Full-cost pricing

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Abstract

In a complete information static monopoly framework, full-cost pricing (letting prices depend on fixed costs) is a behavioral mistake. We propose a simple behavioral model where firm maximizes a misspecified objective and full-cost pricing emerges in equilibrium. The behavioral price can be lower or higher than the rational monopoly price but always increases with fixed costs. With endogenous costs, the behavioral and rational monopolies produce the same level of output. The equilibrium appears as the limit of a Walrasian tâtonnement or of a Bayesian learning process.

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1 Introduction

Full-cost pricing consists in using a unit cost (i.e. average cost) instead of a marginal cost when making a pricing decision. As a result fixed costs are mixed into the price recipe and all equilibrium values are spoiled. More often than not, it is decried as a behavioral mistake the blame being usually put on accountants as from Economics 101 it is well known that fixed costs should not impact profit maximization. As a consequence, economists often normalize fixed costs to zero whenever they do not study entry or investment decisions.[1]

Nevertheless, it would be hard to find a business person not trying to change their prices and quantities after an increase of their fixed costs. More broadly, it might be difficult to gather and transmit within a firm information about the cost function, and managers might not be aware of their marginal costs whereas information about unit costs might be easier to gather.

Instead of debating about or rationalizing full-cost pricing, we assume from the outset that the entity within the firm in charge of pricing does not grasp the details of the cost function and instead uses a linear cost. Therefore the firm maximizes a misspecified model where all units cost the same and we show that this heuristic leads to full-cost pricing.

Whereas it seems easy to write down a misspecified model, it requires an equilibrium concept. The initial mistake should be consistent with profit maximization and ex post observation of profits and costs. Our equilibrium concept is a full-information version of the Berk-Nash equilibrium introduced in Esponda and Pouzo (2016). Martimort and Stole (2020) followed a similar methodology to study average-price bias by consumers in a nonlinear pricing context.

Most applications of misspecified models study a behavioral bias of the consumers. However, at least one misspecified model of firm behavior has a long tradition in economics: the price taking firm of the perfect competition model.

We study the properties of our equilibrium and in particular how the quantity varies with the fixed cost. The behavioral quantity is non increasing with the fixed cost. That is, the higher the fixed cost the higher the price of the behavioral monopoly. Yet, surprisingly, price is not always higher than the rational monopoly price. For relatively low values of the fixed costs, full-cost pricing leads to a lower price and thus a higher welfare.

[1] Although this is reminiscent of the famous “sunk cost fallacy”, this term is mostly used in the sequential investment literature. See Parayre (1995).

We also show that the misspecification equilibrium is intuitive as it obtains as the limit of a tâtonnement process where the firm adjusts the value of the misspecified cost at each steps. This rather naive process is a full information version of the Bayesian framework of Esponda and Pouzo (2016). The logic of Bayesian learning at work here is very different from that of reinforcement learning adopted by Al-Najjar, Baliga, and Besanko (2008) and more recently by Calvano, Calzolari, Denicolo, and Pastorello (2020). In these studies, many firms look for the action most effective at maximizing their profits,[2] and they learn over time how to sustain an equilibrium with supra-competitive prices. Reinforcement learning therefore works as a strategic tool to enforce collusion. This mechanism does not apply to a monopoly. By contrast, in our misspecification equilibrium approach, a single firm learns over time about what it believes is its constant unit cost. The mechanism does not involve any strategic interactions with competitors. Learning eventually leads to an equilibrium where the firm no longer sees any contradiction between its belief and its observation of costs.

Next, we let the monopoly optimize its production function by replicating plants. In this longer term environment, investment choices turn out to be the same as the ones of the rational monopoly. Both invest in the same number of plants and the final production function is such that both types of monopoly produce the same quantity. That is, in the long run, there should be no difference between a full-cost pricing monopoly and a marginal cost pricing one.

Controversy. For 80 years, economists have been arguing on the influence of fixed costs on prices, see Mongin (1992) for an excellent overview.[3] The identified starting point is Hall and Hitch (1939). They interviewed 38 U.K. entrepreneurs without finding evidence they equalized marginal revenue to marginal costs in order to determine their selling price. They concluded that economic theory should be re-thought in light of their findings. Lester (1946) wrote: "The conventional explanation of the output and employment policies of individual firms runs in terms of maximizing profits by equating marginal revenue and marginal cost. Student protests that their entrepreneurial parents claim not to operate on the marginal principle have apparently failed to shake the confidence of the textbook writers in the validity of the marginal analysis."

Machlup (1946) wrote a rebuttal, starting a controversy between anti-marginalists and marginalists (Machlup's terms). The conversation at cross purposes continued with

[2] In Al-Najjar, Baliga, and Besanko, the action consists of the share of fixed cost that the firms choose to allocate to variable costs.

[3] A recent Ph.D. on full-cost pricing is Nubbemeyer (2010) with many references, the author is fair but sympathetic to the anti-marginalist point of view. See also the survey Ellison (2006).

Lester (1947) and two "rejoinders" Machlup (1947) and Stigler (1946). Machlup (1967) recalled the battle to defend marginalism. In between, the influential Friedman (1953) put an end to the debate at least from the point of view of the marginalists. Already present in Friedman and Savage (1948) the famous analogy of the billiard player[4] is one of the decisive blows (in 1947, Machlup used a similar analogy with a driver on a highway who ponders to overtake a truck or not). More recently, Altomonte, Barattieri, and Basu (2015) use a survey of 14,000 European firms and finds 75% of them set their prices according to full cost pricing.

In the accounting literature[5] one can still find surveys where firms declare using full cost when setting their list prices. E.g. Govindarijian and Anthony (1983), Drury, Braund, Osborne, and Tayles (1993) and Shim and Sudit (1995). See the surveys Balakrishnan and Sivaramakrishnan (2002) and Göx and Schiller (2006), as well as Bouwens and Steens (2016).

Strategic use of internal transfer prices. Building on the logic of Brander and Spencer (1985) and Eaton and Grossman (1986),[6]a number of papers showed that oligopoly firms have an incentive to inflate internal transfer prices. That is, firms organize themselves in a vertical structure where a production center sell for a transfer price the good to a marketing division which sells to final consumers. A transfer price above marginal cost softens competition downstream. See Alles and Datar (1998), Göx (2000), Arya and Mittendorf (2008), and Thépot and Netzer (2008). See also Buchheit and Feltovich (2011) for an experimental study. Al-Najjar, Baliga, and Besanko (2008) assume that boundedly rational firms maximize their profits following an adaptive pricing process. In a world of price competition and differentiated products, firms benefit from basing their pricing decision on an inflated marginal cost. In contrast with this literature, our analysis provides a new explanation for full-cost pricing where strategic motivations are absent as we focus on the monopoly case.

[4]The assumption that an expert billiard player makes his shots as if he knew complex mathematical formulas, should give good predictions of what is observed.

[5]See the literature review of accounting textbooks in Al-Najjar, Baliga, and Besanko (2008).

[6]See also Katz (1991).

2 Monopoly Framework

2.1 Classical Monopoly

Let $q > 0$ denote the quantity and $P(q)$ the inverse demand, $P'(q) \leq 0$. The domain of the function $P(.)$ is a finite interval of $\mathbb{R}^+$. Throughout, $q = 0$ means the firm is out and makes zero profit. Total cost is

$$TC(q\,;\phi) = \phi + C(q)$$

where $\phi \geq 0$ is the fixed cost of production and $C(q)$ is the convex variable cost with $C(0) = 0$, $C' \geq 0$, and $C'' \geq 0$.[7] It is convenient to work with the average cost

$$AC(q\,;\phi) = \frac{TC(q)}{q} = \frac{\phi + C(q)}{q}$$

with derivative (for $q > 0$): $AC'(q\,;\phi) = (C'(q) - AC(q\,;\phi))\,/q$.

