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A Class of Behavioural Models for the Profit-Maximizing Firm

Abstract

We study the behavior of a firm that consistently maximizes a misspecified profit function. We provide an equilibrium concept where the misspecification error remains undetected. We examine the uniqueness and stability of the equilibria. The model of the price-taking firm belongs to this class. In one of these models, the cost-taking firm, the equilibrium price increases with fixed costs. The behavioural price can be lower or higher than the rational price, meaning consumers can benefit from the lack of rationality. Finally in a long-run perspective where the cost is endogenous, we show that the behavioral and rational firms end with the same level of output.

JEL-Codes: L120, L210, L230, L250, M410.

Keywords: behavioural model of a firm, misspecified profit function, fixed costs.

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Economic theory formulates thoughts via what we call “models.” The word model sounds more scientific than the word fable or tale, but I think we are talking about the same thing.
Ariel Rubinstein, *Economic Fables*, 2012

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1 Introduction

According to the Merriam-Webster dictionary, a model is "a system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs". At the heart of the theory of the firm, is the profit function, which the firm aims to maximize. Although profit is easily understood as revenue minus costs, for which numerous indicators are provided by accountants, even the brightest MBA student would struggle to write down her firm's profit function. Despite these practical difficulties, many economists share the optimistic belief that would a firm get her profit function wrong, the day of reckoning would soon come, and the firm would either exit the market or adjusts its profit function in the right direction.

At least since the seminal work of Esponda and Pouzo (2016) on the Berk-Nash equilibrium concept, we know, however, that such a reckoning might never come. In this paper, we propose a simple (i.e. with no noise) class of behavioral models of the firm where the profit function is misspecified. In equilibrium the firm's wrong belief about its profit function is comforted (i.e. goes undetected). In our framework, the reality check is the accounting profit. The equilibrium concept is based on the notion of rational expectations. The firm makes her quantity decision based on expectations regarding the value of a key variable (e.g. unit costs), and these expectations are correct in equilibrium. This simple concept can be seen as a full-information version of the Berk-Nash equilibrium.[1]

More specifically, to construct our class of behavioral models, we remark that the standard profit function reflects two economic constraints. A market constraint linking price and quantity through the demand function, on the one hand. A technological constraint, on the other, linking unit cost and quantity. The firm should anticipate that producing more (or less) modify both the selling price and the unitary cost. We assume a behavioral firm does not, however, fully grasp these constraints. This generates various models which we analyze in detail.

A first model in our class is the well known price-taking firm. The behavioral firm, in that case, wrongly believes that its selling price is fixed (the market constraint is therefore not understood), and maximizes its profit accordingly. This mistake remains unnoticed, in equilibrium, as the firm rationally anticipates the right price equalizing supply and demand.[2] In terms of profits, the misperception that price is fixed is not inconsequential as the firm cannot achieve the optimal profit.

The counterpart of the price-taking firm is the cost-taking firm. In that case, the

[1] 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.

[2] In the model of competitive firms, one of the pilar of microeconomics, the rationality of the price taking behavior is sidestepped by assuming firms are atomistic.

behavioral firm understands the market constraint but wrongly believes that the unit cost of production is constant. Again, in equilibrium, the mistake remains unnoticed as the firm rationally anticipates the right average-cost. The implied misspecification equilibrium is new to the literature and presents the intuitive (outside the economists' realm) property that price varies with fixed costs. When these costs increase, a price raise follows.

The next possibility is the margin-maximizing firm. This behavioral firm understands that both the price and the unit-cost vary with the chosen quantity but wrongly believes that the sold quantity is fixed. Admittedly a strange belief, but nevertheless, in equilibrium, the firm rationally anticipates the correct sold quantity and does not realize its profits could be larger. In this model also the price varies with fixed costs but in an opposite direction. When these costs increase, a price reduction follows.

Finally, we present the cost-minimizing firm. Here the firm takes both the price and the sold quantity as fixed, and thus maximizes profits by minimizing the average costs. This is the mirror case of the cost-taking firm. As in the margin-maximizing firm model, the equilibrium price decreases with the fixed costs. For completeness, we also have the quantity-maximizing and the quantity-minimizing firm. But these two models are rather trivial and lead to zero profits.

From the perspective of the consumers and welfare, the models have different predictions. First, assume that the fixed costs are low enough so the firm produces in equilibrium. Consumers can benefit from a behavioral mistake. In particular, the price-taking-firm's price is always lower than the rational price. For relatively low values of the fixed costs, cost-taking behavior also leads to a lower price. The reverse is true for the cost-minimizing firm which price is lower than the rational price when the fixed costs are relatively large. Finally, the margin-maximizing quantity is always lower than the rational quantity. So, in this model, the lack of rationality of the firm hurts both the firm and the consumers.

Next, it is worth to emphasize that as behavioral profits are lower than the rational profits, the behavioral firm finds it unprofitable to produce when fixed costs become large. The cost-taking firm is the first to drop out, followed by the cost-minimizing and the price-taking firms (they drop out for the same value of fixed costs). Finally, the margin-maximizing firm remains active as long as the rational firm is active.

We also show that in the long run, when the firm can duplicate its technology, the investments of both the rational and the cost-taking firm are similar. Moreover they are such that the quantities and profits are the same in both models. Meaning that in the long run, the cost-taking firm would behave optimally. An intriguing result that underlines that even if a firm holds the entrenched belief that fixed-costs should impact the selling price, there could be no distortion in terms of profit maximization.

After a literature review which concludes the introduction, the article is organized as follows. Section 2 presents the general logic of our behavioral models for the misspecified-profit-maximizing firm. Then in section 3 we introduce our simple class of behavioral models and characterize the misspecification equilibrium of each model. In section 4, we solve completely a parametric example. Section 6 presents a couple of additional models that fit in our general framework and provide a complementary view to our simple class. Section 5 study the long run investment strategy of a cost-taking firm and compare it to the choice of the rational firm. Finally, section 7 concludes.

Literature review. In several of our misspecification equilibria, fixed costs have an influence on the price. Thus, our work is related to the "full-cost" pricing literature. Despite Economics 101, there has been a controversy for at least 80 years between economists on whether prices depend or not on fixed cost.[3] Staged as an anti-marginalists vs marginalists debate, it started with Hall and Hitch (1939) who interviewed 38 U.K. entrepreneurs without finding evidence they equalized marginal revenue to marginal costs. Hall and Hitch concluded that economic theory should be re-thought in light of their findings. Lester (1946) shares their conclusion: "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) is a rebuttal. The conversation at cross purposes continued with Lester (1947) and two "rejoinders" Machlup (1947) and Stigler (1946). Later, Machlup (1967) recounted the battle.[4] 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[5] seems to have been the decisive blow. Mongin (1992) is an excellent discussion of this controversy.

Recently, Altomonte, Barattieri, and Basu (2015) use a survey of 14,000 European firms. They asked these firms whether "their prices are fixed by the market, set as a margin over a measure of total (including fixed) cost, or fixed as a margin over a measure of variable cost." Among the 60% of firms which are not price takers, 75% of them set

[3]See the survey Ellison (2006). As well as Nubbemeyer (2010), a Ph.D. on full-cost pricing. The author is fair but sympathetic to the anti-marginalist point of view.

[4]See also, in the *Journal of Post Keynesian Economics*, a journal (according to one of his Editor) "devoted primarily to criticizing destructively the analytical foundations of neoclassical theory" Davidson (1990). First, Langlois (1989), then a symposium at the end of 1990 on "The marginalist controversy and Post Keynesian price theory". *Journal of Post Keynesian Economics*, volume 13, number 2.

