Online Appendix

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

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1 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

($\epsilon_S \to +\infty$) 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:

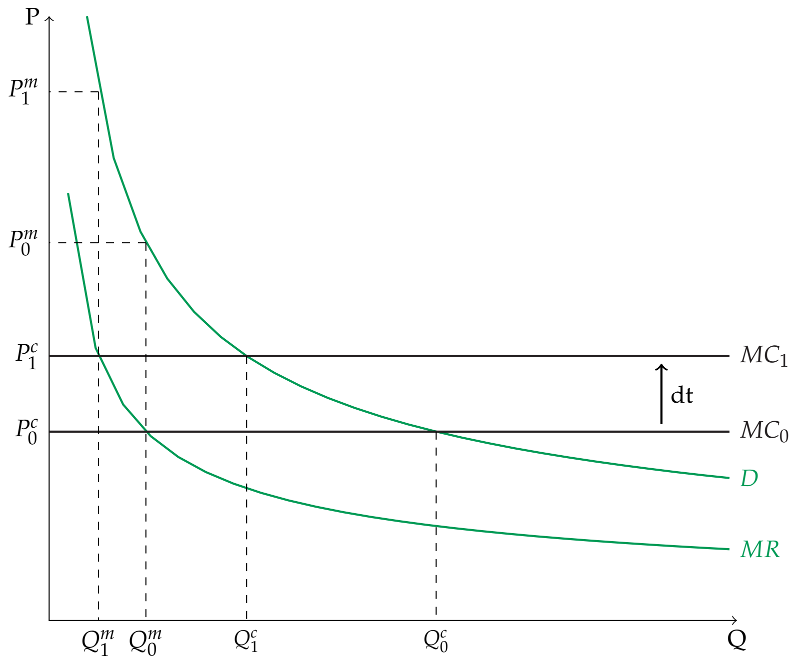
$$\frac{dp_m}{dt} = \frac{\frac{\partial p(q_m)}{\partial q_m}}{2\frac{\partial p(q_m)}{\partial q_m} + q_m\frac{\partial^2 p(q_m)}{\partial q_m^2}}$$

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%. Figure A1 depicts supply and demand curves for which market power raises pass-through to above 100 percent.

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

Figure A1: *Pass-Through with Isoelastic Demand*



Notes: Subscripts indicate pre-tax (0) and post-tax (1) values. Superscripts denote perfect competition (c) and monopoly (m). p_1^m and p_0^m are defined by the monopoly equilibrium equivalence of $MR = MC$. It is evident with this isoelastic demand curve (and constant marginal cost curve) that the monopoly price impact, $p_1^m - p_0^m$, is greater than the price impact under perfect competition, $p_1^c - p_0^c$.

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 $m_i = p_i - c_i - t$.

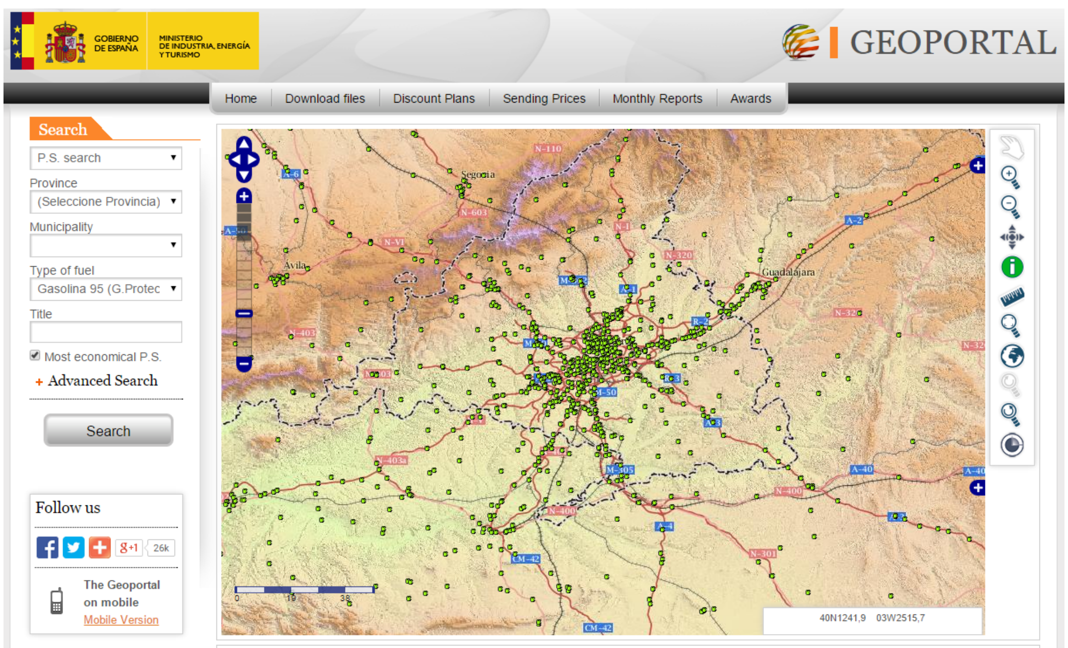
Equation 1 expresses tax pass-through firm i as a function not just of market primitives (demand elasticities and marginal costs) but also of the j other firms' pass-through; it is difficult to simplify further without additional assumptions. If one assumes symmetry among firms in a market, then Equation 1 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 1, which defines monopoly pass-through - if there were no other firms j in the market, Equation 1 would collapse back down to Equation 1. 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 $\sum_{j \neq i} \frac{\partial^2 q_i}{\partial p_i \partial p_j}$.