Assumption 1. *Throughout we maintain the following usual assumptions. (i) The revenue function $R(q) = P(q)q$ is concave. (ii) The average cost $AC(q\,;\phi)$ is convex. For all $\phi > 0$, it is U-shaped with a minimum reached for $q = q^0(\phi)$ and for all $\phi > 0$, $\lim_{q\to 0} AC(q\,;\phi) = \lim_{q\to +\infty} AC(q\,;\phi) = +\infty$. (iii) On the interval $[0, q^0(\phi))$, the marginal revenue is less convex than the average cost.*

Therefore the marginal revenue $MR(q) = P'(q)q + P(q)$ decreases with q. An important limiting case is the constant marginal cost one: $AC(q;\phi) = \phi/q + c$.[8] Using the average cost function, the "objective" profit writes (for $q > 0$)

$$\Pi^{\mathcal{O}}(q;\phi) = P(q)q - C(q) - \phi = \left(P(q) - \frac{\phi + C(q)}{q}\right) q = (P(q) - AC(q\,;\phi))\,q \qquad (1)$$

A rational monopolist maximizes $\Pi^{\mathcal{O}}(q;\phi)$. Let q^m be such that $MR(q^m) = C'(q^m)$, moreover let $\phi^{\max}$ be such that $\Pi^{\mathcal{O}}(q^m;\phi^{\max}) = 0$. The quantity chosen by the fully rational monopoly is q^m if $0 \leq \phi \leq \phi^{\max}$ and zero if $\phi^{\max} < \phi$. The monopoly quantity, q^m, is independent of ϕ, except at $\phi = \phi^{\max}$.

2.2 Misspecified models

We explore the idea that the firm uses a misspecified profit function. From the next section on, we focus on a simple mispecification model, in the spirit of the price-taking firm. Yet, we start with a general framework.

[7] The fixed cost ϕ is often called manufacturing overhead by managers. It includes capital depreciation, repairs, insurance, wages of workers not directly involved in production, etc...

[8] Assume $AC(q;\phi) = \phi/q + c + \alpha q$. Assumptions 1 are satisfied for all $\alpha > 0$ and the constant marginal cost case obtains when $\alpha \to 0$.

The firm has a (family of) subjective profit function $\Pi^{\mathcal{S}}(q\,;\theta)$ where θ is a parameter (possibly a list). The objective profit function, $\Pi^{\mathcal{O}}(q;\phi)$, is not necessarily part of this family. Each subjective profit is quasi-concave in q, and $\Pi^{\mathcal{S}}(0;\theta)=0$. For a given θ, the firm maximizes this subjective profit with respect to q leading to an anticipated profit. This amount is not automatically consistent with the true profit that the firm observes in its books. Thus, a minimal consistency condition is that the two amounts are equal. This simple (two-part) idea defines an equilibrium concept.

Definition 1. *For a family of misspecified profit functions $\Pi^{\mathcal{S}}(q;\theta)$, the quantity choice $q^{\mathcal{S}}$ and the parameter $\theta^{\mathcal{S}}$ form a misspecification equilibrium if and only if:*

$$(i)\ q^{\mathcal{S}} \in \arg\max_{q} \Pi^{\mathcal{S}}\left(q\,;\theta^{\mathcal{S}}\right)$$

and

$$(ii)\ \Pi^{\mathcal{O}}\left(q^{\mathcal{S}}\,;\phi\right) = \Pi^{\mathcal{S}}\left(q^{\mathcal{S}}\,;\theta^{\mathcal{S}}\right).$$

Condition (i) insures optimality and condition (ii) consistency.[9]

Classical example: price taking. Assume

$$\Pi^{\mathcal{S}}(q\,;\theta) = (\theta - AC(q\,;\phi))\,q \ \text{ with } \theta \in \left[\underline{p}, \overline{p}\right]$$

the firm believes the inverse demand function is constant. Let q^c and p^c be such that $C'(q^c) = P(q^c) = p^c$, and let ϕ^c be such that $\Pi^{\mathcal{O}}(q^c\,;\phi^c) = 0$. If $0 \leq \phi \leq \phi^c$, the quantity $q^{\mathcal{S}} = q^c$ and $\theta^{\mathcal{S}} = p^c$ form a misspecification equilibrium.

3 Linear cost-taking monopolist

As we are interested in illustrating full-cost pricing, we make all along the simplifying assumption that the firm has a correct perception about the revenue part of its profits and that the misspecification is only on the cost function. That is, the behavioral monopoly believes it has cost function $C^{\mathcal{S}}(q\,;\theta)$ different from the objective one.

3.1 Full-cost pricing

The behavioral monopoly envisions the following family of misspecified profit functions. Let $\theta = (\theta_0, \theta_1)$,

$$C^{\mathcal{S}}(q\,;\theta) = \begin{cases} \theta_1 q + \theta_0 & \text{if } q > 0 \\ 0 & \text{if } q = 0 \end{cases} \tag{2}$$

[9]Notice that whenever it exists θ such that it is optimal not to produce, i.e. $q^{\mathcal{S}} = 0$, then a misspecification equilibrium exists as $\Pi^{\mathcal{O}}(0\,;\phi) = 0 = \Pi^{\mathcal{S}}(0\,;\theta)$. That is, if the firm anticipates the worst, it is optimal not to produce and to expect no profit.

and

$$\Pi^{\mathcal{S}}(q\,;\theta) = P(q)q - C^{\mathcal{S}}(q\,;\theta)$$

The firm behaves as if it had a fixed cost θ_0 and a constant marginal cost θ_1. Although it is intuitive to include the parameter θ_0, it turns out to be superfluous. A parsimonious model with only θ_1 would be enough to have full-cost pricing at the misspecification equilibrium. So the case $\theta_0 = 0$ is of particular interest. In that case the misspecification is that both the marginal and the average costs are constant and equal to θ_1. The presence of θ_0 insures that a misspecification equilibrium exists whenever a traditional monopolist makes a profit.

Applying definition 1 the quantity $q^{\mathcal{S}}$ and the cost parameters $\theta^{\mathcal{S}}$ form of a misspecification equilibrium if

$$(i)\; MR(q^{\mathcal{S}}) = \frac{\partial C^{\mathcal{S}}}{\partial q}\left(q^{\mathcal{S}}\,;\theta^{\mathcal{S}}\right) = \theta_1^{\mathcal{S}}$$

and

$$(ii)\; C^{\mathcal{S}}\left(q^{\mathcal{S}}\,;\theta^{\mathcal{S}}\right) = \theta_1^{\mathcal{S}} q^{\mathcal{S}} + \theta_0^{\mathcal{S}} = C\left(q^{\mathcal{S}}\right) + \phi$$

Condition (i) makes it clear that the behavioral monopolist understands that his perceived fixed cost, θ_0, is not relevant for profit maximization. The true and the perceived fixed cost, however, play a central role in the consistency condition (ii). Two equilibrium equations and three unknowns leave a degree of freedom and we parameterize the equilibrium with θ_0. Without loss of generality, we interpret θ_0 as a fixed parameter, and only the constant marginal cost θ_1 is adjusted in order to satisfy the consistency condition.

Proposition 1. *For a given fixed cost ϕ, $0 < \phi \leq \phi^{\max}$, there exists $\theta_0 \geq 0$ such that a misspecification equilibrium exists with a strictly positive quantity and full-cost pricing. It is characterized as the largest root $q^{\mathcal{S}}(\phi)$ of*

$$MR(q) = AC(q\,;\phi - \theta_0). \tag{3}$$

Proof. See Appendix A. □

Assumption 1 (iii) implies there are at most two solutions to the equation $MR(q) = AC(q; \phi - \theta_0)$. The largest is $q^{\mathcal{S}}(\phi)$. Let $q^{\mathcal{U}}(\phi)$ denote the the lowest root when it exists.[10] When both exist, we select $q^{\mathcal{S}}$. Indeed, the profit is always larger at $q^{\mathcal{S}}$ and (as $q^{\mathcal{S}} > q^{\mathcal{U}}$) welfare is also larger implying that $q^{\mathcal{S}}$ Pareto dominates $q^{\mathcal{U}}$. We also show

[10] Whenever $\phi - \theta_0 \leq 0$, the function $AC(q; \phi - \theta_0)$ is increasing in q and there is only one root.

in section 3.3 that $q^{\mathcal{S}}$ can be obtained as the limit of a learning process whereas $q^{\mathcal{U}}$ cannot.

