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Why do petrol prices fluctuate so much?

Klaus Beckmann

Why do petrol prices fluctuate so much?

Klaus Beckmann, Hamburg *

November 2007

Upon moving to Hamburg, Germany, after a couple of years abroad, I noticed that gas prices at the pump varied much more over time than I had been accustomed to in Hungary. Neither did these fluctuations tally well with previous personal experience living in Bavaria for almost two decades. To be sure, 2006 and 2007 have been stormy years for the petrol market. But it still strikes one as odd that consumer prices, while exhibiting an upwards trend and being marked up for such periods as holidays, would suddenly drop by a couple of percentage points one ordinary day in an ordinary working week, only to rebound a few days later. This type of behaviour is also well documented in the empirical literature [2], and high volatility in retail gasoline prices has been cited in antitrust proceedings in Canada [5] as well as in Norway [6] (and possibly elsewhere).

This brief note explains such phenomena as the result of firms' differentiating prices optimally over time. Specifically, assume that there is a group of consumers with price-inelastic demand who must travel on a particular day (business travellers, say), while customers with more elastic demand can also delay filling up by a day or so. In this case, filling stations can increase their profits over uniform pricing by charging an above-average price on certain days of the week. One interesting feature of this mechanism is that price discrimination, by segregating temporally flexible from inflexible demand, also *creates* intertemporal differences in the price elasticity of market demand, which it then exploits. In this sense, it is self-reinforcing.

A lot of work has been done on collusion in the petrol market, more than can usefully be surveyed in a short paper. Driffield and Ioannides [4] sum up the relevant antitrust and competition policy issues, while Bettendorf, van der Geest and Varkevisser [2] as well as Eckert and West [5] analyse gasoline retail pricing in a dynamic setting. Specifically, Borenstein and Shepard [3] note that expected future demand has a statistically significant impact on current price-setting by petrol retailers.² This literature is mainly empirical, however, and focuses on other margins and dimensions of price discrimination such as location, mean income of consumers, service quality and so on. An important temporal effect that it covers is the well-known "holiday effect", which can be viewed as a special case of our model. Again, one finds little theoretical work on this particular sub-topic, and the more general mechanism described (admittedly in a very simple setting) in the

¹Professor of Economics, Institute for Public Economics, *Helmut-Schmidt-Universität* (UAF), Hamburg. I am indebted to my wife Nicole for long discussions (in the car) on how petrol prices in our neighbourhood behave (or don't), and to my colleagues at HSU, in particular to Andrea Schneider, for useful comments on the present short note. The usual caveat applies.

present paper has to the best of my knowledge not been formally proposed elsewhere.

I work out the basic idea using a simple partial equilibrium model in section 1. Section 2 derives some implications from the model and discusses some (at first blush) surprising properties of its solution, while section 3 concludes with directions for empirical research.

1 A simple formal model

Consider a risk-neutral monopolistic filling station³ in a two-period setting. We will call the periods of time "days" and use these terms interchangeably. The firm either purchases or produces gasoline at a constant per unit cost of c and sells it to consumers, charging consumer prices p_i ($i = 1, 2$), where the subscript denotes the day for which a price is set. There are two types of customers: people on business trips and ordinary consumers. The two classes differ in both their demand schedule and their temporal flexibility: while business trips must be consummated on a particular day, other trips may be postponed or brought forward in time to take advantage of price differences. Denote the share of business customers as σ and fix the probability that any business trip must be undertaken on day one at ϕ . We assume linear demand schedules for simplicity, these are

$$p = \alpha - \beta x_B$$

and

$$p = \gamma - \delta x_C$$

for business users and consumers, respectively. Some key implications of the model hinge on the plausible assumption that $\alpha > \gamma$, i.e. that the marginal willingness to pay for the first litre of fuel (for the first few miles of the first trip) is higher for business than for personal uses, which in the case of linear demand schedules implies that business demand is less elastic than personal demand *at any given price* p . (Note that the direct price elasticity of business demand, expressed in terms of p , is just $\epsilon = \frac{p}{\alpha - p}$, and likewise for personal demand.)

1.1 Uniform pricing

As a benchmark, let us begin by deriving the optimal uniform price $p^\times = p_1 = p_2$. With identical pricing in both periods, the firm's profits are

$$\pi_{UP} = (p^\times - c) \left(\sigma \frac{\alpha - p^\times}{\beta} + (1 - \sigma) \frac{\gamma - p^\times}{\delta} \right) \quad (1.1)$$

²For a general analysis of the rôle customer behavior plays for competition policy, see Waterson [7].

³*Cum grano salis*, the analysis would also apply to monopolistic competition if all firms remained in the "standard" (inelastic, monopolistic) part of the demand schedule they are facing, or to a cartelised oil industry.