[5]The mathematical formulae which explain the best hits are extremely complicated. Yet, the assumption that an expert billiard player makes his shots as if he knew the formulas, should give good predictions of what is observed. In 1947 Machlup used a similar analogy with a driver on a highway who ponders to overtake a truck or not

their prices according to full cost pricing. Next, focusing on U.S. data, they show that the correlation between changes in output prices and changes in variable inputs prices is significantly lower when fixed costs are likely to be more important.

Our results are connected to the literature building on or extending Esponda and Pouzo (2016). The focus of this literature is on beliefs and their convergence through repeated Bayesian learning. In Appendix F, we discuss briefly how to introduce noise in our model and apply the insight of Esponda and Pouzo. There is a growing theoretical literature building on and refining the Berk-Nash equilibrium concept. The focus is on the formation/convergence of beliefs or how to reach an equilibrium whereas our focus is on the properties of the equilibrium. Heidhues, Kőszegi, and Strack (2018) focus, as we do, on a single player framework and combine the idea of overconfidence with learning in a misspecified model. Heidhues, Kőszegi, and Strack (2021) derive further convergence results in a more general framework for the objective and subjective production functions (which play the role of our profit functions) while restricting on Gaussian shocks.

Whereas the idea of full-cost pricing lost traction among economists[6] it always remained present in the accounting literature[7] which still refers to surveys where firms declare using the full cost of a product when setting their list prices. E.g. Govindarijian and Anthony (1983), Drury, Braund, Osborne, and Tayles (1993) and Shim and Sudit (1995). Balakrishnan and Sivaramakrishnan (2002) and Göx and Schiller (2006) present this literature. Finally, Bouwens and Steens (2016) is an empirical study of a single firm.

2 A general class of behavioral models

A cornerstone principle in economics is that choices are made in order to maximize an objective. Even a behavioral firm has a profit function which it maximizes. Yet, instead of maximizing the real profit function, which we call the objective profit, the firm might maximize a misspecified profit function, which we call the subjective profit function. Nevertheless, even a mistaken firm cashes in profits and only objective profits can be cashed in. So for a firm to keep maximizing its subjective profit function, the objective profits earned should be equal to the subjective ones the firm expected to earn. If this consistency requirement is satisfied, the behavioral firm has no reason to suspect its profit function is misspecified. Such a configuration is called a misspecification equilibrium.

[6]The idea that in some circumstances sunk costs might influence a rational decision maker has, however, been illustrated in several papers: Friedman, Pommerenke, Lukose, Milam, and Huberman (2007) survey the literature on the sunk cost fallacy. More recently, McAfee, Mialon, and Mialon (2010) list several explanations compatible with the use of sunk cost and rational behavior and Baliga and Ely (2011) model a simple two-period investment game with a single decision maker where 'sunk cost verity' holds.

[7]See the literature review in Al-Najjar, Baliga, and Besanko (2008).

2.1 The objective profit function

To keep the matter simple, we consider a firm which produces and sells a single product, and we take the quantity as its strategic variable. The objective profit writes (for $q > 0$)

$$\Pi^{\mathcal{O}}(q) = P(q)q - C(q) - \phi$$

where $P(q)$ the inverse demand, $\phi \geq 0$ is the fixed cost of production,[8] $C(q)$ is the variable cost with $C(0) = 0$. Irrespectively of its beliefs, when a firm produces q the profits are $\Pi^{\mathcal{O}}(q)$.

Let $AC(q\,;\phi) = (C(q) + \phi)\,/q$ denote the average cost. We make the usual technical assumptions: i) increasing and convex cost $C' \geq 0$, and $C'' \geq 0$, ii) convex and U-shaped average cost, iii) decreasing marginal revenue $MR(q) = P'(q)q + P(q)$.

We denote the profit maximizing quantity q^m. It is solution to $MR(q) = C'(q)$. Let $\phi^m = P(q^m)q^m - C(q^m)$. The rational profit is $\phi^m - \phi$, and the rational quantity, q^m, is independent of ϕ as long as $\phi \leq \phi^m$. If ϕ is larger than ϕ^m, the market is unprofitable even for a rational firm.

Finally, let $\underline{q}(\phi)$ be the lowest root and $\overline{q}(\phi)$ the highest root of $P(q) = AC(q\,;\phi)$. The profit $\Pi^{\mathcal{O}}(q)$ is positive for q between $\underline{q}$ and $\overline{q}$.

2.2 Misspecification equilibrium

The subjective profit function of the firm is part of a family and writes $\Pi^{\mathcal{S}}\left(q\,;\theta\right)$ where θ is a parameter (possibly a list of parameters). Notice that the objective profit function $\Pi^{\mathcal{O}}(q)$ is not necessarily part of this family.

Definition 1. *For a family of misspecified profit functions $\Pi^{\mathcal{S}}\left(q;\theta\right)$, 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

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

Condition (i) insures optimality and condition (ii) consistency. This simple (two-part) idea (maximization on the one hand, reality check on the other) defines our equilibrium concept.[9]

[8] 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…

[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 $\Pi^{\mathcal{O}}\left(0\right) = 0 = \Pi^{\mathcal{S}}\left(0\,;\theta\right)$. That is, if the firm anticipates the worst, it is optimal not to produce and to expect no profit. Our goal is to study misspecification equilibria where the firm does produce.

3 A simple class of behavioral models

The objective profit function which writes

$$\Pi^{\mathcal{O}}(q) = (P(q) - AC(q\,;\phi))\,q \tag{1}$$

reflects two economic constraints. First, a market constraint: price and quantity are linked by the demand function as consumers cannot be forced to buy and the firm cannot profit from rationing them in this set-up. Second, a technological constraint: the unit cost varies with q. The firm should anticipate that producing more (or less) would modify the unitary cost. Writing (1) as

$$(P(q_1) - AC(q_2\,;\phi))\,q_3\,,$$

the market constraint is $q_1 = q_3$ and the technological constraint is $q_2 = q_3$. Our approach is to assume that a behavioral firm does not fully understand these forces.[10]

Assuming these constraints are active or not is a simple way to introduce the parameter θ and this allows us to define the following four behavioral models.

3.1 Price-taking firm

The simplest illustration of a misspecified profit function is given by the classical price-taking firm. Indeed, assume:

$$\Pi^{\mathcal{S}}(q\,;\theta) = (P(\theta) - AC(q\,;\phi))\,q \;\text{ with } \theta \in \left[\underline{q}, \overline{q}\right]\,. \tag{2}$$

In this well known model, the firm wrongly believes that the inverse demand function $P(.)$ is constant. The market constraint is not understood, i.e. $q_1 \neq q_3$, while the technological constraint is active, i.e. $q_2 = q_3$.

To derive the misspecification equilibrium, let q^c be the unique quantity such that $C'(q^c) = P(q^c)$. Moreover let $\phi^c = P(q^c)q^c - C(q^c)$.

Lemma 1. *In the model of the price-taking firm, when $\phi \leq \phi^c$, there exists a unique misspecification equilibrium: the quantity is $q^{\mathcal{S}} = q^c$ and the parameter $\theta^{\mathcal{S}} = q^c$.*

Proof. We can check that the quantity $q^{\mathcal{S}} = q^c$ and the parameter $\theta^{\mathcal{S}} = q^c$ form a misspecification equilibrium for this model. By construction condition (i) of definition 1 is satisfied. Condition (ii) also holds as $\Pi^{\mathcal{S}}\left(q^{\mathcal{S}}\,;\theta^{\mathcal{S}}\right) = (P(q^c) - AC(q^c\,;\phi))\,q^c$ which is exactly $\Pi^{\mathcal{O}}(q^c)$. □

The profit made by the price-taking firm is $\max\{0\,;\,\phi^c - \phi\}$. It is always strictly lower than the rational profit $\max\{0\,;\,\phi^m - \phi\}$ as long as the market is profitable $\phi < \phi^m$. Notice that the quantity q^c and the profit difference $\phi^m - \phi^c$ (which is the profit loss due to the misspecification) are both independent of ϕ.