Figure 1 illustrates Proposition 1. It pictures the equation $MR(q) = AC(q^{\mathcal{S}}\,; \phi - \theta_0)$ for the case $\theta_0 = 0$ and $0 < \phi < \phi^{\max}$. The objective monopoly quantity, q^m, is at the intersection of $MR(q)$ (the blue decreasing line) and $C'(q)$ (the blue increasing line). The solutions of $MR(q) = AC(q^{\mathcal{S}}\,;\phi)$ are $q^{\mathcal{S}}$ (blue dot) and $q^{\mathcal{U}}$ (red dot). On this graph, ϕ is such that $q^{\mathcal{U}} < q^m < q^{\mathcal{S}}$ but it is not always the case. Typically, if ϕ is small enough, then, indeed $q^{\mathcal{U}} < q^m < q^{\mathcal{S}}$, but when ϕ is large enough, then $q^{\mathcal{U}} < q^{\mathcal{S}} < q^m$. Three other average cost functions are plotted (dashed blue) for $\phi = 0$, $\overline{\phi}$, and $\phi^{\max}$. The equation $MR(q) = AC(q^{\mathcal{S}}\,;\phi)$ has no solution for $\overline{\phi} < \phi \leq \phi^{\max}$. That is, when ϕ is too large, the behavioral firm is unable to generate a positive profit and shuts down.[11]

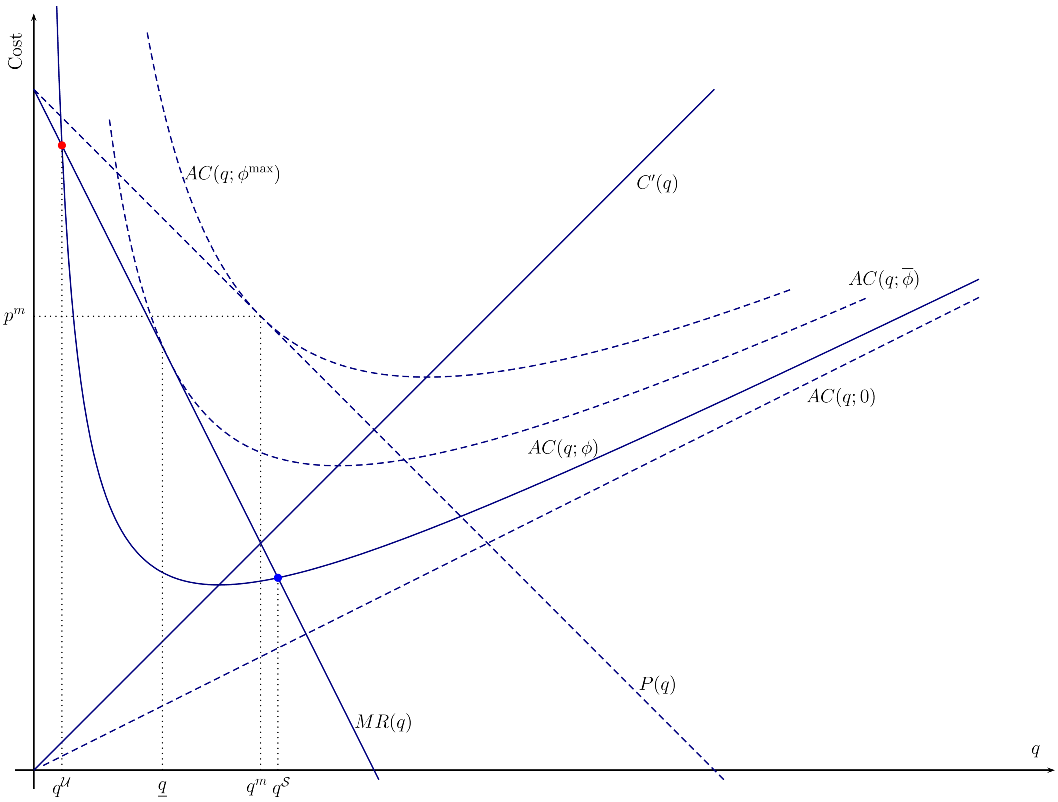

Figure 1: Behavioral monopoly: Equation $MR(q) = AC(q^{\mathcal{S}}\,;\phi)$

By the way of three examples, we show now that $q^{\mathcal{S}}$ can be always greater than q^m, always lower, or that its relative position with regards to q^m depends on ϕ.

[11]In order not to shut down θ_0 should increase but here we assumed $\theta_0 = 0$.

Example: Inelastic demand and quadratic cost. Assume $P(q) = a$ if $0 < q \leq \overline{q}$ and $P(q) = 0$ if $\overline{q} < q$, and $AC(q;\phi) = \phi/q + \gamma q/2$ where $\gamma > 0$. Then (assuming $\overline{q}$ is large enough, namely $\overline{q} > a/\gamma$)

- $q^c = a/\gamma$, • $q^m = a/\gamma$, and • $q^{\mathcal{S}}(\phi) = \min\left\{\frac{a+\sqrt{a^2-2\gamma\phi}}{\gamma}\,;\,\overline{q}\right\}$.

Here for all $\phi \in [0, \overline{\phi}]$, the behavioral monopoly is copious: $q^{\mathcal{S}}(\phi) > q^m = q^c$.

Constant marginal cost. Assume $AC(q;\phi) = \phi/q + c$ where c is the constant marginal cost. Then

- q^c is solution of $P(q) = c$,[12] • q^m is solution of $MR(q) = c$, and
- $q^{\mathcal{S}}(\phi)$ is solution of $MR(q) = \phi/q + c$.

Here for all $\phi \in [0, \overline{\phi}]$, the behavioral monopoly is cautious: $q^{\mathcal{S}}(\phi) < q^m < q^c$.

Linear demand and quadratic cost. Assume $P(q) = a - bq$ and $AC(q;\phi) = \phi/q + \gamma q/2$ where $\gamma > 0$. Then

- $q^c = a/(b+\gamma)$, • $q^m = a/(2b+\gamma)$, and • $q^{\mathcal{S}}(\phi) = \frac{a+\sqrt{a^2-2\phi(4b+\gamma)}}{4b+\gamma}$.
- $p^c = \gamma a/(b+\gamma)$, • $p^m = (b+\gamma)a/(2b+\gamma)$, and • $p^{\mathcal{S}}(\phi) = \frac{(3b+\gamma)a-b\sqrt{a^2-2\phi(4b+\gamma)}}{4b+\gamma}$.

Here depending on ϕ, the behavioral monopoly is either cautious, i.e. $q^m > q^{\mathcal{S}}(\phi)$, or copious, i.e. $q^m < q^{\mathcal{S}}(\phi)$. Production is copious when $\phi < \widehat{\phi} = \frac{a^2\gamma}{2(2b+\gamma)^2}$. Eventually, $q^{\mathcal{S}}(\phi)$ is so copious, it is larger than q^c. One can check this possibility by comparing $q^{\mathcal{S}}(0) = \frac{2a}{4b+\gamma}$ which is the largest value of $q^{\mathcal{S}}(\phi)$ with q^c. It turns out that $q^{\mathcal{S}}(0) > q^c$ if and only if $\gamma > 2b$. Such a prodigal behavioral monopoly benefits consumers but reduces welfare by serving consumers with a marginal valuation lower than the marginal cost.

3.2 Comparative statics in ϕ

In this section we make precise the extend of the quantity distortion. We characterize a minimal quantity $\underline{q}$ independent of ϕ and an maximal quantity $\overline{q}(\phi)$ between which the behavioral quantity $q^{\mathcal{S}}$ always lies. The minimal quantity $\underline{q}$ is the quantity that would be produced by a chain of monopolies under linear wholesale pricing. In Appendix C we show that $\underline{q}$ and $\phi = \overline{\phi}$ are the unique solutions of the simultaneous equations: $MR(q) = AC(q\,;\phi)$ and $MR'(q) = AC'(q\,;\phi)$. In addition, $\overline{q}$ be the largest root of $P(q) = AC(q\,;\phi)$.

[12] As we are in a natural monopoly framework the competitive quantity q^c could not be produced privately when $\phi > 0$ unless the firm is compensated.

Proposition 2. *For a given demand, $P(.)$ and a given cost function, $C(.)$, the maximal (perceived) fixed cost such that $q^{\mathcal{S}} > 0$ is $0 < \overline{\phi} \leq \phi^{\max}$. That is, if $\overline{\phi} < \phi - \theta_0 \leq \phi^{\max}$, then the behavioral firm does not produce. Whereas if $\phi - \theta_0 \leq \overline{\phi}$, then the behavioral monopoly's quantity $q^{\mathcal{S}}(\phi - \theta_0)$ is always larger than $\underline{q}$ and lower than $\overline{q}(\phi)$. Moreover $q^{\mathcal{S}}(\phi - \theta_0)$ is non increasing (resp. non decreasing) with the fixed cost ϕ (resp. θ_0).*

Figure 3 in Appendix B describes all equilibria in the (ϕ, θ_0) space. Thus summarizing graphically Propositions 1 and 2.

