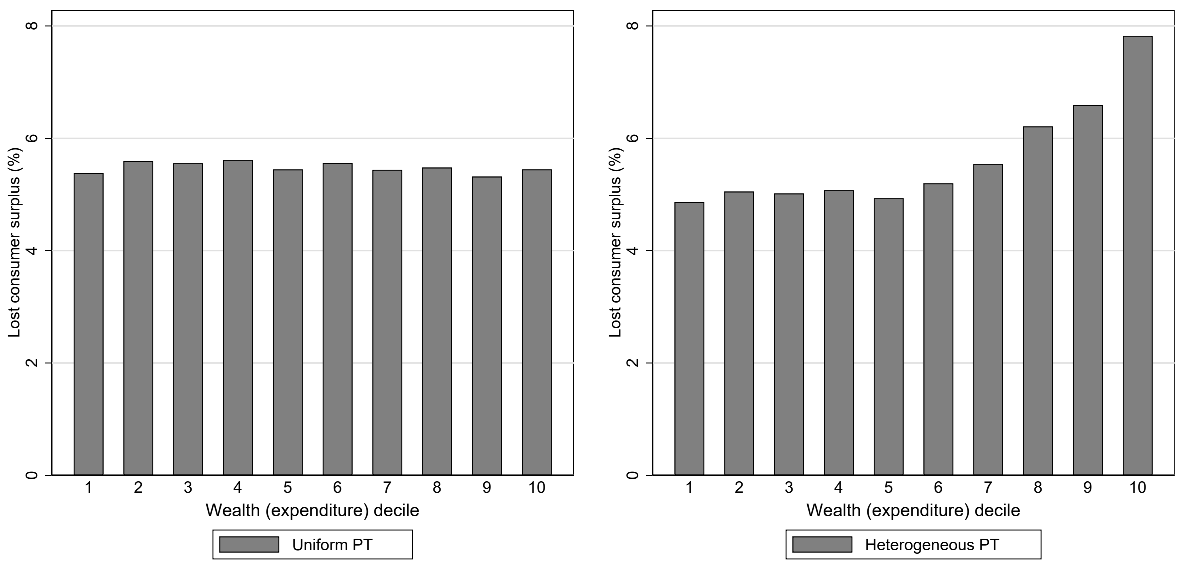
$$P_{it} = \alpha + \beta_0 Tax_{it} * 1[Rural]_i + \sum_{Q=1}^{6} \left(\beta_Q Tax_{it} * 1[HPQuantile = Q]_{it}\right) + \delta \mathbf{X}_{it} + \lambda_i + \sigma_t + \varepsilon_{it} \quad (9)$$

The dummy variable $1[Rural]_i$ equals one for all stations in areas with no house price data; β_0 thus provides an average pass-through rate in rural areas, which comprise roughly 40 percent of Spain's total population. That leaves 60 percent of the population in urban areas, and consequently I estimate a pass-through rate β_Q for each of six quantiles Q of the house price distribution. These rates are then used to compute $\frac{\frac{dp}{dt}Q}{E}$ at different expenditure deciles. I match the rural pass-through rate to the bottom four expenditure deciles, given the likelihood that rural areas feature the lowest house prices. I then match the six quantile-specific pass-through rates to the top six expenditure deciles.

Figure 6 plots the proportional tax burdens with and without the pass-through adjustment. Interestingly, when pass-through is assumed full and uniform (solid line), households appear to have roughly equal fuel tax burdens as a proportion of their full budget (i.e., equal fuel-tax rates). Incidence is neither regressive nor progressive in this formulation of the exercise. This pattern runs counter to the belief that poorer households spend more of their budget on fuel than richer ones, which would yield a downward-sloping graph in Figure 6. Understanding the flat trend with respect to Spanish automotive fuel consumption is thus a subject for further research; however, the main point of Figure 6 is the effect of heterogeneous pass-through relative to this flat baseline. When pass-through heterogeneity is explicitly accounted for in analysis (dashed line), higher-expenditure households appear to have much higher effective fuel-tax rates. Incidence now looks strongly progressive over the top half of the wealth distribution.

While the magnitude of the pass-through effect on progressivity is large, it should not be surprising.

Figure 6: *The distributional impact of fuel taxes*



Notes: The left panel plots household consumption of auto fuel as a percentage of total household expenditure, averaged by expenditure decile. The right panel does the same, except that consumption is multiplied by the pass-through rate corresponding to a household's expenditure decile. See Section 5 for details. Pass-through rates come from Equation 10.