From the first-order condition of this profit maximisation problem, we have

$$p^\times = \frac{c(\beta(1-\sigma) + \delta\sigma) + \alpha\delta\sigma + \beta\gamma(1-\sigma)}{2(\beta(1-\sigma) + \delta\sigma)} \quad (1.2)$$

1.2 Differentiated pricing

Now let us consider temporal price differentiation. Expected profits are

$$\begin{aligned} E\pi_{|p_1 > p_2} &= \sigma\phi \frac{\alpha - p_1}{\beta}(p_1 - c) + [\sigma(1-\phi) \frac{\alpha - p_2}{\beta} + (1-\sigma) \frac{\gamma - p_2}{\delta}](p_2 - c) \\ E\pi_{|p_1 < p_2} &= [\sigma\phi \frac{\alpha - p_1}{\beta} + (1-\sigma) \frac{\gamma - p_1}{\delta}](p_1 - c) + \sigma(1-\phi) \frac{\alpha - p_2}{\beta}(p_2 - c) \end{aligned} \quad (1.3)$$

and the first-order conditions for maximising (1.3) yield the following closed-form solutions for optimal pricing:

$$\begin{aligned} p_1 &= \frac{c + \alpha}{2} \\ p_2 &= \frac{c(\beta(1-\sigma) + \delta\sigma(1-\phi)) + \alpha\delta\sigma(1-\phi) + \beta\gamma(1-\sigma)}{2(\beta(1-\sigma) + \delta\sigma(1-\phi))} \end{aligned} \quad (1.4)$$

for $p_1 > p_2$ and

$$\begin{aligned} p_1 &= \frac{c(\beta(1-\sigma) + \delta\sigma\phi) + \alpha\delta\sigma\phi + \beta\gamma(1-\sigma)}{2(\beta(1-\sigma) + \delta\sigma(1-\phi))} \\ p_2 &= \frac{c + \alpha}{2} \end{aligned} \quad (1.5)$$

for $p_1 < p_2$. Equipped with these solutions, we can proceed to establish two intermediate results concerning the choice of pricing régime (ascending or descending) on the one hand and the optimality of intertemporal price differentiation on the other.

Lemma 1.1. *Choice of pricing régime.*

Assume $\phi > \frac{1}{2}$. Then, the firm will set prices in such a way that $p_1 > p_2$.

Proof. Plug (1.5) and (1.4) into (1.3) and subtract the two resulting expressions for the expected profit. We obtain the expression below, from which the result is immediate.

$$E\pi_{|p_1 < p_2} - E\pi_{|p_1 > p_2} = \frac{\beta\sigma(1-2\phi)(\alpha-\gamma)^2(\sigma-1)^2}{4(\beta(\sigma-1) - \delta\sigma\phi)(\beta(\sigma-1) + \delta\sigma(\phi-1))}$$

□

As the numbering of periods is immaterial, we can restrict our attention to the case $p_1 > p_2$ without loss of generality and will do so for the remainder of this note. The remaining step is to show that the expected profit under price discrimination exceeds the profit under uniform pricing, which we do with Lemma 1.2 below.

Lemma 1.2. *Profit maximisation entails intertemporal price differentiation.*

Proof. Plug (1.2) into (1.1) and subtract the resulting expression from the expected profit under price discrimination, which we have already calculated for Lemma 1.1 above:

$$\mathbb{E}\pi_{|p_1 > p_2} - \mathbb{E}\pi_{|p^\times} = \frac{\beta\sigma\phi(\alpha - \gamma)^2(\sigma - 1)^2}{4(\beta(\sigma - 1) - \delta\sigma)(\beta(\sigma - 1) + \delta\sigma(\phi - 1))} > 0$$

□

2 Implications

We are primarily interested in the level and dispersion of prices *over time* - things the average person might notice when repeatedly driving by a filling station on her way to work, and data that may be available for empirical research. So we define the average price over time \bar{p} as

$$\bar{p} = \frac{2c(\beta(1 - \sigma) + \delta\sigma(1 - \phi)) + \alpha(\beta(1 - \sigma) + 2\delta\sigma(1 - \phi)) + \beta\gamma(1 - \sigma)}{4(\beta(1 - \sigma) + \delta\sigma(1 - \phi))} \quad (2.1)$$

and the variance of prices as

$$\text{var}(p) = \frac{1}{2}((p_1 - \bar{p})^2 + (p_2 - \bar{p})^2) = \frac{\beta^2(\alpha - \gamma)^2(\sigma - 1)^2}{16(\beta(\sigma - 1) + \delta\sigma(\phi - 1))^2} \quad (2.2)$$

One ought to bear in mind that neither of these two is defined over servings or customers (averages that we might be hard pressed to observe in real life), a fact that will be quite important soon.