As stated in proposition 1, $q^{\mathcal{S}}(\phi-\theta_0)$ is decreasing with the fixed cost $\phi-\theta_0$ (and the price is increasing) a result in line with the intuition of business people that the price should react to a variation of the fixed costs. Three situations can be distinguished. First, when the difference $\phi - \theta_0$ is relatively low, eventually negative, the behavioral monopoly behaves optimistically at the misspecification equilibrium. That is, perceived constant unit costs, $\theta_1^{\mathcal{S}}$, are low, eventually zero, hence the optimism. This (optimally) pushes the firm to produce a lot, i.e. more than the monopoly quantity. This is the case whenever $\theta_0 = \phi$. Indeed, $AC(q\,; 0) = C(q)/q < C'(q)$ because $C(.)$ is convex. So, in this range of $\phi - \theta_0$ values, the behavioral bias of the firm makes society better off. It is even possible that this optimistic behavior drives the price below the competitive price.

Second, for intermediate values of $\phi - \theta_0$, the behavioral monopoly behaves cautiously at the misspecification equilibrium. That is, perceived constant unit costs, $\theta_1^{\mathcal{S}}$, are high which (optimally) pushes the firm to produce little (i.e. less than the monopoly quantity) which, indeed, makes the unit cost high. Finally, for values of $\phi - \theta_0$ larger than $\overline{\phi}$, the behavioral monopoly is fatally tricked into a no production trap and no misspecification equilibrium with a positive quantity does exist. That is, the perceived unit costs are too high and it is optimal no to produce. Given that there is no production, the consistency condition is automatically satisfied.

To illustrate further Proposition 2, Figure 2 plots the equilibrium quantities q^c, q^m, $q^{\mathcal{S}}(\phi)$, $q^{\mathcal{U}}(\phi)$, and $q^0(\phi)$ as functions of ϕ (here to simplify the notations we have fixed $\theta_0 = 0$). In Appendix E, we show how the quantity which minimizes the average cost function, $q^0(\phi)$, can be defined as a misspecification equilibrium. In Figure 2, when ϕ is small enough, $q^{\mathcal{S}}(\phi)$ is larger than q^c. That is, consumers would prefer our behavioral monopolist to a single competitive firm. Then when ϕ increases $q^{\mathcal{S}}(\phi)$ decreases and first passes below q^c and then below q^m, until it reaches $\underline{q}$ (for $\phi = \overline{\phi}$) and the misspecification equilibrium collapses to $q = 0$. The dashed red curve representing $q^0(\phi)$ (the quantity which minimize the average cost) is new. It shows that when $q^{\mathcal{S}}(\phi) = q^m$ then ϕ is such that $MR(q) = C'(q) = AC(q^{\mathcal{S}}\,; \phi)$ and therefore $q^{\mathcal{S}}(\phi) = q^m = q^0(\phi)$. That is, for

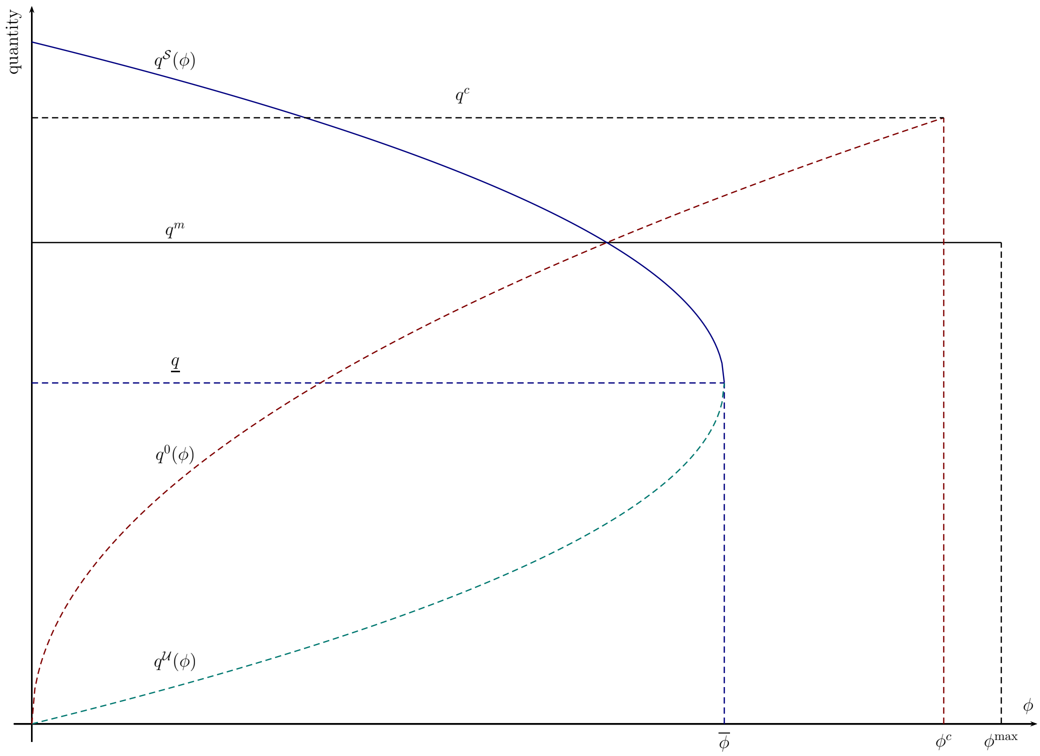

Figure 2: Quantities: Comparative static on ϕ

this value of ϕ, the average cost is minimized and the behavioral quantity is exactly the monopoly quantity.

The comparative statics of equilibrium profits (and welfare) with respect to ϕ follows from the one of quantities. The rational monopolist's profit is decreasing linearly with ϕ. It is always above the misspecification equilibrium profit however as ϕ keeps increasing, $\Pi^{\mathcal{O}}(q^{\mathcal{S}}(\phi);\phi)$ becomes closer and then equal to Π^m before diverging and dropping abruptly around $\overline{\phi}$.

3.3 *Tâtonnement*

We have characterized a misspecification equilibrium with full-cost pricing. An additional question is how does a firm settle on this equilibrium? Indeed, in practice it is difficult to imagine that a firm would start (and remain) at the equilibrium quantity. Intuitively, one would like to have a dynamic sequence of quantities converging to the equilibrium, in the spirit of a Walrasian *tâtonnement*.

Proposition 3. *Whenever the quantity $q^{\mathcal{S}}(\phi - \theta_0)$ is lower than q^c, it is a stable fixed point. In the sense that starting from a neighborhood of $q^{\mathcal{S}}$ any sequence $q_{t+1} =$*

$MR^{-1}\left(AC(q_t;\phi-\theta_0)\right)$ converge to $q^{\mathcal{S}}$. If $q^{\mathcal{S}}(\phi-\theta_0)$ is larger than q^c, it can be stable or not. The quantity $q^{\mathcal{U}}(\phi-\theta_0)$ is a non-stable fixed point.

Proof. See Appendix D. □

To illustrate the idea behind the stability of $q^{\mathcal{S}}$, assume that the firm is divided into a marketing department, in charge of pricing (i.e. choosing the quantity to be sold), and a production department in charge of actually producing and computing the average cost. Several dynamics can be imagined. The following naive dynamics is probably the simplest. The marketing department knows the demand function fairly well but has a weak understanding of production. It summarizes production costs only in terms of constant unit costs and uses this value to maximize profits. Also, communication is coarse: at each date the production department sends the unit cost (i.e. average cost) corresponding to the previous period quantity (which could be produced or be an hypothetical quantity).

Formally, (assume for notational simplicity that there is no perceived fixed cost $\theta_0 = 0$) let θ_1^0 be the initial unit cost. At each date t the marketing department maximize (w.r.t. q) $(P(q)-\theta_1^t))\,q$ which leads to the choice q_t and to the next period unit cost $\theta_{t+1} = AC(q_t\,;\phi)$. This dynamic process writes, for $t \geq 1$:

$$q_t = MR^{-1}\left(AC(q_{t-1};\phi^S)\right)$$

The misspecification equilibrium quantities $q^{\mathcal{S}}$ and $q^{\mathcal{U}}$ are both fixed point of such a sequence. Yet, for a fixed point, q, to be stable the condition $\left|\left(MR^{-1}\left(AC(q;\phi)\right)\right)'\right| < 1$ or

$$\left|\frac{AC'(q\,;\phi)}{MR'(q)}\right| < 1$$

needs to hold. We show in Appendix D that it never holds for $q^{\mathcal{U}}$ and always holds for $q^{\mathcal{S}} \leq q^c$.