[10] Informally, it is sometimes useful to see the firm as the marketing (selling) division which is at the interface between the market (i.e. consumers) and the technology (i.e. the production division).

3.2 Cost-taking firm

The most natural pendant to the price-taking model, is when the firm wrongly believe that its cost is constant by which we mean its unit-cost (or average cost) is constant. The technology constraint is not understood, i.e. $q_2 \neq q_3$ while the market constraint is understood, i.e. $q_1 = q_3$. Formally,

$$\Pi^{\mathcal{S}}(q\,;\theta) = (P(q) - AC(\theta;\phi))\,q \;\text{ with } \theta \in \left[\underline{q}, \overline{q}\right]. \tag{3}$$

To characterizes a misspecification equilibrium of this model, let $q^{\mathcal{S}}$ denote a quantity solution of

$$MR(q^{\mathcal{S}}) = AC(q^{\mathcal{S}}\,;\phi)\,. \tag{4}$$

Under the assumption that the marginal revenue is less convex than the average cost on the interval where the average cost function is decreasing, (4) has at most two roots. If ϕ is too large, the average cost curve is everywhere above the marginal revenue curve and (4) has no solution. In Appendix A we characterize $\phi^{\mathcal{AC}}$ such that (4) has two solutions whenever $\phi < \phi^{\mathcal{AC}}$. We denote the largest root of (4) $q_H^{\mathcal{AC}}$ and the lowest root $q_L^{\mathcal{AC}}$.

Lemma 2. *In the model of the cost-taking firm, there is at most two misspecification equilibrium: $q^{\mathcal{S}} = \theta^{\mathcal{S}} = q_L^{\mathcal{AC}}$ and $q^{\mathcal{S}} = \theta^{\mathcal{S}} = q_H^{\mathcal{AC}}$. The equilibrium at $q_H^{\mathcal{AC}}$ is better for the consumers and the firm.*

Proof. Notice the optimality condition is $MR(q^{\mathcal{S}}) = AC(\theta^{\mathcal{S}};\phi)$ and the consistency condition is $C(q^{\mathcal{S}}) + \phi = AC(\theta^{\mathcal{S}};\phi)q^{\mathcal{S}}$. Combining these two conditions leads to (4). In Appendix B we show that the profits are larger at $q_H^{\mathcal{AC}}$ than $q_L^{\mathcal{AC}}$. □

As long as $\phi \leq \phi^{\mathcal{AC}}$, the profit of the cost-taking firm is positive. Both the quantity and the profits are positive for $\phi = \phi^{\mathcal{AC}}$. But the firm collapses (no production and no profit) for $\phi = \phi^{\mathcal{AC}} + \varepsilon$ with $\varepsilon > 0$. In Appendix D, it is further shown that $q_H^{\mathcal{AC}}$ (resp. $q_L^{\mathcal{AC}}$) is a decreasing (resp. increasing) and concave (resp. convex) function of ϕ.

3.3 Margin-maximizing firm

A third model is obtained by assuming that the firm understand that its unit margin is given by $P(q) - AC(q;\phi)$ but wrongly believes that the total quantity is constant. That is, neither the market nor the technological constraints are understood, i.e. $q_1 \neq q_3$ and $q_2 \neq q_3$, yet the maximizing variable is $q_1 = q_2$. Formally,

$$\Pi^{\mathcal{S}}(q\,;\theta) = (P(q) - AC(q;\phi))\,\theta \;\text{ with } \theta \in \left[\underline{q}, \overline{q}\right]. \tag{5}$$

The mistake in this model, although less intuitive, is easy to explain. The behavior of the firm is simply to maximize its unitary margin.

Let $q^{\mathcal{MA}}$ be the unique solution to $P'(q) = AC'(q;\phi)$ which also writes:

$$MR(q) = C'(q) + (P(q) - AC(q\,;\phi)) \ . \tag{6}$$

To show uniqueness, notice that the derivative of the right-hand side is $C''(q) + P'(q) - AC'(q\,;\phi)$ which simplifies into $C''(q^{\mathcal{MA}}) \geq 0$ for $q = q^{\mathcal{MA}}$.

Lemma 3. *In the model of the margin-maximizing firm, when $\phi \leq \phi^m$, there exists a unique misspecification equilibrium: $q^{\mathcal{S}} = \theta^{\mathcal{S}} = q^{\mathcal{MA}}$.*

Proof. The optimality condition is $P'(q^{\mathcal{S}}) = AC'(q^{\mathcal{S}};\phi)$ and the consistency is again $\theta^{\mathcal{S}} = q^{\mathcal{S}}$. Rearranging the optimality condition, using $AC'(q;\phi) = (C'(q) - AC(q;\phi))\,/q$ we have (6). □

Whenever the rational firm is active (i.e. $\phi \leq \phi^m$) so is the margin-maximizing firm. In particular when $\phi \to \phi^m$, $q^{\mathcal{MA}} \to q^m$ and the choice of the margin-maximizing firm becomes rational allowing survival.

3.4 Cost-minimizing firm

A fourth model can be derived by assuming, as in the cost-taking case, that the market constraint is satisfied, i.e. $q_1 = q_3$ and the technological one is not, i.e. $q_2 \neq q_3$ but assuming that the maximizing variable is q_2 (whereas it is $q_1 = q_3$ in the cost-taking case). Formally,

$$\Pi^{\mathcal{S}}(q\,;\theta) = (P(\theta) - AC(q;\phi))\,\theta \ \text{ with } \theta \in \left[\underline{q}, \overline{q}\right] \ . \tag{7}$$

Here the behavioral firm minimizes its average cost of production. Let $q^{\mathcal{MI}}$ be the unique solution to

$$C'(q) = AC(q\,;\phi) \,. \tag{8}$$

Lemma 4. *In the model of the cost-minimizing firm, when $\phi \leq \phi^c$, there exists a unique misspecification equilibrium: $q^{\mathcal{S}} = \theta^{\mathcal{S}} = q^{\mathcal{MI}}$.*

Proof. As $AC'(q;\phi) = (C'(q) - AC(q;\phi))\,/q$ the optimality condition is $C'(q) = AC(q^{\mathcal{S}};\phi)$, implying $q = q^{\mathcal{MI}}$, and the consistency is again $\theta^{\mathcal{S}} = q^{\mathcal{MI}}$. □

3.5 Wrap-up

First of all, notice that one could also try two other possibilities $(P(\theta) - AC(\theta;\phi))\,q$ and $(P(q) - AC(\theta;\phi))\,\theta$. But both of them would lead to zero profits. It is easy to check that when the firm maximizes the quantity the only misspecification equilibrium is $q = \overline{q}$ and no profit as $P(\overline{q}) = AC(\overline{q};\phi)$. Whereas when the firm maximizes the price (it minimizes the quantity) the only misspecification equilibrium is $q = \underline{q}$ and no profit as $P(\underline{q}) = AC(\underline{q}; \phi)$.

To summarize, we have defined, besides the rational quantity, q^m, four quantities compatible with a maximizing-profit model of the firm. First, the price-taking quantity, q^c. Second, the cost-taking quantities, $q_H^{\mathcal{AC}}$ and $q_L^{\mathcal{AC}}$. Third, the quantity maximizing the unitary margin, $q^{\mathcal{MA}}$. Fourth, the quantity minimizing the average cost, $q^{\mathcal{MI}}$.