Pass-through is inherently related to demand elasticity, so the pass-through/wealth relationship is inseparable from the demand elasticity/wealth relationship. Some have argued that richer people are more sensitive to fuel prices than poorer ones (Keyser 2000; Hughes, Knittel, Sperling 2008), because, for example, the rich have more "discretionary" uses of automotive fuel. A large body of research in the structural industrial organization literature, however, suggests that disutility of prices falls in income (e.g., Houde 2012), which implies *less* price sensitivity among the rich. Furthermore, the effect of variable demand elasticities is the focal point of research by West (2004) and by West and Williams (2004); they estimate that demand for gasoline is more inelastic in richer areas. My findings are consistent with this result; a question for future research is, does pass-through rise in wealth for taxes on other goods, in other markets and countries?

The consensus finding in the energy tax incidence literature (see Section 2) is that such taxes are regressive. This is generally due to the fact that poorer households are observed to spend a greater portion of their wealth on energy, at least in the U.S. However, several factors that mitigate this regressivity have been identified. First of all, regressivity estimates are sensitive to the specification of wealth; Poterba (1991) shows that annual expenditure is a better proxy for lifetime wealth than annual income, and that using the former leads to smaller magnitudes of regressivity in the U.S. gasoline tax. Second of all, the poorest households often do not own energy capital such as automobiles; including these households in analysis can vastly reduce regressivity (Fullerton and West 2003), especially in the developing country context (Blackman, Osakwe, and Alpizar 2009). Third of all, the demand response to taxes is unlikely to be static across the wealth distribution; West (2004) and West and Williams (2004) estimate that the gasoline demand elasticity drops (in absolute magnitude) as income rises in the U.S., which makes consumer surplus impacts less regressive than when demand response is assumed to be homogeneous.

To this literature, I add a fourth-mitigating factor: pass-through heterogeneity. Just like the demand elasticity – indeed, *because* of the demand elasticity – pass-through need not be static across the wealth spectrum. In fact, pass-through heterogeneity is likely to have a much greater effect on tax incidence than corresponding heterogeneity in demand elasticity, because the welfare lost due to higher prices on maintained consumption probably dwarfs the welfare lost from consumption foregone. In my own context, I find economically significant variation in pass-through rates across the house-price distribution. Pass-through rises in municipal wealth, and this, in turn, should make the retail diesel tax relatively less regressive (or more *pro*gressive).

One important question that follows from the presented findings is, do these local pass-through differences extend to the input cost of fuel? Answering this question informs our understanding of pass-through in the longer run, since the market is well-accustomed to frequent fluctuations in the cost of refined gasoline and diesel. I investigate this by estimating pass-through patterns for crude oil price shocks. Following a long literature on the "rockets and feathers" of oil price pass-through (e.g., Borenstein, Cameron, and Gilbert 1997), I include lagged values of crude price out to eight weeks (denoted by j below):

$$P_{it} = \alpha + \sum_{j=0}^{8} \left(\beta_j Crude_{it}^{t-j} \right) + \delta \mathbf{X}_{it} + \lambda_i + \sigma_t + \varepsilon_{it} \tag{10}$$

I additionally interact crude price variables with the same station and area characteristics as in the rest of my analysis. The results are displayed in Table 5.

Average eight-week cumulative pass-through of a crude oil price shock is 107 percent, as shown in column 1. According to columns 2 and 3, higher house prices are still predictive of higher pass-through, but the magnitude of the effect is only about 15 percent of the corresponding magnitude for

Table 5: *Crude Oil Price Pass-Through*

	National	Urban		Rural
	(1)	(2)	(3)	(4)
Crude oil price (c/l)	1.070***	0.997***	1.004***	1.065***
	(0.003)	(0.012)	(0.012)	(0.004)
Crude price X Avg. house price		0.037***	0.039**	
		(0.006)	(0.005)	
Crude price X 1[Refiner]			-0.003	-0.001
			(0.004)	(0.002)
Crude price X # rivals			-0.006**	0.000
			(0.002)	(0.001)
Crude price X Brand market share			0.001	0.010**
			(0.006)	(0.003)
R-Squared	0.492	0.517	0.521	0.481
N	2,592309	1,004,887	1,004,887	1,587,422