3.4 Bayesian learning

In this section, we assume that at each date $t = 0, 1, \ldots$ the firm believes that its unit cost is constant and equal to θe^{ε_t}, where the ε_t's are iid draws from the normal distribution $\mathcal{N}(0, s^2)$, $s > 0$. We denote by $P_0(\theta)$ the firm's prior belief about θ and by θ_0 its expectation. At date 0, the firm maximizes its subjective expected profit $\Pi^S(q;\theta_0) = qP(q) - \theta_0 q$, and hence produces q_0 given by

$$\mathrm{MR}(q_0) = \theta_0.$$

Then the unit cost $\mathrm{AC}(q_0)$ is realized and observed. The firm's posterior belief about the distribution of θ is denoted by P_1, and its expectation by θ_1. Given θ_1, the firm decides to produce q_1, observes its true average cost $AC(q_1)$, and the process iterates. We denote P_t the firm's belief at date t and by θ_t its expectation.

Proposition 4. *Suppose that the prior distribution P_0 is log-normal. Then the posterior distributions P_t, $t \geq 0$, are log-normal and converge to the mass point at $\theta^{\mathcal{S}}$. The variance of $\ln\theta$ under P_t tends to zero at the rate $1/t$.*

The convergence of P_t to a mass point located at a Berk-Nash equilibrium is a general property, see Appendix F for details. Contrary to what happens in the tâtonnement process described in Section 3.3, the firm here is never surprised by the realization of its average cost. It interprets that cost as coming from θe^{ε_t} and updates its belief about θ accordingly. The revision formula yields

$$\ln\theta_{t+1} = (1-w_t)\ln\theta_t + w_t \ln\,\mathrm{AC}\left(\mathrm{MR}^{-1}(\theta_t)\right), \tag{4}$$

where the weight w_t is given by

$$w_t = \frac{\sigma_0^2}{s^2+(t+1)\sigma_0^2},$$

with σ_0^2 denoting the variance of $\ln\theta$ under P_0. The revision formula involves a weighted sum of the prior belief and the new information delivered by the observed cost. The weight w_t is placed on the new information. In the framework of Section 3.3, the weight of the latest observation is essentially one. By contrast, whenever the firm sees its average cost as being affected by a random component ($s > 0$), there s is inertia, the weight of the latest observation tends to zero as t grows large: Asymptotically, there is no learning, as if $\theta = \theta^{\mathcal{S}}$ were known to the firm.

4 Long-term view of the cost function

In this section, we show that in a longer run, our behavioral monopolist makes the same choices as a rational one. The intuition is fairly simple. In the long run, a rational monopolist produces at the minimum of the average cost function, thus behaving as our behavioral monopolist. It remains to show that both types follow the same investment strategy.

Consider a monopolist building n plants. Each plant produces according to the total cost function $TC(q;\phi) = \phi + C(q)$. Assume the firm wants to produce Q. Given the convexity of $C(.)$ it is optimal for the monopoly to produce Q/n in every plant. Thus its total cost is:

$$\mathcal{TC}(Q;\phi,n) = n\phi + nC\left(Q/n\right)$$

and its average and marginal costs are respectively

$$\mathcal{AC}(Q;\phi,n) = \mathcal{TC}(Q;\phi,n)/Q = \frac{\phi}{Q/n} + \frac{C\left(Q/n\right)}{Q/n} = AC\left(Q/n;\phi\right)$$

and

$$\mathcal{MC}(Q;\phi,n) = \frac{\partial \mathcal{TC}(Q;\phi,n)}{\partial Q} = C'\left(Q/n\right) = MC\left(Q/n\right)$$

The following property plays a key role in the following results. therefore

$$\frac{\partial \mathcal{TC}(Q;\phi,n)}{\partial n} = \phi + C\left(Q/n\right) - \frac{Q}{n}C'\left(Q/n\right) = \frac{Q}{n}\left(AC\left(Q/n;\phi\right) - C'\left(Q/n\right)\right)$$

that is $\frac{\partial \mathcal{TC}(Q;\phi,n)}{\partial n} = 0$ implies $AC\left(Q/n;\phi\right) = C'\left(Q/n\right)$ but then the quantity chosen by the behavioral firm (which is given by $MR = AC$) should coïncide with the standard monopoly choice (which is given by $MR = C'$) as shown in the following proposition.

Proposition 5. *The behavioral and the rational monopolists choose the same number of plants, n, and produce the same quantity. This result holds whether it is assumed that n and Q are chosen simultaneously or sequentially.*

Proof. As the profit function of a rational monopolist is:

$$\Pi^{\mathcal{O}}(Q;\phi,n) = P(Q)Q - \mathcal{TC}(Q;\phi,n)$$

the f.o.c. which determine n and Q are:

$$\begin{cases} \frac{\partial \Pi^{\mathcal{O}}}{\partial Q} = 0 & \Rightarrow MR(Q) = C'(Q/n) \\ \frac{\partial \Pi^{\mathcal{O}}}{\partial n} = 0 & \Rightarrow C'(Q/n) = AC\left(Q/n;\phi\right) \end{cases}$$

these conditions hold whether the choice of n and Q are simultaneous or sequential.

For the behavioral firm, and when the choices are simultaneous, we have two optimality conditions (i.e. maximizing $\Pi^{\mathcal{S}}(Q;Z,\phi,n) = \left(P(Q) - \mathcal{AC}(Z;\phi,n)\right)Q$ with respect to both n and Q) plus a consistency condition (i.e. the objective profit should coïncide with the subjective profit):

$$\begin{cases} (i) & \begin{cases} \frac{\partial \Pi^{\mathcal{S}}}{\partial Q} = 0 & \Rightarrow MR(Q) = AC\left(Z/n;\phi\right) \\ \frac{\partial \Pi^{\mathcal{S}}}{\partial n} = 0 & \Rightarrow C'(Z/n) = AC\left(Z/n;\phi\right) \end{cases} \\ (ii) & Z = Q \end{cases}$$

Obviously, these equations imply that the choices of the behavioral and the rational monopolists are identical when simultaneous.

For the behavioral firm, it is not immediate that the sequential choices should lead to the same solution. For a given n, the profit function of a behavioral monopolist is:

$$\Pi^{\mathcal{S}}(Q; Z, \phi, n) = (P(Q) - \mathcal{AC}(Z; \phi, n))\, Q$$

therefore, for a given n, in a misspecification equilibrium, the behavioral monopolist settles on the quantity $Q^b(n)$ such that

$$MR(Q) = AC\left(Q/n; \phi\right)$$

The behavioral monopolist anticipates profits as a function of n given by

$$\begin{aligned} \Pi^b(n) &= \Pi^{\mathcal{S}}(Q^b(n); Z = Q^b(n), \phi, n) \\ &= Q^b(n) P\left(Q^b(n)\right) - n\phi - nC\left(Q^b(n)/n\right) = \Pi^{\mathcal{O}}(Q^b(n); \phi, n)\,. \end{aligned}$$

Here it is a little bit tricky because how should the behavioral firm derive this function? Indeed, it could see it as $\Pi^{\mathcal{O}}(Q^b(n); \phi, n)$ and take the derivative as any mathematician would. Or it can see it as $\Pi^{\mathcal{S}}(Q^b(n); Z = Q^b(n), \phi, n)$ and not understand that Z varies with n (and only substituting Z by $Q^b(n)$ after taking the derivative). This second approach is ad hoc but maybe more in line with the behavioral missperception. In both case the result is the same.

The maximization of $\Pi^b(n) = \Pi^{\mathcal{O}}(Q^b(n); \phi, n)$ leads to the following f.o.c.

$$\frac{\partial Q^b}{\partial n} \frac{\partial \Pi^{\mathcal{O}}}{\partial Q} + \frac{\partial \Pi^{\mathcal{O}}}{\partial n} = 0$$

substituting $MR(Q^b)$ by $AC\left(Q^b/n; \phi\right)$, and rearranging terms

$$\left(1 - \frac{\partial Q^b/\partial n}{Q^b/n}\right)\left(AC\left(Q^b/n; \phi\right) - C'\left(Q^b/n\right)\right) = 0$$

and therefore $AC\left(Q^b/n; \phi\right) = C'\left(Q^b/n\right)$ (because $\frac{\partial Q^b/\partial n}{Q^b/n} < 1$) and the conditions are the same as the rational monopolist.

The maximization of $\Pi^b(n) = \Pi^{\mathcal{S}}(Q^b(n); Z = Q^b(n), \phi, n)$ leads to the following f.o.c.

$$\frac{\partial Q^b}{\partial n} \frac{\partial \Pi^{\mathcal{S}}}{\partial Q} + \frac{\partial \Pi^{\mathcal{S}}}{\partial n}$$

where

$$\frac{\partial \Pi^{\mathcal{S}}}{\partial Q} = MR(Q) - AC(Q/n; \phi) = 0$$

hence the f.o.c. is directly

$$AC\left(Q^b/n;\phi\right) = C'\left(Q^b/n\right)$$

$\square$

APPENDIX

A Proof of Proposition 1

If $q = 0$, both the objective and the misspecified profits are null. Now if $\theta_1 = +\infty$, it is, indeed, best for the behavioral monopolist not to produce.