Proposition 1 shows how these quantities vary with the fixed cost ϕ.

Proposition 1. *Among q^m and the misspecification equilibrium quantities q^c, $q_H^{\mathcal{AC}}$, $q_L^{\mathcal{AC}}$, $q^{\mathcal{MA}}$, and $q^{\mathcal{MI}}$, the cost-taking quantity, $q_H^{\mathcal{AC}}$, is the only one decreasing with ϕ (and thus the corresponding price is increasing). The quantities q^m and q^c are weakly decreasing with ϕ and the others are increasing with ϕ before becoming null when ϕ crosses a threshold. In the absence of fixed cost, $q_L^{\mathcal{AC}} = q^{\mathcal{MA}} = q^{\mathcal{MI}} = 0$ whereas $q_H^{\mathcal{AC}}$, q^m, and q^c are positive.*

The proof is in Appendix B. As a consequence, among these models, the only one compatible with the "full-cost" pricing intuition (i.e. that the price should increase (not decrease) with fixed costs) is the cost-taking model.

Let define $\phi^* = q^m MR(q^m) - C(q^m)$. It corresponds to the profit the upstream firm would have in a chain of monopolies by producing q^m.[11] As a consequence $\phi^* < \phi^{\mathcal{AC}} = \max_q qMR(q) - C(q)$.

Proposition 2. *When $\phi = \phi^*$, $q_H^{\mathcal{AC}} = q^{\mathcal{MI}} = q^m$, and the profits are the same in these three models. When $\phi < \phi^*$, $q_H^{\mathcal{AC}} > q^m > q^{\mathcal{MI}}$, and when $\phi^* < \phi$, then $q_H^{\mathcal{AC}} < q^m < q^{\mathcal{MI}}$.*

Proof. When $\phi = \phi^*$,

$$AC(q^m; \phi^*) = \frac{C(q^m) + q^m MR(q^m) - C(q^m)}{q^m} = MR(q^m)$$

and therefore $q_H^{\mathcal{AC}} = q^m$.[12] Moreover, as for the rational quantity $MR(q^m) = C'(q^m)$, it also shows that $q^{\mathcal{MI}} = q^m$. Moreover, when ϕ is close enough to zero, the average cost is mainly $C(q)/q$ (the ϕ/q part becomes negligible). Now as $C(q)$ is a convex function, the average-variable-cost, $C(q)/q$ is lower than the marginal cost $C'(q)$ and therefore $q_H^{\mathcal{AC}} > q^m$. □

Therefore if the fixed cost is close to ϕ^* a cost-taking or a cost-minimizing firm behaves similarly to a rational firm. That is, the lack of rationality would be (almost) costless.

[11] Notice that $qMR(q) - C(q)$ is maximum for q^{dm} (the double marginalization quantity), see Appendix A.

[12] Recall that the lowest root $q_L^{\mathcal{AC}}$ is strictly lower than q^m.

Consumers prefer the cost-taking firm to the rational firm (and to the cost-minimizing firm) when $\phi < \phi^*$ but they prefer the cost-minimizing firm when $\phi^* < \phi < \phi^c$. Finally, they (have no choice but to) prefer the rational firm when $\phi^c < \phi < \phi^m$.

3.6 *Tâtonnement*

In the spirit of a Walrasian *tâtonnement*, we look for a dynamic sequence of quantities converging to the equilibrium. Quite generally, a given fixed point $q^* = f(q^*)$ is locally stable, if starting from a neighborhood of q^* any sequence $q_{t+1} = f(q_t)$ converge to q^*. This property holds if and only if $|f'(q^*)| < 1$. For the price-taking and the cost-taking firms such a dynamic sequence can be defined and studied.

Starting with a $\theta_0 \in \left[\underline{q}, \overline{q}\right]$, the maximization of (2) leads to q_0 such that $C'(q_0) = P(\theta_0)$. Setting then $\theta_1 = q_0$ and starting again the maximization leads to the sequence $q_{t+1} = (C')^{-1}(P(q_t))$.

Similarly, starting with a $\theta_0 \in \left[\underline{q}, \overline{q}\right]$, the maximization of (3) leads to q_0 such that $MR(q_0) = AC(\theta_0\,;\phi)$. Setting then $\theta_1 = q_0$ and starting again the maximization leads to the sequence $q_{t+1} = (MR)^{-1}(AC(q_t\,;\phi))$.

By analogy, for the rational firm, starting with a $\theta_0 \in \left[\underline{q}, \overline{q}\right]$, the maximization of $(P(q) - C'(\theta_0))\,q$ leads to q_0 such that $MR(q_0) = C'(\theta_0)$. Setting then $\theta_1 = q_0$ and starting again the maximization leads to the sequence $q_{t+1} = (MR)^{-1}(C'(q_t))$.[13]

For the margin-maximizing and the cost-minimizing firms there is no dynamics as for any θ the maximization of the misspecified profit function leads immediately to $q^{\mathcal{MA}}$ and $q^{\mathcal{MI}}$ respectively.

Proposition 3. *The price-taking equilibrium quantity q^c is locally stable if $|P'(q^c)| < C''(q^c)$. The rational quantity q^m is locally stable for the equation $q^m = (MR)^{-1}(C'(q^m))$ if $C''(q^m) < |MR'(q^m)|$. The quantity $q_L^{\mathcal{AC}}$ is a non-stable fixed point. For the largest cost-taking quantity:*

- *If $q_H^{\mathcal{AC}}$ is lower than q^m, then it is locally stable.*
- *If $q_H^{\mathcal{AC}}$ is larger than q^m, then it is locally stable if and only if $AC'(q_H^{\mathcal{AC}}\,;\phi) < \left|MR'(q_H^{\mathcal{AC}})\right|$. In particular,*
  - *If $q_H^{\mathcal{AC}} \leq q^c$, and $qP''(q)/P'(q) > -1$, then it is locally stable.*
  - *If $q_H^{\mathcal{AC}}$ is close enough to $q^{\mathcal{MI}}$ (i.e. ϕ close enough to ϕ^*), then it is locally stable.*

Proof. See Appendix C. ◻

[13] Beware that this is not the description of a behavioral model where the equilibrium is q^m. Typically the consistency condition is not satisfied without the inclusion of an additional parameter, see section 6.2.

To illustrate the idea behind the stability of $q_H^{\mathcal{AC}}$, 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. 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).

4 Parametric example

The study of the following parametric example provides a good overview of the different simple models and help compare them both formally and graphically. We assume a linear inverse demand and a quadratic cost function:

$$P(q) = a - bq \ \ ; \ \ C(q) = c_1 q + c_2 q^2/2$$

The rational quantity and profits are

$$q^m = \frac{a - c_1}{2b + c_2} \ \text{ and } \ \Pi^m = \frac{(a - c_1)^2}{2(2b + c_2)} - \phi = \phi^m - \phi\,.$$

For a quantity q, the profit $\Pi^{\mathcal{O}}(q)$ is positive only if $q \in [q, q]$ where the quantities $\underline{q}$ and $\overline{q}$ are such that $\Pi^{\mathcal{O}}(q) = 0$:

$$\underline{q} = \left(1 - \sqrt{1 - \phi/\phi^m}\right) q^m \text{ and } \overline{q} = \left(1 + \sqrt{1 - \phi/\phi^m}\right) q^m\,.$$

For the price-taking firm the misspecification equilibrium values are

$$q^c = \frac{a - c_1}{b + c_2} \ \text{ and } \ \Pi^c = \frac{c_2(a - c_1)^2}{2(b + c_2)^2} - \phi = \phi^c - \phi\,.$$

Obviously, $q^c > q^m$ and $\Pi^c < \Pi^m$.

