The Dynamics of Gasoline Prices: Evidence from Daily French Micro Data APPENDIX

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Appendix A. Likelihood function

The contribution to the likelihood function of price constancy in firm i at date t is :

$$\begin{aligned}
l_{1i,t} &= \Pr(dp_{i,t,\tau}|dp_{i,t,\tau}=0,p_{i,t-\tau},X_{it},p_t^o) \\
&= \Pr(s_{it}<p_{i,t-\tau}-p_{i,t}^*<S_{it}) \\
&= \Pr(\gamma_{is}X_{it}+\varepsilon_{2,it}<p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\varepsilon_{1,it}<\gamma_{iS}X_{it}-\varepsilon_{2,it}) \\
&= \Pr(\varepsilon_{1,it}+\varepsilon_{2,it}<p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\gamma_{is}X_{it};p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\gamma_{iS}X_{it}<\varepsilon_{1,it}-\varepsilon_{2,it}) \\
&= \Phi\left[\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\gamma_{is}X_{it}}{\sqrt{\sigma_{1i}^2+\sigma_{2i}^2}}\right] \\
&\qquad -\Phi_2\left[\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\gamma_{is}X_{it}}{\sqrt{\sigma_{1i}^2+\sigma_{2i}^2}};\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o-\gamma_{iS}X_{it}}{\sqrt{\sigma_{1i}^2+\sigma_{2i}^2}};\frac{\sigma_{1i}^2-\sigma_{2i}^2}{\sigma_{1i}^2+\sigma_{2i}^2}\right]
\end{aligned} \tag{1}$$

where Φ is the c.d.f of the Gaussian distribution and $\Phi_2$is the bivariate c.d.f of the Gaussian distribution.

The contribution to the likelihood function of a price increase in firm i at date t is:

$$\begin{aligned}
l_{2i,t} &= \Pr(dp_{i,t,\tau}|dp_{i,t,\tau}>0,p_{i,t-\tau},X_{it},p_t^o) \\
&= \Pr\left(\varepsilon_{1,it}=p_{i,t}-\alpha_i-\beta_i p_t^0\right)\times\Pr\left[p_{i,t-\tau}-p_{i,t}^*\leq s_{it},\quad p_{i,t-\tau}-p_{i,t}^*<S_{it}\mid\varepsilon_{1,it}=p_{i,t}-\alpha_i-\beta_i p_t^0\right] \\
&= \frac{1}{\sigma_{1i}}\phi\left(\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o}{\sigma_{1i}}\right) \\
&\times\Pr\left[\begin{array}{c} p_{i,t-\tau}-\alpha_i-\beta_i p_t^0-\varepsilon_{1,it}\leq\gamma_{is}X_{it}+\varepsilon_{2,it},\quad p_{i,t-\tau}-\alpha_i-\beta_i p_t^0-\varepsilon_{1,it}<\gamma_{iS}X_{it}-\varepsilon_{2,it} \\ \mid\varepsilon_{1,it}=p_{i,t}-\alpha_i-\beta_i p_t^0\end{array}\right] \\
&= \frac{1}{\sigma_{1i}}\phi\left(\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o}{\sigma_{1i}}\right)\times\Pr\left[-dp_{i,t,\tau}-\gamma_{is}X_{it}\leq\varepsilon_{2,it},\quad dp_{i,t,\tau}+\gamma_{iS}X_{it}>\varepsilon_{2,it}\right] \\
&= \frac{1}{\sigma_{1i}}\phi\left(\frac{p_{i,t-\tau}-\alpha_i-\beta_i p_t^o}{\sigma_{1i}}\right)\times\left[\Phi\left(\frac{dp_{i,t,\tau}+\gamma_{iS}X_{it}}{\sigma_{2i}}\right)-\Phi\left(\frac{-dp_{i,t,\tau}-\gamma_{is}X_{it}}{\sigma_{2i}}\right)\right]
\end{aligned} \tag{2}$$

where ϕ is the p.d.f of the Gaussian distribution and $dp_{i,t,\tau}=p_{it}-p_{it-\tau}$.