Our first duty is clearly to examine equilibrium prices, and the subsequent sums up the results of our analysis so far.

Proposition 2.1. *In a profit maximum, $p_1 > p^\times \geq \bar{p} > p_2$.*

Proof. Immediate from comparing (1.2), (1.3), and (2.1). □

It should come as no surprise that we fail to rank the temporal average of prices and the uniform price unambiguously. Another candidate for analysis would be an average based on the number of transactions, $\sigma\phi p_1 + ((1 - \sigma) + \sigma(1 - \phi))p_2$, while the *effective* average price is based on the quantities traded. Even the latter need not exceed the uniform price for profits to be higher under price discrimination than with a unitary price, though.

For our purposes, the first and second moments of the distribution of prices over time are the statistics of primary interest; in addition, the required data are likely to be more readily observable than the information we would need in order to calculate the other averages mentioned above. Let us therefore turn to the comparative statics of the model with respect to these statistics (Proposition 2.2 below).

Proposition 2.2. *Comparative statics. (a) The average price is strictly increasing (decreasing) in the share of business customers σ (the proportion of business trips on day one ϕ). (b) The higher $\sigma(\phi)$, the lower (higher) the temporal variance of prices.*

Proof. Taking the appropriate partial derivatives of (2.1) and (2.2), we obtain:

$$\begin{aligned}
 \frac{\partial \bar{p}}{\partial \sigma} &= \frac{\beta\delta(1-\sigma)(\alpha-\gamma)}{4(\beta(\sigma-1) + \delta\sigma(\phi-1))^2} > 0 \\
 \frac{\partial \bar{p}}{\partial \phi} &= \frac{\beta\delta\sigma(\alpha-\gamma)(\sigma-1)}{4(\beta(\sigma-1) + \delta\sigma(\phi-1))^2} < 0 \\
 \frac{\partial \text{var}(p)}{\partial \sigma} &= \frac{\beta^2\delta(\alpha-\gamma)^2(1-\sigma)(1-\phi)}{8(\beta(\sigma-1) + \delta\sigma(\phi-1))^3} < 0 \\
 \frac{\partial \text{var}(p)}{\partial \phi} &= -\frac{\beta^2\delta\sigma(\alpha-\gamma)^2(\sigma-1)^2}{8(\beta(\sigma-1) + \delta\sigma(\phi-1))^3} > 0
 \end{aligned} \tag{2.3}$$

□

As expected, a higher proportion of customers with inelastic demand will prompt an increase in prices on average. It may appear surprising at first that an increasing concentration of business trips leads to lower prices on average and does in fact hurt profits (this is easy to check by substituting (1.4) and (1.5) into (1.3) and then differentiating with respect to ϕ). The reason is borderline trivial, however: Only businesspeople fill up on "expensive" days (day one by definition), and so, the composition of the clientèle in that period does not change, which is why formally p_1 does not depend on ϕ . But an increase in ϕ also means that the composition of demand on "cheap" days worsens from the standpoint of the firm; there are comparatively fewer customers with inelastic demand, and the firm has to *reduce* p_2 accordingly.

The same reason is behind the comparative statics for the variance; the larger the share of "doubly" price-inelastic customers - with respect to the quantity they demand at any given day and price as well as with respect to the timing of their trips to the filling station -, the less reason there is for price discrimination, and the lower will the variance be. As concentration of trips will lower the price on "budget" days whilst leaving the high price unaffected, it will also tend to increase the variance.

3 Conclusion

Oscillating gasoline prices (at the pump) are surely not just one economist's impression. In this note, I have offered one explanation for this phenomenon, citing intertemporal price discrimination as a plausible reason. I do not, however, want to imply that this is the only mechanism driving fuel prices. Well-known supply-side factors [1] as well as other ways to separate elastic and inelastic demand [5] may also play a rôle, and may eclipse the mechanism expunged here. Time horizons are important, too: we can imagine elastic customers deferring their trips to the filling station for a week (or visiting more often and buying smaller amounts), but not much longer than that.

In the final analysis, we have to take this model to the data. The presence of a "day of the week effect" [2] suggests that this might prove a fruitful undertaking. So allow me to end with a few simple and testable hypotheses that can be derived from the above analysis:

1. Average prices should be higher on major routes, such as motorways and important highways, than in residential areas as the latter have a smaller percentage of business travel.
2. By the same token, prices should be more variable in residential areas.
3. The temporal variance of fuel prices at the pump should increase if business traffic becomes more concentrated. (The recent strikes in the German railway system might generate the variance required for this.) In this case, we would also require prices in off-peak periods to subside relative to the status quo.

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