Turning to the cost-taking firm, equation (4) has two solutions when ϕ is low enough. More precisely, if $\phi < \phi^{\mathcal{AC}} = \frac{(a - c_1)^2}{2(4b + c_2)}$ then

$$q_H^{\mathcal{AC}} = \frac{a - c_1}{4b + c_2} + \sqrt{2\,\frac{\phi^{\mathcal{AC}} - \phi}{4b + c_2}} \ \text{ and } \ q_L^{\mathcal{AC}} = \frac{a - c_1}{4b + c_2} - \sqrt{2\,\frac{\phi^{\mathcal{AC}} - \phi}{4b + c_2}}$$

with $q_L^{\mathcal{AC}} < q_H^{\mathcal{AC}}$. Notice that when $\phi = 0$, then $q_L^{\mathcal{AC}} = 0$ and $q_H^{\mathcal{AC}} = \frac{a-c_1}{2b+c_2/2}$ which is larger than q^m whenever $c_2 > 0$. If $c_2 > 2b$, then $q_H^{\mathcal{AC}}$ is also larger than q^c for $\phi = 0$. Substituting in (1) q for these values allows to compute the profits $\Pi_L^{\mathcal{AC}}$ and $\Pi_H^{\mathcal{AC}}$.

$$\Pi_H^{\mathcal{AC}} = \frac{2b\phi^{\mathcal{AC}}}{4b+c_2}\left(1+\sqrt{\frac{\phi^{\mathcal{AC}}-\phi}{\phi^{\mathcal{AC}}}}\right)^2 \quad \text{and} \quad \Pi_L^{\mathcal{AC}} = \frac{2b\phi^{\mathcal{AC}}}{4b+c_2}\left(1-\sqrt{\frac{\phi^{\mathcal{AC}}-\phi}{\phi^{\mathcal{AC}}}}\right)^2$$

It is readily confirmed that for $0 \leq \phi \leq \phi^{\mathcal{AC}}$, $\Pi_H^{\mathcal{AC}}$ is decreasing with ϕ and larger than $\Pi_L^{\mathcal{AC}}$ which is increasing with ϕ. When $\phi = \phi^{\mathcal{AC}}$, then $q_L^{\mathcal{AC}} = q_H^{\mathcal{AC}} = q_{HL} = \frac{a-c_1}{4b+c_2} < q^m$, and the profits are both equal to $2b\phi^{\mathcal{AC}}/(4b+c_2)$ which is strictly positive. Finally, for $\phi > \phi^{\mathcal{AC}}$, equation (4) has no solution as the average cost curve is always above the marginal revenue curve.

For the margin-maximizing firm quantity and profits are

$$q^{\mathcal{MA}} = \sqrt{\frac{2\phi}{2b+c_2}} \quad \text{and} \quad \Pi^{\mathcal{MA}} = 2\sqrt{\phi}\left(\sqrt{\phi^m}-\sqrt{\phi}\right)$$

these values are well defined for $0 \leq \phi \leq \phi^m$. The behavioral quantity $q^{\mathcal{MA}}$ is increasing with ϕ from zero for $\phi = 0$ up to q^m when $\phi = \phi^m$. The profit is increasing for $0 \leq \sqrt{\phi} \leq \sqrt{\phi^m}/2$ and then decreasing.

For the cost-minimizing firm,

$$q^{\mathcal{MI}} = \sqrt{\frac{2\phi}{c_2}} \quad \text{and} \quad \Pi^{\mathcal{MI}} = \frac{2(b+c_2)}{c_2}\sqrt{\phi}\left(\sqrt{\phi^c}-\sqrt{\phi}\right)$$

these values are well defined for $0 \leq \phi \leq \phi^c$.

Finally the value of ϕ^* is

$$\phi^* = \frac{c_2(a-c_1)^2}{2(2b+c_2)^2}$$

Figure 1 depicts the different quantities as functions of ϕ. The cost-taking quantity, $q_H^{\mathcal{AC}}$, is the dark blue decreasing curve. For $0 \leq \phi \leq \phi^*$, it is larger than the rational quantity q^m. Consumers are better off with this type of behavioral firm than with a rational firm. For this example, when ϕ is close enough to zero, then $q_H^{\mathcal{AC}}$ is even larger than q^c. Meaning that from the welfare point of view the cost-taking inefficiently produces too much.

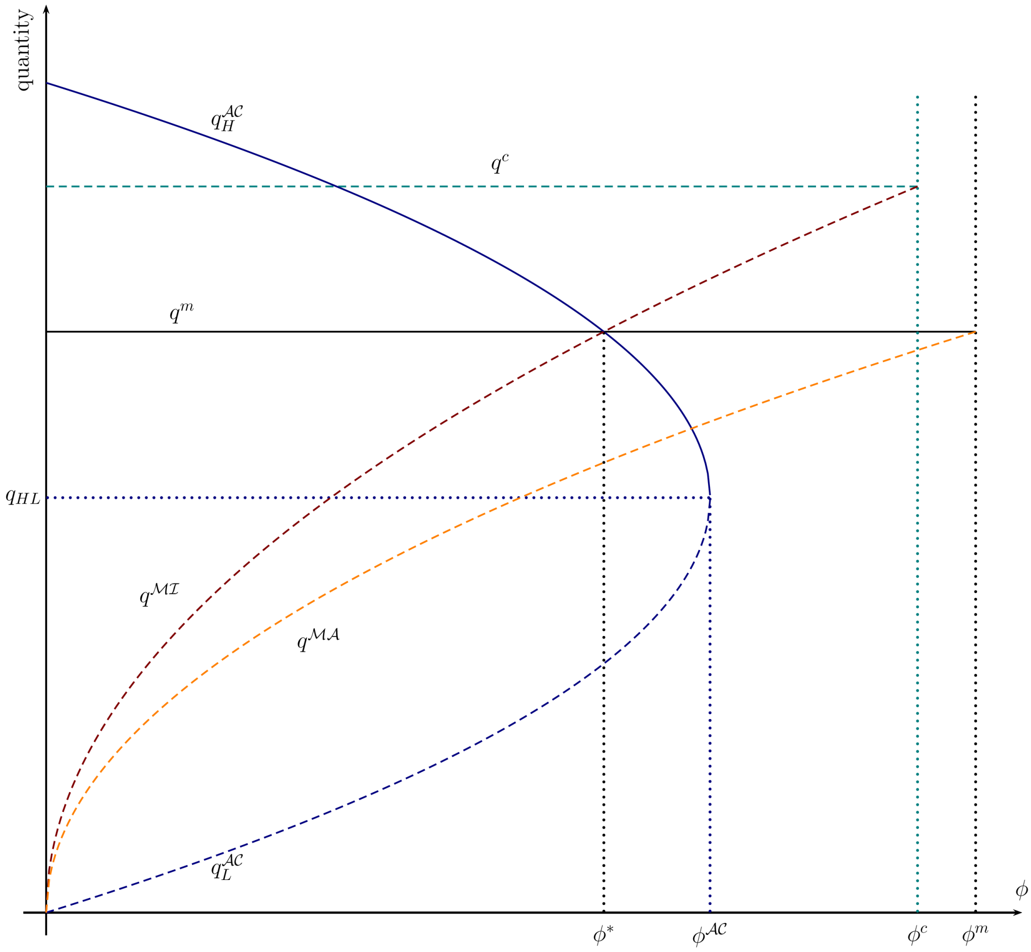

Figure 1: Quantities: Comparative static on ϕ, for $a = 64$, $b = 1$, $c_1 = 0$, and $c_2 = 3$.