The contribution to the likelihood function of a price decrease in firm i at date t is:

$$\begin{aligned}
l_{3i,t} \quad &= \Pr(dp_{i,t,\tau}|dp_{i,t,\tau} < 0, p_{i,t-\tau}, X_{it}, p_t^o) \\
&= \Pr\left(\varepsilon_{1,it} = p_{i,t} - \alpha_i - \beta_i p_t^0\right) \times \Pr\left[p_{i,t-\tau} - p_{i,t}^* > s_{it}, \quad p_{i,t-\tau} - p_{i,t}^* \geq S_{it} \mid \varepsilon_{1,it} = p_{i,t} - \alpha_i - \beta_i p_t^0\right] \\
&= \frac{1}{\sigma_{1i}} \phi\left(\frac{p_{i,t-\tau} - \alpha_i - \beta_i p_t^o}{\sigma_{1i}}\right) \\
&\times \Pr\left[\begin{array}{c} p_{i,t-\tau} - \alpha_i - \beta_i p_t^0 - \varepsilon_{1,it} > \gamma_{is} X_{it} + \varepsilon_{2,it}, \quad p_{i,t-\tau} - \alpha_i - \beta_i p_t^0 - \varepsilon_{1,it} \geq \gamma_{iS} X_{it} - \varepsilon_{2,it} \\ \mid \varepsilon_{1,it} = p_{i,t} - \alpha_i - \beta_i p_t^0 \end{array}\right] \\
&= \frac{1}{\sigma_{1i}} \phi\left(\frac{p_{i,t-\tau} - \alpha_i - \beta_i p_t^o}{\sigma_{1i}}\right) \times \Pr\left[-dp_{i,t,\tau} - \gamma_{is} X_{it} > \varepsilon_{2,it}, \quad dp_{i,t,\tau} + \gamma_{iS} X_{it} < \varepsilon_{2,it}\right] \\
&= \frac{1}{\sigma_{1i}} \phi\left(\frac{p_{i,t-\tau} - \alpha_i - \beta_i p_t^o}{\sigma_{1i}}\right) \times \left[\Phi\left(\frac{-dp_{i,t,\tau} - \gamma_{is} X_{it}}{\sigma_{2i}}\right) - \Phi\left(\frac{dp_{i,t,\tau} + \gamma_{iS} X_{it}}{\sigma_{2i}}\right)\right]
\end{aligned} \tag{3}$$

where ϕ is the p.d.f of the Gaussian distribution and $dp_{i,t,\tau} = p_{it} - p_{it-\tau}$.

The likelihood function for an i.i.d. sample of a given firm i is thus:

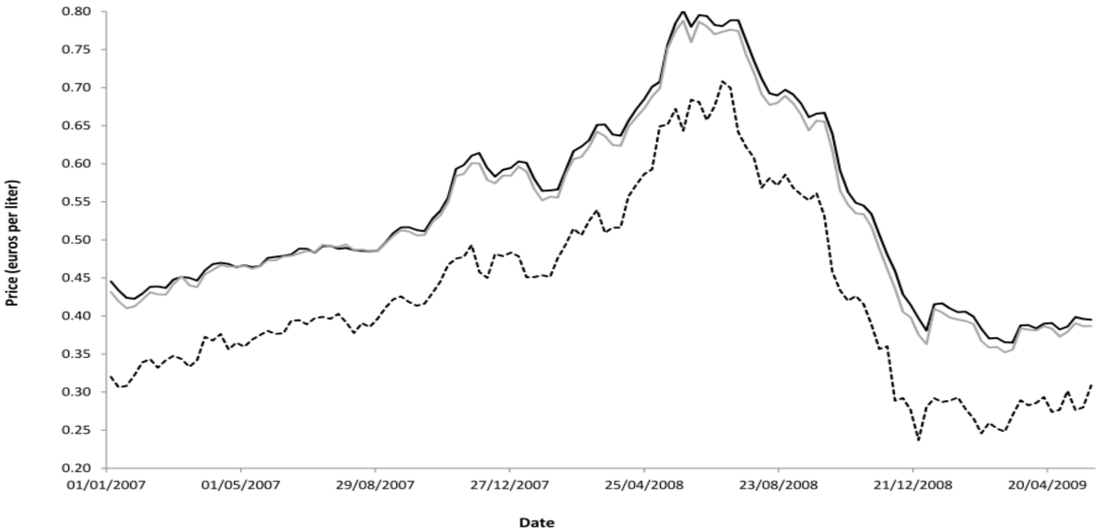
$$\ln L_i(\theta) = \sum_{t=1}^{T_i} (l_{1i,t} \times y_{1it} + l_{2i,t} \times y_{2it} + l_{3i,t} \times y_{3it})$$