Notes: The dependent variable is after-tax retail diesel price in c/l. Retail and crude price variables are specified as lagged one-week differences. An observation is a station-week. All specifications are estimated via OLS with station and state-year fixed effects. Point estimates report cumulative 8-week price impacts. Standard errors, clustered at the province level, are in parentheses.

tax changes. Branding does not predict any differences in crude price pass-through. Spatial isolation and brand market share do show some predictive power, but the former only in urban areas, and the latter only in rural ones. The overall picture is of real differences in pass-through of input cost shocks vs. retail taxes. Crude price pass-through is, on average, greater than 100 percent. "Overfull" pass-through has been found before in spatially differentiated markets (Marion and Muehlegger 2011; Miller, Osborne, and Sheu 2017) and is plausibly explained by demand convexity. Pass-through patterns for crude oil price shocks – including both the high average pass-through rate and the relative lack of heterogeneity in "local" rates – are consistent with a lower elasticity of demand with respect to crude oil price, relative to the retail tax level. I cannot confirm this empirically in my context, but such a finding could be explained, for instance, by the greater persistence and salience of tax changes relative to oil price changes.

6 Conclusion

Pass-through is an important parameter in a wide variety of economic analyses. In this paper, I have shown that pass-through varies significantly at the local level. In a large national market for a product exhibiting brand and spatial differentiation, I find that pass-through is consistently higher in places characterized by greater market power. Moreover, higher property values – a proxy for local wealth – are also strongly, positively associated with pass-through. Predicting firm-specific pass-through as a function of observable firm and area characteristics yields a distribution centered on 90 percent but ranging from 70 percent to 115 percent.

These pass-through patterns reveal something about economic primitives. They strongly suggest that imperfect competition has a meaningful effect in retail automotive fuel markets. At the same time, they inform the shape of the demand curve. The positive relationship between pass-through and market power, as well as the prevalence of stations with predicted pass-through greater than 100 percent, are consistent only with convex demand curves. This finding exemplifies how pass-through can be used as a "sufficient statistic" for identifying attributes of the demand curve, which in turn can be used to calibrate more realistic demand forms (Fabinger and Weyl 2017).

Perhaps more importantly, the strong association between property values and pass-through suggests that the latter plays an important role in determining distributional outcomes. In my context, pass-through itself is progressive, rising monotonically in the quartile of municipal average house prices. A conventional distributional calculation, relying only on consumption totals from a consumer expenditure survey, suggests that the Spanish diesel tax is distributionally neutral with respect to consumer surplus. A calculation that incorporates progressive pass-through, however, shows a strong progressive trend in the upper half of the wealth distribution.

An accurate picture of the distributional impacts of energy taxes is important because of widespread reliance on these taxes across the world and the potential for even more. In the United States, automotive fuel tax hikes at both the federal and state levels continue to be proposed. In countries all over the world, carbon taxation is a frequent policy considered in climate policy design. For any policy that raises the price of consumption or production, whether through a physical tax or some other regulation, the distribution of welfare impacts is a fundamental consideration for both political viability and economic justice. In this paper, I show that relative price effects have major implications for distributional welfare, and that incorporating local pass-through estimates can in principle change one's conclusions about the progressivity or regressivity of a policy.