The market is profitable for $0 \leq \phi \leq \phi^m$. Yet, only q^m and the margin-maximizing quantity remain positive up to $\phi = \phi^m$. The other quantities collapse for some values of ϕ. The optimal quantity and the cost-minimizing quantity collapse when $\phi = \phi^c$. Finally, both cost-taking quantities collapse at $\phi = \phi^{\mathcal{AC}}$.

Notice that for the parameter values of Figure 1 and 2, we have $\phi^{\mathcal{AC}} < \phi^c$. This is not always the case, however. It is readily confirmed that if $c_2 < b/2$ then $\phi^c < \phi^{\mathcal{AC}}$ (in fact $\phi^c \to 0$ when $c_2 \to 0$). Whereas $\phi^{\mathcal{AC}} < \phi^c$ when $b/2 < c_2$.

Figure 2 complements Figure 1 by plotting the equilibrium profits as functions of ϕ. The rational profit is linear in ϕ as well as the price-taking-firm profit. It underlines that around $\phi = \phi^*$ the three profits π^m, $\pi_H^{\mathcal{AC}}$, and $\pi^{\mathcal{MI}}$ are very close. Whereas for the largest values of ϕ, only $\pi^{\mathcal{MA}}$ and π^m are positive and they are very close.

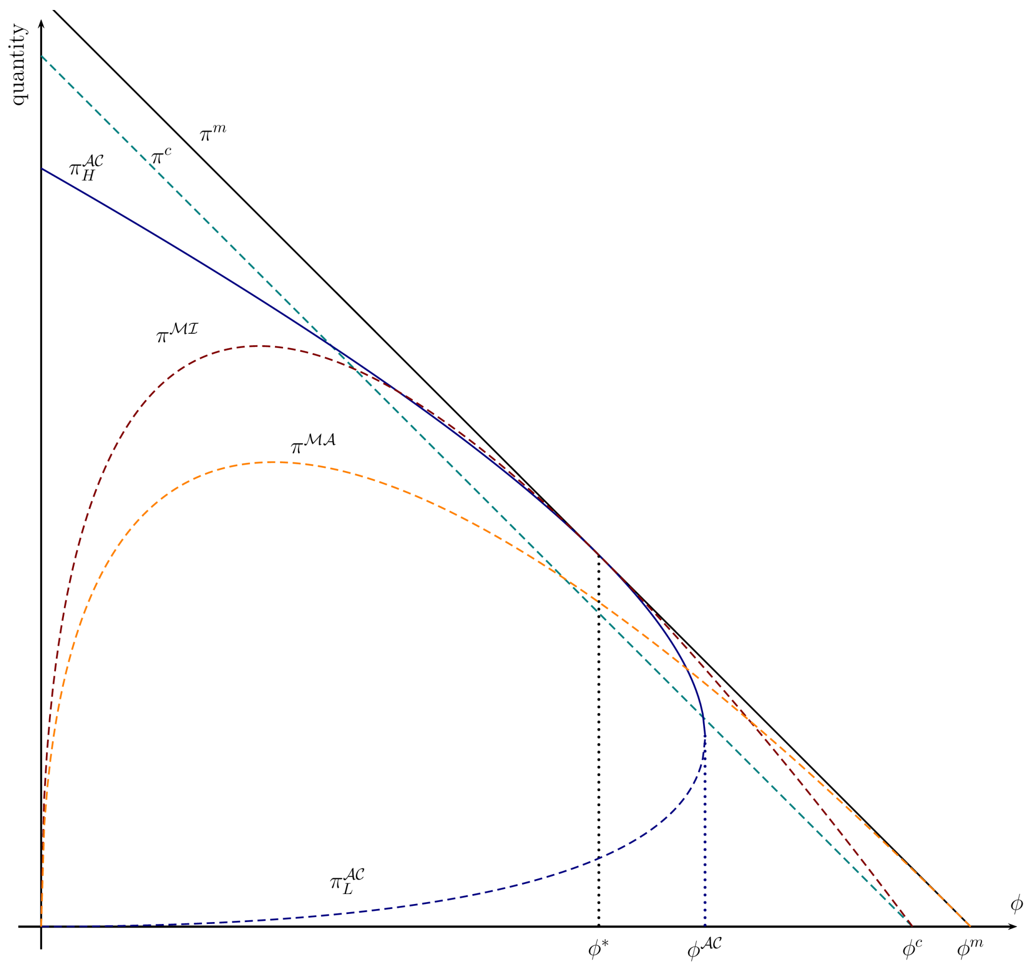

Figure 2: Profits: Comparative static on ϕ, for $a = 64$, $b = 1$, $c_1 = 0$, and $c_2 = 3$.

5 Long term view of the cost function

Whereas technology is given in the short run, with time a firm should be able to duplicate it in order to produce more efficiently. In this section, we show that in a longer run, our behavioral firm makes the same choices as a rational one. At first, this result might seems surprising. However the intuition is fairly simple. In the long run, a rational firm produces at the minimum of the average cost function. Thus behaving as our behavioral firm. It remains to show that both type of firms follow the same investment strategy.

Let assume that the firm can build 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 firm to produce Q/n in every plant. Integer issues are neglected and n is treated as a continuous variable. 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

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

Proposition 4. *In the long run, both the rational and the cost-taking firm invest in the same number of plants and produce the same quantity, thus achieve the same profit.*

Proof. The rational firm would thus choose n and Q to maximize $\Pi^{\mathcal{O}}(Q\,;\phi,n) = P(Q)Q - \mathcal{TC}(Q\,;\phi,n)$ leading to the f.o.c.:

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

these conditions hold whether the choice of n and Q are simultaneous or sequential. Let n^{LT} and Q^{LT} denote the rational firm's long term choices. Given (6) the second f.o.c. writes $Q^{LT}/n^{LT} = q^{\mathcal{MI}}$ and the first one is $MR(Q^{LT}) = C'(q^{\mathcal{MI}})$. The long term quantity is chosen as if the firm had a constant marginal cost equal to $C'(q^{\mathcal{MI}})$. We assume (for simplicity) that q^m (and therefore $q_H^{\mathcal{AC}}$) is larger than Q^{LT}, ensuring that it is optimal to build more than one plant.

As $MR(Q^{LT}) = AC\left(Q^{LT}/n^{LT};\phi\right) = \mathcal{AC}(Q^{LT};\phi,n^{LT})$, the quantity Q^{LT} is a misspecification equilibrium quantity for a cost-taking firm with n^{LT} factories. The question is then: Would such a behavioral firm build this number of plants? As such a firm has a wrong belief about the profit function, it is, at first sight, more difficult to model how it should anticipate future behavioral profits. To circumvent the difficulty, we assume the firm follow an iterative process where the firm is divided into a marketing unit and a production unit. Both behave myopically.

Starting with $n_0 = 1$ (one plant), the cost-taking marketing unit produces $Q_1 = q_H^{\mathcal{AC}}$ defined by (4). Next, the production unit takes for granted this quantity and choose a number n_1 of plants to minimize the total cost of production: $\mathcal{TC}(Q_1; \phi, n)$. That is n_1 such that $C'(Q_1/n) = AC\left(Q_1/n\,; \phi\right)$. Therefore $n_1 = Q_1/q^{\mathcal{MI}}$, which is larger than 1 under the assumption $q_H^{\mathcal{AC}} > q^{\mathcal{MI}}$. The process then starts again with the quantity choice by the marketing unit but this time for an average cost function $\mathcal{AC}(Q\,; \phi, n_1)$.