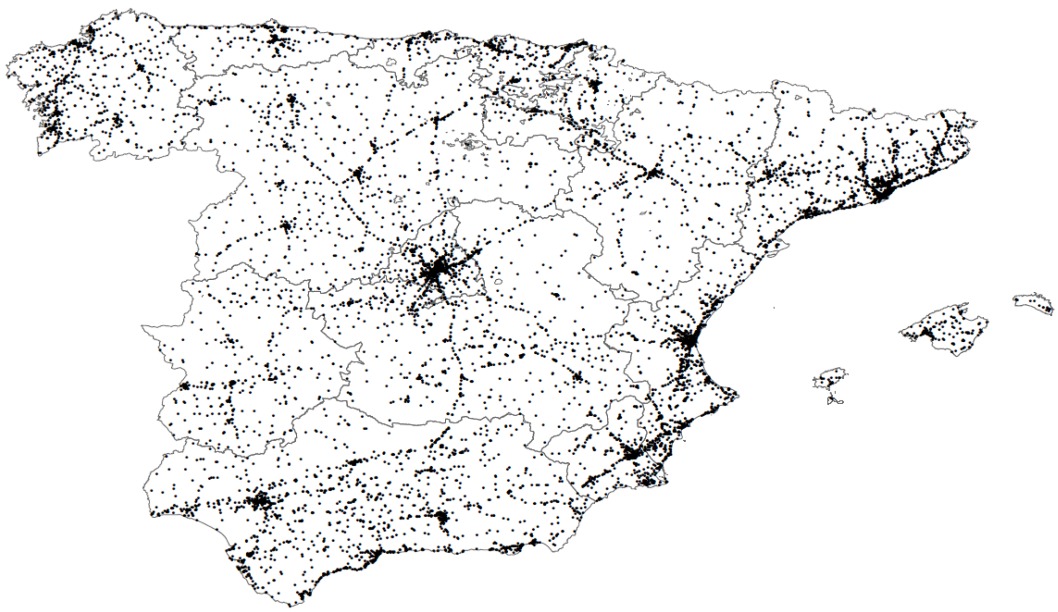
2 Supplementary figures and tables

Figure A2: *Screenshot of* Geoportal



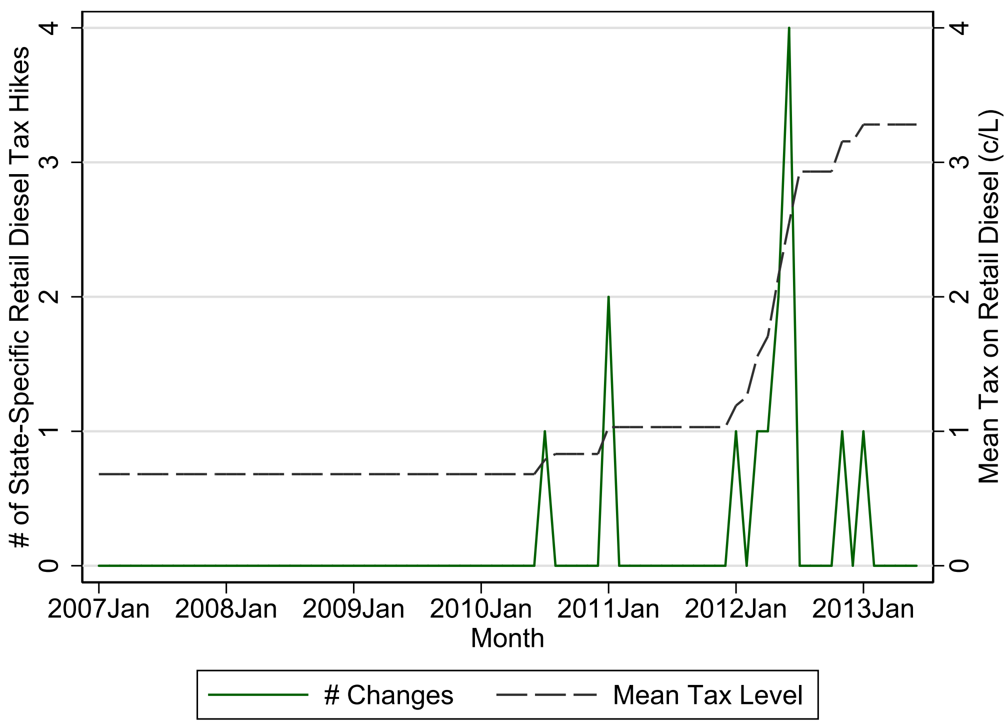
Notes: Green dots are Spanish retail diesel stations. The screenshot shows the Madrid metro area. Source: <http://geoportalgasolineras.es/>, accessed on February 15th, 2015.

Figure A3: *Station Geography*



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

Figure A4: *Tax Variation*



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

Table A1: *Overall Pass-Through*

	(1)	(2)	(3)	(4)	(5)
Mean tax level (c/l)	0.938***	0.924***	0.938***	0.936***	0.930***
	(0.025)	(0.022)	(0.035)	(0.025)	(0.034)
# of rivals (distance-weighted)	-0.158***	-0.122**	-0.175***	-0.435***	-0.185**
	(0.038)	(0.040)	(0.028)	(0.101)	(0.068)
Brand market share ([0,1])	0.038	0.027	0.070	0.057	0.079
	(0.022)	(0.022)	(0.060)	(0.063)	(0.065)
Population density (1000s per km^2)	-0.596	-0.063	-1.287*	-0.734	-0.769
	(0.378)	(0.397)	(0.573)	(0.791)	(0.429)
Average house price (1000s of Euros/m^2)					0.269
					(0.169)
Sample	National				Urban
State-year FE		X			
Population weights			X		
2010-2013 only				X	
R-Squared	0.995	0.995	0.997	0.991	0.996
N	2,644,898	2,644,898	2,644,898	1,525,457	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. The sample time period is January 2007 to June 2013, except for in column 4, where it is January 20010 to June 2013 (there are no tax changes prior to 2010). "# of rivals" is a count of rivals within a driving distance of 10 minutes, weighted by inverse driving distance. "Brand market share" is the proportion of those rival stations that bear the same brand as the station in question. Population density and average house price are observed at the municipality level.

Table A2: *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 X 1[Wholesaler]	0.079**	0.021	0.099**
	(0.030)	(0.049)	(0.034)
Tax X # of 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. The omitted brand designation is "1[Independent]", so that coefficients on "1[Refiner]" and "1[Wholesaler]" are interpretable as relative to unbranded independent stations.

Table A3: *Crude Oil Price Pass-Through*

	National	Urban		Non-urban
	(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 # of 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.

3 Math formulation of the distributional welfare calculation

My preferred calculation of the diesel tax's proportional burden requires estimates of pass-through corresponding to wealth, of the form

$$\tau = \alpha + \beta Q_E + \varepsilon \tag{1}$$

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:

$$Q_E = a + bQ_{HP} + e \tag{2}$$

I estimate pass-through as a function of house prices rather than expenditure, which is equivalent to substitution of Equation 2 into Equation 1. This yields

$$\tau = \alpha + a\beta + \beta b Q_{HP} + \varepsilon + \beta e \tag{3}$$

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 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.