where $y_{1it} = 1$ if $dp_{i,t,\tau} = 0$ and 0 otherwise, $y_{2it} = 1$ if $dp_{i,t,\tau} < 0$ and 0 otherwise and $y_{3it} = 1$ if $dp_{i,t,\tau} > 0$ and 0 otherwise.

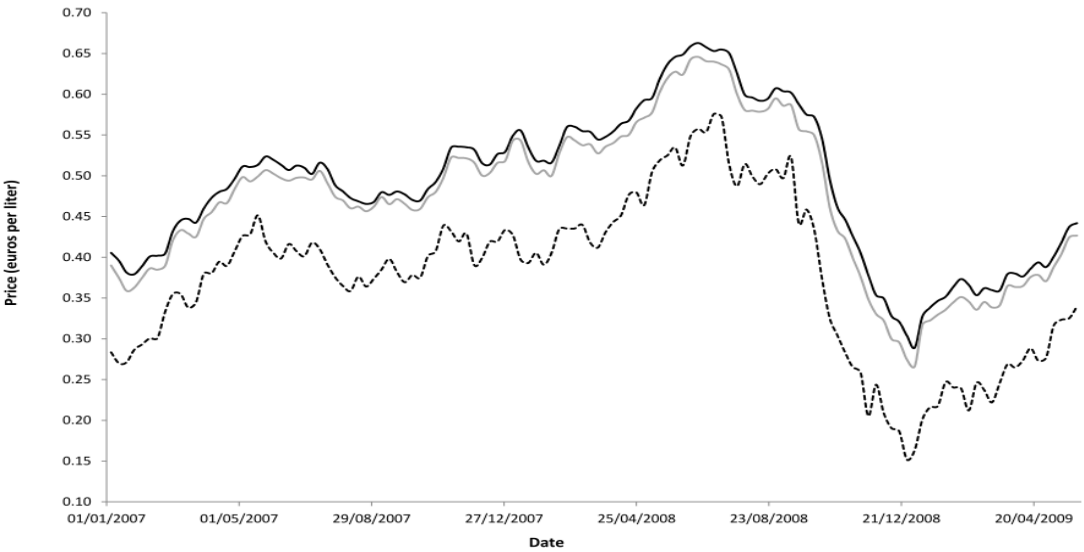
Appendix B

Figure B1: Average retail prices (individual data set), weekly retail prices published by the Ministry of Economy and wholesale market prices (Rotterdam)