Using condition (i) one can substitute into (ii) $\theta_1^{\mathcal{S}}$ by $MR\left(q^{\mathcal{S}}\right)$. Thus condition (ii) simplifies into $MR(q^{\mathcal{S}})q^{\mathcal{S}} = C\left(q^{\mathcal{S}}\right) + \phi - \theta_0^{\mathcal{S}}$ or (for $q^{\mathcal{S}} > 0$)

$$MR(q^{\mathcal{S}}) = \frac{C\left(q^{\mathcal{S}}\right) + \phi - \theta_0^{\mathcal{S}}}{q^{\mathcal{S}}} = AC(q^{\mathcal{S}}\,; \phi - \theta_0^{\mathcal{S}}) = \theta_1^{\mathcal{S}}$$

Now, the equation $MR(q) = AC(q^{\mathcal{S}}\,; \phi - \theta_0)$ has two solutions, for $0 < \phi - \theta_0 < \overline{\phi}$, one solution for $-C(\overline{q}) \leq \phi - \theta_0 \leq 0$ or $\phi - \theta_0 = \overline{\phi}$ and zero otherwise. Figure 1 illustrates this equation. When they exist, the largest root is denoted $q^{\mathcal{S}}$ (the blue dot) and the smallest root $q^{\mathcal{U}}$ (the red dot).

Variation of $q^{\mathcal{S}}$ and $q^{\mathcal{U}}$ with ϕ. From the equation $MR(q^{\mathcal{S}}) = AC(q^{\mathcal{S}}\,; \phi)$ it follows that

$$\frac{\partial q^{\mathcal{S}}}{\partial \phi} = \frac{\frac{\partial AC}{\partial \phi}}{MR' - AC'} = \frac{1/q^{\mathcal{S}}}{MR' - AC'}$$

where AC' stands for $\frac{\partial AC}{\partial q}$. Assumption 1 means that $MR' - AC' < 0$ (resp. > 0) for $q^{\mathcal{S}} > \underline{q}$ (resp. $q^{\mathcal{U}} < \underline{q}$).

B Equilibria in the (ϕ, θ_0) space

Figure 3 describes more completely all equilibria in the (ϕ, θ_0) space. It highlights that for a given value of ϕ, not all value of θ_0 are compatible with the existence of the equilibria. First, in the hatched area θ_0 is so large that $q^{\mathcal{S}}$ would larger than $q_{\max}$ meaning that the profit would be negative.

C Chain of monopoly quantity

The quantity $\underline{q}$ characterized in Proposition 1 is the quantity that would be produced by a chain of rational monopolies under linear wholesale pricing. Indeed, if an upstream monopoly set a wholesale price w, then the downstream monopoly (which is assumed to have no production cost of its own) would choose a quantity $x(w)$ maximizing $(P(x) - w)\,x$ that is such that $MR(x) = w$. Anticipating this the upstream monopoly

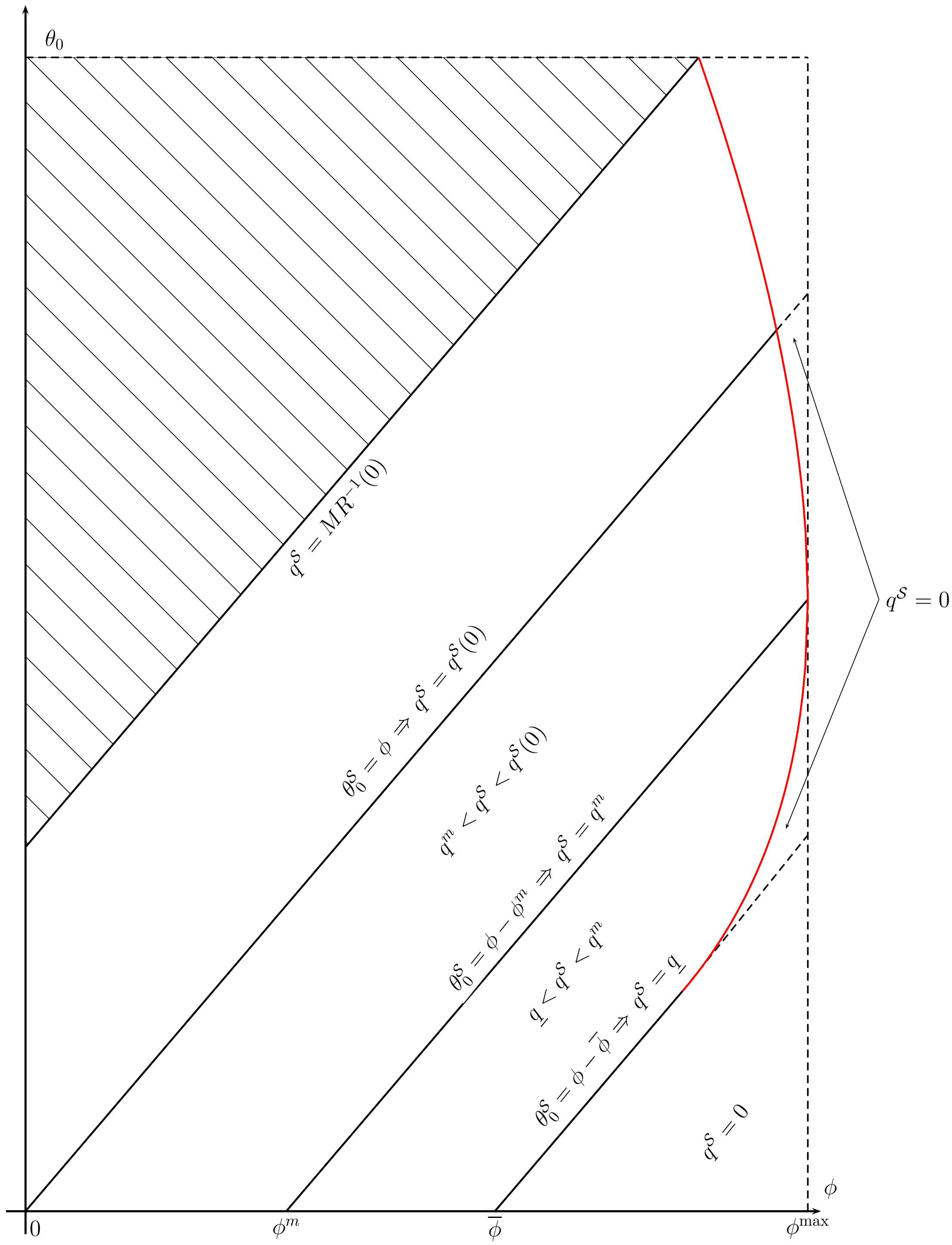

Figure 3: Equilibrium for the misspecified model

chooses w in order to maximize $wx(w) - C(x(w))$ or equivalently a quantity x maximizing $MR(x)x - C(x)$ which leads to the first order condition $MR'(x)x + MR(x) = C'(x)$ rearranged into $MR(x) = C'(x) + (2 + \eta(q))(-qP'(q))$. This last equation has a unique solution.

Now $\underline{q}$ and $\overline{\phi}$ are characterized by $MR(q) = AC(q; \phi)$ and $MR'(q) = AC'(q; \phi)$. The latter writes $MR'(q) = AC'(q; \phi) = (C'(q) - AC(q; \phi))/q$ and using the former we can substitute $MR(q)$ for $AC(q; \phi)$ which leads to $MR'(q) = (C'(q) - MR(q))/q$. Rearranging terms it writes $MR'(q)q + MR(q) = C'(q)$ which is exactly the f.o.c. of the monopoly chain.