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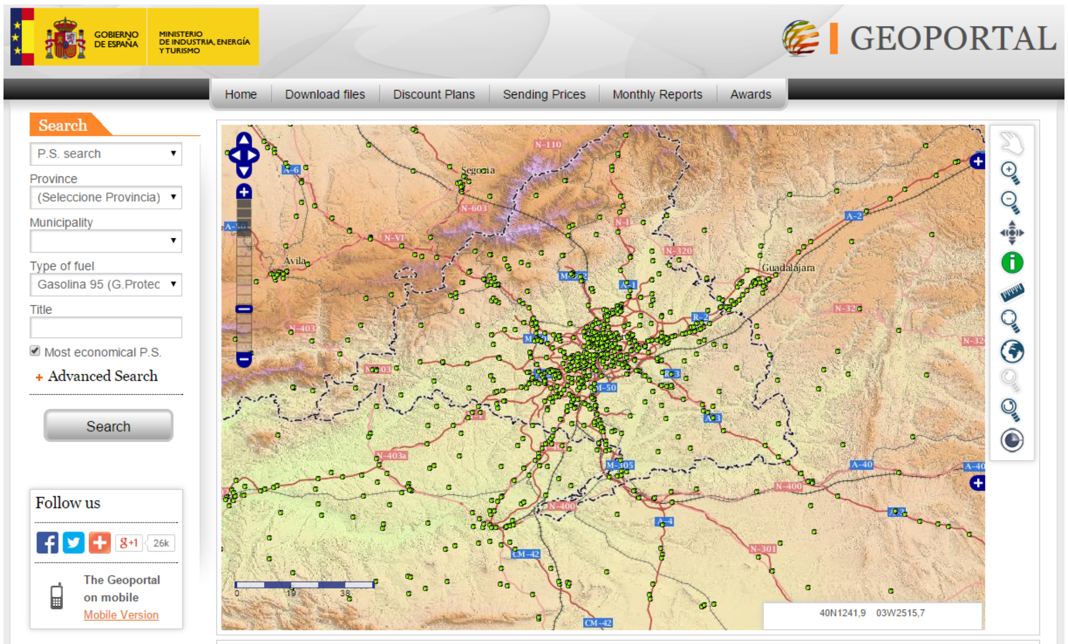
Appendix

Figure 7: *Screenshot of* Geoportal



Notes: Green dots are Spanish retail diesel stations. The screenshot shows the Madrid metro area. Source: <http://geoportalgasolineras.es/>, accessed on February 15th, 2015.

Appendix A Theoretical Derivation of Pass-Through

The structural determination of pass-through depends integrally on the nature of competition. To illustrate this fact, below I derive the equation for pass-through under (a) perfect competition, (b) monopoly, and (c) Bertrand oligopoly. None of the derivations below are original. To my knowledge, the perfect competition result is due to Jenkin (1872); the monopoly result is due to Bulow and Pfleiderer (1983); and the oligopoly result is due to Anderson, de Palma, and Kreider (2001).

Perfect competition

In the special case of perfect competition, all firms are identical and there is one market price (p_c). Equilibrium is given by the meeting of aggregate demand with competitive supply, given a tax t:

$$D(p_c) = S(p_c, t)$$

Total differentiation yields an expression for pass-through $\frac{dp_c}{dt}$, which is the same for all firms:

$$\frac{dp_c}{dt} = \frac{-\frac{\partial S}{\partial t}}{\frac{\partial S}{\partial p_c} - \frac{\partial D}{\partial p_c}}$$

Finally, assuming $\frac{\partial S}{\partial t} = -\frac{\partial S}{\partial p_c}$, substituting, and multiplying the numerator and denominator by p_c/q yields:

$$\frac{dp_c}{dt} = \frac{\frac{\partial S}{\partial p_c}}{\frac{\partial S}{\partial p_c} - \frac{\partial D}{\partial p_c}} * \frac{\frac{p_c}{q}}{\frac{p_c}{q}} = \frac{\epsilon_S}{\epsilon_S - \epsilon_D} = \frac{1}{1 - \frac{\epsilon_D}{\epsilon_S}}$$

Thus, equilibrium pass-through under perfect competition is a function only of the ratio of absolute demand elasticity (ϵ_D) to supply elasticity (ϵ_S). Importantly, pass-through need not be one-for-one (100%) in this setting; it is, however, bounded between 0 and 100%. To see this, consider the polar cases of demand: A market with perfectly inelastic consumption ($\epsilon_D = 0$) will be characterized by 100% pass-through, since suppliers will lose no sales from raising prices; on the other hand, a market with perfectly *elastic* consumption ($\epsilon_D \rightarrow -\infty$) will be characterized by 0% pass-through, since consumers will cease buying all energy if the price rises at all. Similarly, perfectly elastic supply

($\epsilon_S \rightarrow +\infty$) and perfectly inelastic supply ($\epsilon_S = 0$) produce 100% and 0% pass-through, respectively.