a) Diesel



a) Unleaded petrol

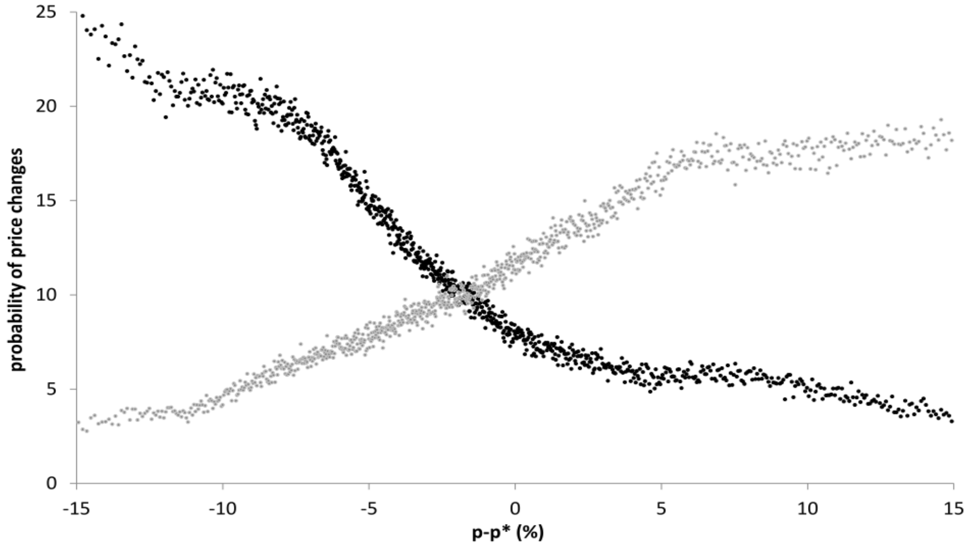


Note: dashed line is for Rotterdam prices, black line is for the average of individual prices collected in our data set and grey line is for the aggregate retail price series published by the Ministry of Economy each Friday.

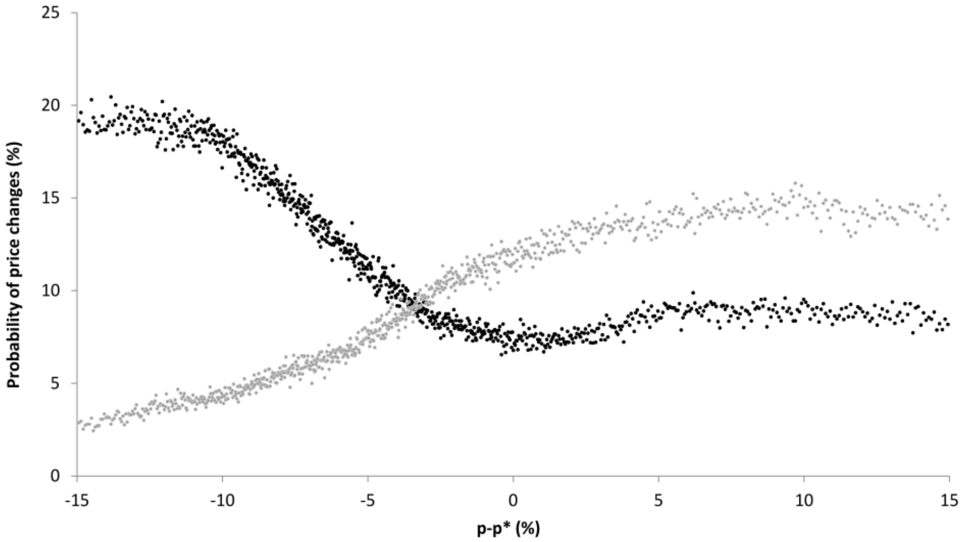
Appendix C

Figure C1: Adjustment hazard functions

a) Diesel



b) Unleaded petrol



Note: Adjustment hazard functions are computed as the probability of price increases or decreases as a function of the difference between log price of gasoline (p) and the log frictionless price ($p*$) (ie Rotterdam market price). For each retailer, the difference $p - p*$ is centered. Black points are for probability of price increases. Grey points are for probability of price decreases.