D Proof of Proposition 3

The stability of the equilibrium quantity depends on the condition:

$$\left| \frac{AC'(q^{\mathcal{S}}; \phi)}{MR'(q^{\mathcal{S}})} \right| < 1$$

This condition implies that if a sequence starts close enough to a fixed point, it will converge to it. On the other hand, if a fixed point is such that this stability ratio is larger than one, then no sequence will converge to it. Recall that $q^{\mathcal{S}}$ is the largest root of the equation $MR(q) = AC(q; \phi)$. If $q^{\mathcal{S}} \leq q^m$, then $q^{\mathcal{S}}$ is stable. Idea of the proof: in this range of q, both MR' and AC' are negative. As $q^{\mathcal{S}}$ is the largest root, MR does not cross again AC after $q^{\mathcal{S}}$ which means that MR crosses AC from above at $q^{\mathcal{S}}$ and then $\left|MR'(q^{\mathcal{S}})\right| > \left|AC'(q^{\mathcal{S}}; \phi)\right|$. If $q^{\mathcal{S}} > q^m$, then $AC'(q^{\mathcal{S}}; \phi) > 0$ and $q^{\mathcal{S}}$ is stable if it is close enough to q^m but could be unstable otherwise. Yet, if $qP''(q)/P'(q) > -1$ then it is stable as long as $q^{\mathcal{S}} \leq q^c$. Idea of the proof:

$$\left| \frac{AC'(q^{\mathcal{S}}; \phi)}{MR'(q^{\mathcal{S}})} \right| = \frac{\frac{C'(q^{\mathcal{S}}) - AC(q^{\mathcal{S}}; \phi)}{q^{\mathcal{S}}}}{-MR'(q^{\mathcal{S}})}$$

and by definition $AC(q^{\mathcal{S}}; \phi) = MR(q^{\mathcal{S}}) = P(q^{\mathcal{S}}) + q^{\mathcal{S}}P'(q^{\mathcal{S}})$ and the ratio writes

$$\left| \frac{AC'(q^{\mathcal{S}}; \phi)}{MR'(q^{\mathcal{S}})} \right| = \frac{\frac{C'(q^{\mathcal{S}}) - P(q^{\mathcal{S}})}{q^{\mathcal{S}}}}{-MR'(q^{\mathcal{S}})} + \frac{-P'(q^{\mathcal{S}})}{-MR'(q^{\mathcal{S}})}$$

the first term is negative if $q^{\mathcal{S}} \leq q^c$ (it is null for $q^{\mathcal{S}} = q^c$). Moreover $MR' = 2P' + qP''$ which means that

$$\left| \frac{AC'(q^{\mathcal{S}}; \phi)}{MR'(q^{\mathcal{S}})} \right| < \frac{-P'(q^{\mathcal{S}})}{2P'(q^{\mathcal{S}}) + q^{\mathcal{S}}P''(q^{\mathcal{S}})} = \frac{1}{2 + \frac{q^{\mathcal{S}}P''(q^{\mathcal{S}})}{P'(q^{\mathcal{S}})}}$$

therefore the condition $qP''(q)/P'(q) > -1$ ensures that the stability ratio is lower than one.

E Cost minimizing monopoly

The cost minimizing monopoly produces the quantity which minimizes the average cost. A misspecified model leading to this choice is

$$\Pi^{\mathcal{S}}(q\,;\theta,\phi) = (P(\theta) - AC(q;\phi))\,\theta \tag{5}$$

that is, the firm behaves as if the quantity to be sold were given by θ (notice that the price is such that all demand is served) but the average cost $AC(q;\phi)$ can be independently chosen. Thus, this model is the dual of the behavioral monopoly's model: compared to (2) the role of q and θ have been inverted. Maximizing this misspecified objective amounts to $\min_q AC(q;\phi)$ and the solution is $q^0(\phi)$ as long as the profit is positive for this level. As the solution of $\Pi(q^0(\phi);\phi) = 0$ is ϕ^c, the solution of (5) is $q^0(\phi)$ if $0 \leq \phi \leq \phi^c$, and zero if $\phi^c < \phi$. Moreover $q^0(0) = 0 < q^m < q^0(\phi^c)$ and $q^0(\phi)$ is increasing with ϕ. Let ϕ be such that , the equilibrium of the price taking monopoly model is q^c if $\phi \leq \phi^c$ and zero if $\phi^c < \phi$. The solution of (5) is an equilibrium, for $\theta = q^0(\phi)$, in the sense of our definition 1.

F Proof of Proposition 4

We prove by induction that the posterior distribution P_t is log-normal for all t. Suppose that the prior distribution at date t is log-normal (μ_t, σ_t^2). Then the expectation of θ under P_t is

$$\theta_t = \mathbb{E}P_t = e^{\mu_t + \sigma_t^2/2}.$$

The produced outcome is $\mathrm{MR}(q_t) = \theta_t$ and the average cost $\mathrm{AC}(q_t)$ is observed. The posterior belief is proportional to

$$P_{t+1}(\theta) \propto P_t(\theta)\,\frac{1}{s}\phi\left(\frac{\ln\theta - \ln\,\mathrm{AC}(q_t)}{s}\right) \propto \frac{1}{\theta}\exp -\frac{(\ln\theta-\mu_t)^2}{2\sigma_t^2}\,\exp -\frac{(\ln\theta - \ln\,\mathrm{AC}(q_t))^2}{2s^2}.$$

By identification, we find that the posterior is log-normal $(\mu_{t+1}, \sigma_{t+1}^2)$ with

$$\mu_{t+1} = \frac{s^2}{s^2+\sigma_t^2}\,\mu_t + \frac{\sigma_t^2}{s^2+\sigma_t^2}\,\ln\,\mathrm{AC}(q_t) \tag{6}$$

and

$$\sigma_{t+1}^2 = \frac{s^2\sigma_t^2}{s^2+\sigma_t^2}.$$

The variance σ_{t+1}^2 is the harmonic mean of σ_t^2 and s^2. More precisely

$$\frac{1}{\sigma_{t+1}^2} = \frac{1}{\sigma_t^2} + \frac{1}{s^2}$$

hence for all $t \geq 0$

$$\frac{1}{\sigma_t^2} = \frac{1}{\sigma_0^2} + \frac{t}{s^2}$$

and

$$\sigma_t^2 = \frac{s^2\sigma_0^2}{s^2 + t\sigma_0^2}. \tag{7}$$

It follows that σ_t^2 tends to zero as t goes to infinity at a slow rate, namely s^2/t. Using (6) and (7) together with $\ln\theta_t = \mu_t + \sigma_t^2/2$ yields (4).

The revision formula for μ_{t+1} is a weighted sum of the prior μ_t and the new information y_t. The *no memory case* is $s = 0$: the firm takes for granted the new information provided by the upstream division, completely forgetting its earlier belief. When on the contrary s is large relative to σ_t^2, the firm's beliefs about θ exhibit strong inertia: the firm changes very little its belief when it receives feedback from the upstream division.

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Supplementary Material (for online publication only)

Pass-through Let assume the variable cost function increases with a parameter γ: $C(q;\gamma)$. How does the equilibrium quantity (price) varies with γ? A priori q^m and $q^{\mathcal{S}}$ are different which complicates the interpretation of these equations. However, in the long run we have seen that $q^m = q^{\mathcal{S}}$ which allows us to derive the following proposition.

Proposition 6. *Assume that both the behavioral and rational monopolists produce at the production efficient level and that $C(q;\gamma) = C(q) + \gamma q$ or $C(q;\gamma) = (1+\gamma)C(q)$, then the behavioral monopoly reacts more to a shock on the cost function than a rational one.*

Proof. For a rational monopoly, the f.o.c. is (where the prime in C' denotes the derivative with respect to q)

$$MR(q^m) = C'(q^m;\gamma)$$

therefore differentiating w.r.t. γ and rearranging terms leads to

$$\frac{\partial q^m}{\partial \gamma} = \frac{\frac{\partial C'(q^m;\gamma)}{\partial \gamma}}{MR'(q^m) - C''(q^m;\gamma)}$$

For a behavioral monopoly, the equilibrium condition is (ignoring in the notation the dependence of AC on ϕ)

$$MR(q^{\mathcal{S}}) = AC(q^{\mathcal{S}};\gamma)$$

therefore differentiating w.r.t. γ, noting that $\frac{\partial AC(q^{\mathcal{S}};\gamma)}{\partial \gamma} = \frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma}$ and rearranging terms leads to

$$\frac{\partial q^{\mathcal{S}}}{\partial \gamma} = \frac{\frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma}}{MR'(q^m) - AC'(q^{\mathcal{S}};\gamma)}$$

For the optimally chosen production structure, $q^m = q^{\mathcal{S}}$ and $AC'(q^{\mathcal{S}};\gamma) = 0$ (monopolists produce at the minimum of the average cost, see Section 4. Moreover, if $C(q;\gamma) = C(q) + \gamma q$, then $\frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma} = 1$ and $\frac{\partial C'(q^m;\gamma)}{\partial \gamma} = 1$ also. Therefore

$$\left|\frac{\partial q^{\mathcal{S}}}{\partial \gamma}\right| = \left|\frac{1}{MR'(q^m)}\right| > \left|\frac{1}{MR'(q^m) - C''(q^m;\gamma)}\right| = \left|\frac{\partial q^m}{\partial \gamma}\right|$$