This defines a sequence Q_t such that $Q_1 = q_H^{\mathcal{AC}}$ and Q_t is the largest root of

$$MR(Q_t) = \mathcal{AC}(Q_t; \phi, n_{t-1}) = AC(\frac{Q_t}{n_{t-1}}; \phi) = AC(\frac{Q_t}{Q_{t-1}} q^{\mathcal{MI}}; \phi)$$

In consequence, the sequence Q_t (resp. n_t) is increasing and converges to Q^{LT} (resp. n^{LT}). To show that Q_t is increasing, remark that the function $\mathcal{AC}(Q; \phi, n_{t-1})$ is by construction minimal for $Q = Q_{t-1}$, increasing for $Q > Q_{t-1}$, and such that $MR(Q_{t-1}) > \mathcal{AC}(Q_{t-1}; \phi, n_{t-1})$. □

6 Variants and extensions

The previous behavioral models were based on a particular misspecification: either the market constraint or the technological constraint was not understood. Many variants are possible and we present a few here.

6.1 Average-variable-cost and average-fixed-cost

It is instructive to distinguish in the unit-cost, the role played by the average-variable-cost, $C(q)/q$ from the one played by the average-fixed-cost ϕ/q. For that purpose, assume first, that the firm understand the technological constraint for the former but not the latter. Then the misspecified profit writes

$$\Pi^{\mathcal{S}}\left(q\,; \theta\right) = \left(P(q) - \frac{C(q)}{q} - \frac{\phi}{\theta}\right) q \;\text{ with } \theta \in \left[\underline{q}, \overline{q}\right] . \tag{9}$$

Consequently, the misspecification equilibrium quantity is given by $\theta^{\mathcal{S}} = q^{\mathcal{S}}$ and

$$MR(q^{\mathcal{S}}) = C'(q^{\mathcal{S}}) + \frac{\phi}{q^{\mathcal{S}}} \tag{10}$$

which always leads to quantities smaller than q^m and also smaller than $q_H^{\mathcal{AC}}$ (because for C convex, $C(q)/q$ is smaller than $C'(q)$). This emphasizes that in the model of the cost-taking firm, the average-fixed-cost-taking part always pushes to a lower quantity (compared to the choice of the rational firm) and a higher price. Neglecting that the average-fixed-cost decreases with the quantity unambiguously leads to a higher price. It is also readily confirmed that the largest root of (10) is decreasing with ϕ a desirable property of full-cost-pricing, at least from an intuitive point of view.

At the other extreme, the firm could perfectly understand how the average-fixed-cost varies with q but wrongly believe that the average-variable-cost is constant. Leading to

$$\Pi^{\mathcal{S}}\left(q\,;\theta\right) = \left(P(q) - \frac{C(\theta)}{\theta} - \frac{\phi}{q}\right) q \;\text{ with } \theta \in \left[\underline{q}, \overline{q}\right] , \tag{11}$$

and therefore a misspecification equilibrium quantity given by $\theta^{\mathcal{S}} = q^{\mathcal{S}}$ and

$$MR(q^{\mathcal{S}}) = \frac{C(q^{\mathcal{S}})}{q^{\mathcal{S}}} \,. \tag{12}$$

This quantity is always larger, because $C(q)/q < C'(q)$, than the rational quantity and it is invariant with ϕ. In the model of the cost-taking firm, these two forces are combined which explains why $q_H^{\mathcal{AC}}$ can be larger or smaller than q^m.

6.2 More parameters

Similar results as the ones for the cost-taking firm are obtained for the following family of misspecified profit functions. Let $\theta = (\theta_0, \theta_1)$ and

$$\Pi^{\mathcal{S}}\left(q\,;\theta\right) = \left(P(q) - AC(\theta_1\,;\phi)\right) q - \theta_0$$

The firm behaves as if it had a fixed cost θ_0 and a constant marginal cost $C'(\theta_1)$. It is readily confirmed that a misspecification equilibrium obtains when

$$MR(q) = AC(q\,;\phi - \theta_0).$$

A condition similar to the one obtained for the cost-taking firm. The condition is exactly the same for $\theta_0 = 0$. For other values of θ_0 the equilibrium as the same flavor but the interpretation slightly differs. In particular, if $\theta_0 = \phi$ (no misspecification of the fixed cost), then the equilibrium quantity is defined by $MR(q) = C(q)/q$.

The main advantage of the introduction of a second parameter θ_0 is that now, the equilibrium exists for all $0 \le \phi \le \phi^m$.

6.3 De/Inflating the true cost function

Let assume, that the firm de/inflates its true marginal cost by a constant because it is difficult to assess if some costs are fixed or variable.[14] In this spirit, the misspecified

[14] This is what Al-Najjar, Baliga, and Besanko (2008) do, yet in a different context. Moreover, they restrict their analysis to the case where $C(q) = cq$.

profit writes

$$\Pi^{\mathcal{S}}\left(q\,;\theta\right)=\left(P(q)-\frac{C(q)}{q}-\theta_1-\frac{\theta_0}{q}\right)q \;\text{ with } \theta\in\left[\underline{q},\overline{q}\right]. \tag{13}$$

Consequently, the misspecification equilibrium quantity is given by $\theta_1^{\mathcal{S}}q^{\mathcal{S}}+\theta_0=\phi$ (where θ_0 is simply kept as an exogenous parameter) and

$$MR(q^{\mathcal{S}})=C'(q^{\mathcal{S}})+\frac{\phi-\theta_0}{q^{\mathcal{S}}} \tag{14}$$

which is very close to (10). When $\phi-\theta_0>0$ (the intuitive case), then $q^{\mathcal{S}}<q^m$. The marginal cost is inflated which leads to a lower quantity and a higher price. On the contrary, if $\phi-\theta_0<0$ (a less intuitive case), then $q^{\mathcal{S}}>q^m$. The marginal cost is deflated which leads to a higher quantity and a lower price.

A firm would not distort its production choice and would produce the rational quantity only if $\theta_0=\phi$ (which in this context amounts to assume that the firm is rational).

6.4 Pass-through

Let assume the variable cost function increases with a parameter γ: $C(q;\gamma)$. A first question is how does the cost pass-through varies with the fixed cost ϕ? That is what is the sign of $\partial^2 q_H^{\mathcal{AC}}/\partial\gamma\partial\phi$?

Proposition 5. *For the cost-taking firm,*

$$\frac{\partial q_H^{\mathcal{AC}}}{\partial\gamma}<0\;,\;\frac{\partial q_H^{\mathcal{AC}}}{\partial\phi}<0\;,\;\frac{\partial^2 q_H^{\mathcal{AC}}}{\partial\phi^2}<0\;\;\textit{and}$$

$$\frac{\partial^2 q_H^{\mathcal{AC}}}{\partial\gamma\partial\phi}=\frac{\partial C'(q_H^{\mathcal{AC}}\,;\gamma)}{\partial\gamma}\left(\frac{\partial q_H^{\mathcal{AC}}}{\partial\phi}\right)^2+\frac{\partial C(q_H^{\mathcal{AC}}\,;\gamma)}{\partial\gamma}\frac{\partial^2 q_H^{\mathcal{AC}}q}{\partial\phi^2} \tag{15}$$

Proof. See Appendix D □

The first term on the right-hand-side of (15) is positive whether the second term is negative. In our parametric example, assuming further that $C(q;\gamma)=C(q)+\gamma q$ or $C(q;\gamma)=(1+\gamma)C(q)$, the negative term dominates meaning that an increase of γ leads to a larger increase of the price (i.e. a larger pass-through) when ϕ is larger. In Altomonte, Barattieri, and Basu (2015) (see their section 3.2), they find empirically that the pass-through is lower in industry where ϕ/q is larger.