Appendix D: Pricing points

A possible explanation of the M-shape distribution of price changes might be related to the number of digits used to display prices. A large majority of outlets list their prices with three decimal places. So, in principle price changes could be smaller than 1%. For example, if the diesel price (excluding taxes) is 0.45 euros (i.e. close to the minimum price over our sample period), the retailer can decide to increase its price by 0.001 euros and the price increase in percentage would be 0.22%. However, the distribution of the last digit in prices (including all taxes) is not uniform: 31% of gasoline prices end with "9", 29% with "0", 9% with "5", 7% with "4" whereas for other last digit figures this proportion is smaller than 5% (see Table A) and the distribution of the penultimate digit appears uniform. Knotek (2010) and Levy *et al.* (2011) provide similar evidence on different US products. The timing of price changes might be modified by the presence of pricing points: firms wait for large movements of wholesale prices before changing their prices because they want to increase or decrease their prices by 0.10 or 0.05 euros. Price durations for price points are longer (Table A) and small price changes are less frequent.However, even if we restrict our sample to prices not ending in "9", "0", or "5", we still find that the distribution of price changes exhibit an $M-$shape.

Literature cited

Knotek, Edward S. (2010) “The Roles of Price Points and Menu Costs in Price Rigidity” Research Working Paper No. 10-18, Federal Reserve Bank of Kansas City.

Levy, Daniel, Dongwon Lee, Haipeng Chen, Robert J. Kauffman, and Mark Bergen. (2011) “Price Points and Price Rigidity.” *Review of Economics and Statistics*, 93(4), 1417-1431.

Table D1: Distribution of Price Changes and Average Duration by the Last Digit of Price

	Diesel		Unleaded Petrol	
	% of price trajectories	Average price duration (in days)	% of price trajectories	Average price duration (in days)
0	29.0	6.7	29.5	7.0
1	2.9	4.2	3.0	4.6
2	4.2	4.1	4.2	4.4
3	3.6	4.3	3.6	4.7
4	7.2	4.2	7.3	4.4
5	8.8	4.5	8.8	4.9
6	3.7	4.4	3.8	4.7
7	4.1	4.4	3.9	4.7
8	4.7	4.7	4.6	5.0
9	31.8	4.9	31.4	5.3

Note: We consider prices including all taxes, the proportion of price trajectories is computed as the ratio of number of price trajectories ending with one figure on all price trajectories and we compute the simple average duration. The last digit is the third one.

Appendix E: Relating local competition, demand and gas stations characteristics to estimated parameters.

From a theoretical point of view, local competition, in particular the number of supermarkets, should have a negative effect on prices (Zimmerman 2012). Due to competitive pressures, gas stations may reduce the share of other operating costs, which has a positive impact on β the share of wholesale product in marginal costs. According to Vita (2000), demand variables like the population density or car density have an ambiguous impact on prices: a high density should decrease the gasoline demand since alternative transportations are more developed and transportation costs from wholesale rack to retailers are reduced. This would imply that the share of wholesale gasoline in marginal costs is higher since the share of other costs including transportation or labor costs is lower. However, in high population density areas, land rental is also more costly, which should have a negative impact on β_i. Finally, services in gas stations like stores or restaurants may imply to hire more employees, which may decrease the share of wholesale gasoline in marginal costs.

Tables B and C present results of OLS regressions relating β_i to those variables. First, as expected, we find that supermarket density has a positive significant impact on β_i for both diesel and unleaded petrol. The degree of pass through of gasoline stations on motorways is also lower on average since the degree of competition on motorways is lower and the share of operating costs may be higher (in particular rents). Gas stations using pricing points strategies tend to have significant lower β_i, competitive pressures may be lower for those stations since they are able to set attractive prices. Local demand characteristics have a significant impact on β. Gas stations in urban areas show larger pass-through coefficients than in rural areas, which is consistent with lower transportation costs or effect of lower demand. In Paris, we find lower values of β_i since the share of operating costs (e.g. rents) might be much higher. Another indicator of density is the share of households owning at least one car, this variable has a positive effect on β_i, which is also quite consistent with theoretical predictions on the effect of higher demand. Unexpectedly, the unemployment rate tends to slightly increase β_i. Finally, services offered in gas stations have a negative impact on the share of wholesale gasoline in costs. The presence of a store or car services may increase the share of labor cost which has a negative impact on β_i. However, for unleaded petrol, the presence of a restaurant in the station has an unexpected positive effect.