Monopoly

The monopolist's profit function is:

$$\pi_m(q) = qp_m(q) - c(q) - qt$$

where $c(q)$ is a total cost function. Retail gasoline supply is likely very elastic in the short run, since oil production is steady and the great majority of marginal cost in retailing is the purchase of fuel. For simplicity, I therefore proceed with the assumption that marginal costs are constant. This produces the familiar monopoly first-order condition (FOC):

$$\frac{\partial \pi_m}{\partial q_m} = p_m(q) + q\frac{\partial p_m}{\partial q} - c - t = 0$$

where the first two terms comprise marginal revenue and the last two terms comprise marginal cost. Total differentiation of this FOC with respect to t defines monopoly pass-through:

$$\frac{dp_m}{dt} = \frac{\frac{\partial p(q_m)}{\partial q_m}}{2\frac{\partial p(q_m)}{\partial q_m} + q_m\frac{\partial^2 p(q_m)}{\partial q_m^2}}$$

The monopoly price impact of a tax change thus depends most integrally on the shape of demand. If demand is linear, then the second term in the denominator drops out and pass-through is 50%. If demand is non-linear, then the second derivative of demand dictates the relative change to pass-through: concave demand produces less than 50% pass-through; convex demand produces greater than 50% pass-through and is no longer bounded above by 100%.

Oligopoly

Cost pass-through in an oligopolistic market is determined by a much more complex process. Each firm now has its own residual elasticity of demand, and it also now has incentive to respond to the pricing decisions of its neighbors. To see this, consider a model of Bertrand multi-product (-station) competition. There is a set of stations S, indexed $i = \{1, 2, ..., N\}$, each with its own, constant marginal costs c_i. The N stations are owned by F firms, indexed $f = \{1, 2, ...F\}$, with $F \leq N$. The set of stations run by firm f is denoted S_f. Profits for firm f are given by:

$$\pi_f(\mathbf{p}) = \sum_{i \in S_f} q_i(\mathbf{p}) \left[p_i - c_i - t\right]$$

The profit maximization problem for this firm f is to choose price p_i at each station $i \in S_f$ to maximize $\pi_f(\mathbf{p})$. The resulting first-order condition for firm f, station i is:

$$\frac{\partial \pi_f}{\partial p_i} = q_i + \frac{\partial q_i}{\partial p_i}\left[p_i - c_i - t\right] + \sum_{k \neq i, k \in S_f} \frac{\partial q_k}{\partial p_i}\left[p_k - c_k - t\right] = 0$$

Totally differentiating this FOC with respect to t, and rearranging terms, produces:

$$\frac{dp_i}{dt} = \left[\frac{\partial q_i}{\partial p_i} + \sum_{k \neq i, k \in S_f} \frac{\partial q_k}{\partial p_i} \right.$$

$$\left. - \sum_{j \neq i} \left(\frac{\partial q_i}{\partial p_j} + \frac{\partial^2 q_i}{\partial p_i \partial p_j} m_i + \sum_{k \neq i, k \in S_f} \left(\frac{\partial q_k}{\partial p_i}\frac{\partial p_k}{\partial p_j} + \frac{\partial^2 q_k}{\partial p_i \partial p_j} m_k \right) \right) \frac{dp_j}{dt} \right]$$

$$\Bigg/ \left(2\frac{\partial q_i}{\partial p_i} + \frac{\partial^2 q_i}{\partial p_i^2} m_i + \sum_{k \neq i, k \in S_f} \frac{\partial^2 q_k}{\partial p_i^2} m_k \right)$$

where markup $m_i = p_i - c_i - t$.

Equation 11 expresses tax pass-through firm i as a function not just of market primitives (demand elasticities and marginal costs) but also of the j other firms' pass-through; it is difficult to simplify further without additional assumptions. If one assumes symmetry among firms in a market, then Equation 11 reduces to the following:

$$\frac{dp_i}{dt} = \frac{\frac{\partial q_i}{\partial p_i}}{2\frac{\partial q_i}{\partial p_i} + \sum_{j \neq i} \frac{\partial q_i}{\partial p_j} + (p_i - m)\left[\frac{\partial^2 q_i}{\partial p_i^2} + \sum_{j \neq i} \frac{\partial^2 q_i}{\partial p_i \partial p_j}\right]}$$

where m is the now-homogeneous sum of marginal cost and retail tax. This structural equation is a generalized version of Equation 11, which defines monopoly pass-through - if there were no other firms j in the market, Equation 11 would collapse back down to Equation 11. Just as in the monopoly case, both first and second derivatives of demand matter in oligopoly. However, other stations now affect the decision of station i. Its pass-through rate is now additionally a function of the cross-price elasticities $\frac{\partial q_i}{\partial p_j}$ as well the cross-price derivatives of own-price elasticities $\sum_{j \neq i} \frac{\partial^2 q_i}{\partial p_i \partial p_j}$.