If $C(q;\gamma) = (1+\gamma)C(q)$, then $\frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma} = C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}$ and $\frac{\partial C'(q^m;\gamma)}{\partial \gamma} = C'(q^m;\gamma)$

In the general case:

$$\left|\frac{\partial q^{\mathcal{S}}}{\partial \gamma}\right| = \left|\frac{\frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma}}{MR'(q^m)}\right| \gtrless \left|\frac{\frac{\partial C'(q^m;\gamma)}{\partial \gamma}}{MR'(q^m) - C''(q^m;\gamma)}\right| = \left|\frac{\partial q^m}{\partial \gamma}\right|$$

The intuition is that if the cost shift influences more the average cost than the marginal cost, i.e. $\frac{\partial C(q^{\mathcal{S}};\gamma)/q^{\mathcal{S}}}{\partial \gamma} > \frac{\partial C'(q^m;\gamma)}{\partial \gamma}$ then the behavioral monopoly unambiguously reacts more to a shock on the cost function than a rational one. However, if the cost shift impacts more the marginal cost than the average cost the reverse could happens. To illustrate, one can imagine no impact on the average cost if the marginal cost is impacted only from $q^{\mathcal{S}} - \varepsilon$. In that case the behavioral monopolist would not react at all while the rational one would. □

Supply shocks For the convenience of the reader, we now relax the assumption that P_0 is log-normal and show that the dynamic process converges even when the true average cost function $\text{AC}(q)e^{\omega_t}$, where ω_t are iid shocks with zero mean. The results are essentially taken from Esponda and Pouzo (2016).The Bayesian firm starts with the belief $\theta_0 = \mathbb{E}P_0$, which is subsequently revised after the successive realizations of its unit cost are observed. Given P_0 and θ_0, it produces q_0 such that

$$\text{MR}(q_0) = \theta_0.$$

Then the unit cost $\text{AC}(q_0)e^{\omega_0}$ is realized and observed. The posterior belief about the distribution of θ is

$$P_1(\theta) = \frac{P_0(\theta)\phi(\ln\,\text{AC}(q_0) + \omega_0 - \ln(\theta))}{\int P_0(\theta)\phi(\ln\,\text{AC}(q_0) + \omega_0 - \ln(\theta))\,\mathrm{d}\theta},$$

where ϕ is the pdf of $\mathcal{N}(0,1)$. Given its belief $\theta_1 = \mathbb{E}P_1$, the firm chooses to produce q_1 such that $\text{MR}(q_1) = \theta_1$. It then observes its unit cost $\text{AC}(q_1)e^{\omega_1}$ and updates its belief about θ

$$P_2(\theta) = \frac{P_1(\theta)\phi(\ln\,\text{AC}(q_1) + \omega_1 - \ln(\theta))}{\int P_1(\theta)\phi(\ln\,\text{AC}(q_1) + \omega_1 - \ln(\theta))\,\mathrm{d}\theta}.$$

After $T+1$ periods, the posterior P_T is thus proportional to

$$P_T(\theta) \propto P_0(\theta)\prod_{t=0}^{T}\phi(\ln\,\text{AC}(q_t) + \omega_t - \ln(\theta)).$$

For all t, we set $\theta_t = \mathbb{E}P_t$.

Lemma 1. *Assume that θ_t has a finite limit $\bar{\theta}$. Then the limit $\bar{\theta}$ satisfies*

$$\bar{\theta} = \text{AC}\left(\text{MR}^{-1}(\bar{\theta})\right).$$

Moreover, the posterior distribution $P_t(\theta)$ tends to the mass point at $\bar{\theta}$ as t goes to infinity.

Proof. Because θ_t tends to $\bar{\theta}$, the output $q_t = \mathrm{MR}^{-1}(\theta_t)$ tends to $\bar{q} = \mathrm{MR}^{-1}(\bar{\theta})$. For any θ, we compute the ratio

$$\frac{P_T(\theta)}{P_T(\bar{\theta})} = \frac{P_0(\theta)\prod_{t=0}^{T}\phi(\ln\,\mathrm{AC}(q_t)+\omega_t-\ln(\theta))}{P_0(\bar{\theta})\prod_{t=0}^{T}\phi(\ln\,\mathrm{AC}(q_t)+\omega_t-\ln(\bar{\theta}))},$$

and its logarithm divided by the number of periods

$$\begin{aligned}\frac{1}{T}\left[\ln P_T(\theta)-\ln P_T(\bar{\theta})\right] &= \frac{1}{T}\left[\ln P_0(\theta)+\sum_{t=0}^{T}\ln\phi(\ln\,\mathrm{AC}(q_t)+\omega_t-\ln(\theta))\right]\\ &\quad -\frac{1}{T}\left[\ln P_0(\bar{\theta})+\sum_{t=0}^{T}\ln\phi(\ln\,\mathrm{AC}(q_t)+\omega_t-\ln(\bar{\theta}))\right].\end{aligned}$$

From the law of large numbers and the fact that q_t tends to $\bar{q}$, the above expression tends to $L(\theta)$ as T goes to infinity, where

$$L(\theta) = \int\left[\ln\phi(\ln\,\mathrm{AC}(\bar{q})+\omega-\ln(\theta))-\ln\phi(\ln\,\mathrm{AC}(\bar{q})+\omega-\ln(\bar{\theta}))\right]\psi(\omega)\,\mathrm{d}\omega,$$

and ψ is the pdf of the distribution of the shocks ω_t. Replacing ϕ with its value and using the fact that the shocks ω_t have mean zero (i.e., $\int\omega\psi(\omega)\,\mathrm{d}\omega = 0$), we get

$$\begin{aligned}L(\theta) &= \frac{1}{2}\int\left[(\ln\,\mathrm{AC}(\bar{q})+\omega-\ln(\bar{\theta}))^2-(\ln\,\mathrm{AC}(\bar{q})+\omega-\ln(\theta))^2\right]\psi(\omega)\,\mathrm{d}\omega\\ &= \frac{1}{2}\left[(\ln\,\mathrm{AC}(\bar{q})-\ln(\bar{\theta}))^2-(\ln\,\mathrm{AC}(\bar{q})-\ln(\theta))^2\right]\\ &= \frac{1}{2}\left[(\ln\,\mathrm{AC}(\,\mathrm{MR}^{-1}(\bar{\theta}))-\ln(\bar{\theta}))^2-(\ln\,\mathrm{AC}(\,\mathrm{MR}^{-1}(\bar{\theta}))-\ln(\theta))^2\right]\end{aligned}$$

In other words, the asymptotic distribution of θ satisfies

$$\frac{P_T(\theta)}{P_T(\bar{\theta})} \approx e^{TL(\theta)}.$$

If $\bar{\theta} = \mathrm{AC}\left(\mathrm{MR}^{-1}(\bar{\theta})\right)$, we have, for all $\theta \neq \bar{\theta}$

$$L(\theta) = -\frac{1}{2}\left[\ln\,\mathrm{AC}\left(\mathrm{MR}^{-1}(\bar{\theta})\right)-\ln(\theta)\right]^2 = -\frac{1}{2}\left[\ln\bar{\theta}-\ln(\theta)\right]^2 < 0,$$

which implies that $P_T(\theta)/P_T(\bar{\theta})$ tends to zero as T goes to infinity, meaning that P_T asymptotically tends to the mass point at $\bar{\theta}$. This is consistent with θ_t tending to $\bar{\theta}$.

Now suppose by contradiction that $\bar{\theta} \neq \mathrm{AC}\left(\mathrm{MR}^{-1}(\bar{\theta})\right)$. Let $\delta = |\ln\,\mathrm{AC}\left(\mathrm{MR}^{-1}(\bar{\theta})\right)-\ln\bar{\theta}|$. We have $L(\theta) > 0$ if and only if

$$|\ln\,\mathrm{AC}\left(\mathrm{MR}^{-1}(\bar{\theta})\right)-\ln\theta| < \delta.$$

This means that the support of the asymptotic distribution P_T is included in the interval $(\mathrm{AC}(\mathrm{MR}^{-1}(\bar{\theta})) - \delta, \mathrm{AC}(\mathrm{MR}^{-1}(\bar{\theta})) + \delta)$, and hence that its expectation cannot be $\bar{\theta}$, the desired contradiction. $\square$