Tables B and C also show further results on the determinants of heterogeneity of α_i among gas stations.[1] We find that the degree of competition has a negative significant effect on α_i; Zimmerman (2012) obtains negative effect of the density of supermakets on retail gasoline prices whereas Hosken *et al.* (2008) do not find that competition indicators have a significant effect on stations' margins. Population or car density has a small effect: for diesel, markups are larger in Paris (where gas stations are rare and the share of operating costs may be large due to rents) whereas in big cities, for unleaded petrol, markups are lower since gas stations density is higher. Car density has a negative effect on margins for diesel since a high car density may also be related to a high density of gas stations. Finally, the presence of a store, car services or high quality gasoline in the station tend to have a positive effect on markup because those services might lead to a more pronounced product differentiation.

Literature cited

Hosken, Daniel S., Robert S. McMillan, and Christopher T. Taylor.(2008) "Retail Gasoline Pricing: What do we know?" *International Journal of Industrial Organization*, 26(6), 1425-1436.

Vita, Michael G. (2000) "Regulatory Restrictions on Vertical Integration and Control: The Competitive Impact of Gasoline Divorcement Policies." *Journal of Regulatory Economics*, 18(3), 217-233.

Zimmerman, Paul R. (2012) "The Competitive Impact of Hypermarket Retailers on Gasoline Prices." *Journal of Law and Economics*,55(1), 27-41.

Table E1: Determinants of random (S,s) model parameters - Diesel

	α_i	β_i	$\frac{\lvert s_i\rvert+\lvert S_i\rvert}{2}$
Distance to closest supermarket gas station (km)	0.010^{***} (0.003)	-0.001^{***} (0.000)	0.059^{***} (0.011)
Number of supermarket gas stations within 10 kms	-0.008^{***} (0.002)	0.001^{***} (0.000)	-0.030^{***} (0.007)
Motorway	0.064 (0.059)	-0.105^{***} (0.002)	0.369^{*} (0.206)
Pricing points	-0.025 (0.027)	-0.010^{***} (0.001)	1.324^{***} (0.096)
Households owning a car (%)	-0.003^{**} (0.001)	0.000^{***} (0.000)	0.009^{*} (0.005)
Urban area with 20,000 to 100,000 inhabitants	-0.032 (0.035)	0.004^{***} (0.001)	-0.339^{***} (0.123)
Urban area with more than 100,000 inhabitants	-0.078 (0.056)	0.004^{***} (0.002)	-0.205 (0.196)
Paris and its region	0.294^{***} (0.077)	-0.019^{***} (0.003)	-0.232 (0.271)
Unemployment rate (%)	-0.003 (0.004)	0.001^{***} (0.000)	0.041^{***} (0.015)
Pump working with credit/debit cards	-0.062^{**} (0.026)	0.002^{***} (0.001)	-0.098 (0.090)
Store	0.161^{***} (0.036)	-0.006^{***} (0.001)	0.325^{***} (0.125)
Restaurant	0.017 (0.034)	0.002^{*} (0.001)	-0.455^{***} (0.118)
Car services	0.051^{*} (0.028)	-0.003^{***} (0.001)	-0.264^{***} (0.099)
Premium gasoline	0.092^{**} (0.038)	-0.002 (0.001)	-0.097 (0.132)
Adjusted R^2	0.496	0.796	0.322
Number of observations	7,456	7,456	7,456

Note: Columns report the OLS estimates for the time-varying (S,s) model parameters. "Urban area with less than 20,000 inhab." is used as reference. "Motorway" is a dummy variable equal to one if the gas station is on a motorway. "Pricing points" is a dummy variable equal to one if more than 95% of prices end by 0 or 9. Local unemployment and share of households owning at least one car come from the census 2008. "Pump working with credit/debit cards", "Store", "Restaurant", "Car services" and "Premium gasoline" are dummy variables equal to one if the service is provided in the gas station. Dummy variables for 28 different brands and 22 regions are included. Significance level : *** 1%, ** 5%, * 10%.

Table E2: Determinants of random (S,s) model parameters - Unleaded petrol

	α_i	β_i	$\frac{\lvert s_i\rvert+\lvert S_i\rvert}{2}$
Distance to closest supermarket gas station (km)	$0.009^{\star}$ (0.005)	$-0.000^{\star\star\star}$ (0.000)	0.047^{***} (0.013)
Number of supermarket gas stations within 10 kms	-0.004 (0.003)	$0.001^{\star\star\star}$ (0.000)	$-0.038^{\star\star\star}$ (0.010)
Motorway	$0.471^{\star\star\star}$ (0.094)	$-0.066^{\star\star\star}$ (0.003)	$1.621^{\star\star\star}$ (0.269)
Pricing points	$0.141^{\star\star\star}$ (0.044)	$-0.008^{\star\star\star}$ (0.001)	$1.685^{\star\star\star}$ (0.125)
Households owning a car (%)	-0.002 (0.002)	$0.000^{\star}$ (0.000)	-0.003 (0.007)
Urban area with 20,000 to 100,000 inhabitants	-0.048 (0.056)	$0.005^{\star\star\star}$ (0.002)	$-0.817^{\star\star\star}$ (0.160)
Urban area with more than 100,000 inhabitants	-0.146 (0.089)	$0.008^{\star\star\star}$ (0.002)	$-0.779^{\star\star\star}$ (0.255)
Paris and its region	0.211^{*} (0.124)	$-0.011^{\star\star\star}$ (0.003)	-0.468 (0.353)
Unemployment rate (%)	0.001 (0.007)	$0.001^{\star\star\star}$ (0.000)	0.047^{**} (0.020)
Pump working with credit/debit cards	-0.056 (0.041)	0.001 (0.001)	-0.055 (0.118)
Store	0.089 (0.058)	$-0.008^{\star\star\star}$ (0.002)	$0.444^{\star\star\star}$ (0.166)
Restaurant	-0.003 (0.055)	$0.004^{\star\star\star}$ (0.001)	$-0.731^{\star\star\star}$ (0.156)
Car services	0.020 (0.045)	$-0.003^{\star\star}$ (0.001)	$-0.219^{\star}$ (0.130)
Premium gasoline	0.135^{**} (0.061)	-0.002 (0.002)	0.022 (0.174)
Adjusted R^2	0.277	0.659	0.339
Number of observations	7,262	7,262	7,262

Note: Columns report the OLS estimates for the time-varying (S,s) model parameters. "Urban area with less than 20,000 inhab." is used as reference. "Motorway" is a dummy variable equal to one if the gas station is on a motorway. "Pricing points" is a dummy variable equal to one if more than 95% of prices end by 0 or 9. Local unemployment and share of households owning at least one car come from the census 2008. "Pump working with credit/debit cards", "Store", "Restaurant", "Car services" and "Premium gasoline" are dummy variables equal to one if the service is provided in the gas station. Dummy variables for 28 different brands and 22 regions are included. Significance level : *** 1%, ** 5%, * 10%.

Appendix F: Estimation results for alternative price rigidity models

Table F1: Estimation results - Fixed adjustment cost model

	Diesel				Unleaded petrol			
	Mean	Q25	Q50	Q75	Mean	Q25	Q50	Q75
α	2.63	1.56	2.39	3.68	-1.34	-2.58	-1.50	-0.27
β	0.78	0.72	0.80	0.84	0.69	0.64	0.69	0.73
σ_1	2.72	2.31	2.63	3.04	3.38	2.81	3.25	3.80
γ_S	4.29	3.22	4.02	5.16	5.54	4.12	5.20	6.67
γ_s	-4.36	-5.19	-4.15	-3.39	-5.37	-6.38	-5.07	-4.11

Note: We estimate for each individual gas station a fixed (S,s) model and then compute statistics on the parameter estimates we obtained. We consider all gas stations with more than 300 individual observations of prices (excluding Sundays).

Table F2: Estimation results - Calvo model

	Diesel				Unleaded petrol			
	Mean	Q25	Q50	Q75	Mean	Q25	Q50	Q75
α	2.23	1.22	2.00	3.20	-2.03	-3.18	-2.14	-1.02
β	0.77	0.71	0.79	0.83	0.67	0.62	0.68	0.72
σ_1	1.82	1.62	1.78	1.98	2.22	1.92	2.16	2.43
λ_1	-1.27	-1.43	-1.29	-1.12	-1.35	-1.51	-1.36	-1.20
λ_2	1.28	1.13	1.29	1.44	1.28	1.14	1.29	1.43

Note: We estimate for each individual gas station a "Calvo" model and then compute statistics on the parameter estimates we obtained. λ_1 (resp. λ_2) is the intercept triggerring randomly price increases (resp. decreases). We consider all gas stations with more than 300 individual observations of prices (excluding Sundays).

Table F3: Estimation results - Fixed by duration (S,s) model

		Diesel				Unleaded petrol			
		Mean	Q25	Q50	Q75	Mean	Q25	Q50	Q75
α		2.58	1.52	2.37	3.64	-1.37	-2.61	-1.52	-0.30
β		0.78	0.72	0.80	0.83	0.69	0.64	0.69	0.73
σ_1		2.64	2.25	2.56	2.94	3.30	2.75	3.17	3.69
	1 day	12.10	3.49	4.73	6.67	8.38	4.24	5.94	8.59
	2 days	6.77	3.13	4.11	5.79	7.27	3.91	5.28	7.46
γ_s	3 days	5.36	2.94	3.82	5.33	6.68	3.85	5.04	6.93
	4 days	4.96	2.90	3.81	5.18	6.64	3.89	5.09	6.82
	5 days	4.97	3.02	3.96	5.26	6.81	3.99	5.24	7.02
	6 days	4.31	2.61	3.55	4.77	5.99	3.64	4.82	6.40
	7 days	5.60	3.08	4.20	5.76	7.24	4.06	5.40	7.39
	>7 days	3.83	2.86	3.66	4.75	5.17	3.93	4.93	6.27
	1 day	-9.72	-6.16	-4.40	-3.29	-7.59	-7.86	-5.54	-4.12
	2 days	-6.50	-5.37	-3.94	-3.04	-6.67	-6.88	-4.99	-3.87
γ_S	3 days	-5.12	-4.99	-3.73	-2.92	-6.07	-6.40	-4.69	-3.63
	4 days	-4.86	-5.08	-3.95	-3.13	-6.11	-6.42	-4.91	-3.85
	5 days	-5.19	-5.33	-4.24	-3.42	-6.30	-6.55	-5.11	-4.08
	6 days	-4.81	-5.15	-4.10	-3.24	-5.75	-6.20	-4.75	-3.69
	7 days	-6.14	-6.01	-4.69	-3.73	-7.19	-7.16	-5.43	-4.25
	>7 days	-4.57	-5.32	-4.48	-3.78	-5.33	-6.34	-5.24	-4.29

Note: We estimate for each individual gas station a time-varying (S,s) model without idiosyncratic shock ε_2 and then compute statistics on the parameter estimates we obtained. We consider all gas stations with more than 300 individual observations of prices (excluding Sundays).