Another question is the comparison of the pass-through of the rational firm and the one of the behavioral firm. A priori q^m and $q_H^{\mathcal{AC}}$ are different which complicates the interpretation of these equations. However, in the long run (as well as for $\phi=\phi^*$) we have seen that $q^m=q_H^{\mathcal{AC}}$ which allows us to derive the following proposition.

Proposition 6. *Assume that both the cost-taking and rational firms 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 firm reacts more to a shock on the cost function than a rational one.*

Proof. See Appendix E

□

7 Conclusion

A natural extension of our models is the inclusion of competition. This is all the more natural that the Berk-Nash approach of Esponda and Pouzo (2016) is build for several players. Although we are confident that it is possible to extend our work in that direction, that would include additional strategic reasons not to maximize the objective profit function. Indeed, building on the logic of Brander and Spencer (1985) and Eaton and Grossman (1986),[15] a number of papers showed that, in an oligopoly context, firms have an incentive to inflate internal transfer prices. That is, firms organize within themselves a vertical structure where a production center sell for a transfer price the good to a marketing division which sells to final consumers. In such a context, 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) develop a model where firms' total costs of production have two parts: a constant marginal cost and a fixed cost. They assume firms have a distorted view of these costs leading to inflate marginal cost by an exogenous amount. Firms maximize (the framework is one of reinforcement learning rather than Berk-Nash) their profits using this inflated marginal cost they are assumed to be boundedly rational players following an adaptive pricing process. The main result is that in a world of price competition and differentiated products, firms benefit from basing their pricing decision on an inflated marginal cost.

[15]See also Katz (1991). In these seminal articles, two countries (one firm per country) compete for a market in a third country. Governments subsidize or tax exports in order to help their national firm. Under Cournot competition, Brander and Spencer show that subsidies are optimal but that they deteriorate the welfare of the exporting countries. The subsidy game is like a prisoner dilemma. By contrast, under Bertrand competition (with differentiated goods) Eaton and Grossman show that taxes are optimal and that they improve the welfare of the exporting countries.

APPENDIX

A Solutions of (4) and proof of Lemma 2

Number of solutions Equation (4) writes:

$$qP(q) = (-P'(q))q^2 + C(q) + \phi$$

The left-hand-side is the revenue function $qP(q)$ which is assumed to be a concave function of q (i.e. $qP''(q)/P'(q) \geq -2$), a common assumption is the IO literature. Let

$$H(q) + \phi = (-P'(q))q^2 + C(q) + \phi \tag{16}$$

denote the right-hand-side which is like a cost function. It is readily confirmed that H is increasing with q as

$$H'(q) = C'(q) + (-qP'(q))\,(2 + qP''(q)/P'(q)) > 0$$

The functions $qP(q)$ and $H(q)+\phi$ intersect at most twice as long as H is everywhere less concave than the revenue $qP(q)$ which is our assumption throughout. As the convexity of C tends to make H convex, our assumption is certainly intuitive. It trivially holds for a linear demand or for a constant elasticity function $P(q) = q^{-\sigma}$ with $0 < \sigma < 1$ (the usual assumption on σ for an inverse demand function).

Existence Even under the above assumption on H, (4) has no solution if ϕ is too large. The limit case is characterized by both $MR(q) = AC(q\,;\phi)$ and $MR'(q) = AC'(q\,;\phi)$ when the two curves intersect at a tangency point. Using $AC'(q\,;\phi) = (C'(q) - AC(q\,;\phi))\,/q$ the two conditions imply that

$$MR(q) + qMR'(q) = C'(q)$$

that is, q is q^{dm} the double marginalization quantity (notice that q^{dm} is independent of ϕ).[16] Let $\phi^{\mathcal{AC}}$ denote the value of ϕ such that $q_H^{\mathcal{AC}} = q_L^{\mathcal{AC}} = q^{dm}$. The upstream firm profit net of the fixed cost is $(MR(q) - AC(q\,;\phi)q$ and therefore is zero at this point. Thus $\phi^{\mathcal{AC}} = MR(q^{dm})q^{dm} - C(q^{dm})$. The profit of the cost-taking firm, however, is $(P(q) - AC(q\,;\phi)q$ which means that it is positive for $\phi = \phi^{\mathcal{AC}}$.

[16] In a chain of monopolies, it is as if the demand of the upstream firm is $MR(q)$.

B Proof of Proposition 1

Only for the cost-taking firm is the comparative statics with respect to ϕ not straightforward. Using Differentiating $qP(q) = H(q) + \phi$ with respect to ϕ gives:

$$[MR(q) - H'(q)] \frac{\partial q}{\partial \phi} = 1$$

as $MR(q_L^{\mathcal{AC}}) - H'(q_L^{\mathcal{AC}}) > 0$ a $MR(q_H^{\mathcal{AC}}) - H'(q_H^{\mathcal{AC}}) < 0$ it follows that $q_L^{\mathcal{AC}}$ increases and $q_H^{\mathcal{AC}}$ decreases with ϕ. It is straightforward to show that $q_L^{\mathcal{AC}}$ is always lower that q^m whereas $q_H^{\mathcal{AC}}$ is larger than q^m if ϕ is small enough.

Rewriting (4) as:

$$qP(q) - C(q) - \phi = (-P'(q))q^2$$

and given that $qP''(q)/P'(q) \geq -2$ implies $(-P'(q))q^2$ increases with q it is immediate that the profit for $q_H^{\mathcal{AC}}$ is larger than the profit for $q_L^{\mathcal{AC}}$.

C Proof of Proposition 3

The derivative of $(MR)^{-1}(AC(q\,;\phi))$ is $AC'(q\,;\phi)/MR'(q)$ for $q = q_L^{\mathcal{AC}}$ or $q = q_H^{\mathcal{AC}}$. When $q = q_L^{\mathcal{AC}}$, $AC'(q_L^{\mathcal{AC}}\,;\phi) < MR'(q_L^{\mathcal{AC}}) < 0$ and thus $\left|\frac{AC'(q_L^{\mathcal{AC}}\,;\phi)}{MR'(q_L^{\mathcal{AC}})}\right| > 1$ and $q_L^{\mathcal{AC}}$ is non-stable.

On the contrary, when $q_H^{\mathcal{AC}} \leq q^m$ then $MR'(q_H^{\mathcal{AC}}) < AC'(q_H^{\mathcal{AC}}\,;\phi) < 0$ and $q_H^{\mathcal{AC}}$ is locally stable.

When $q^m < q_H^{\mathcal{AC}}$ then $MR'(q_H^{\mathcal{AC}}) < 0 < AC'(q_H^{\mathcal{AC}}\,;\phi)$ and $q_H^{\mathcal{AC}}$ is locally stable if

$$AC'(q_H^{\mathcal{AC}}\,;\phi) < \left|MR'(q_H^{\mathcal{AC}})\right|$$

As the slope of MR' could be arbitrarily close to zero, this condition cannot hold for all demand functions. Yet, let $\varepsilon > 0$ such that for all q, $|MR'(q)| > \varepsilon > 0$, if $q_H^{\mathcal{AC}}$ is close enough to $q^{\mathcal{MI}}$ (which happens when ϕ is close enough to ϕ^*) then $AC'(q_H^{\mathcal{AC}}\,;\phi)$ is arbitrarily close to zero and therefore $AC'(q_H^{\mathcal{AC}}\,;\phi) < \varepsilon < \left|MR'(q_H^{\mathcal{AC}})\right|$ ensuring the local stability property.

Otherwise, using $AC(q_H^{\mathcal{AC}}\,;\phi) = MR(q_H^{\mathcal{AC}})$ it is readily confirmed that for $q = q_H^{\mathcal{AC}}$:

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

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

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

therefore the condition $qP''(q)/P'(q) > -1$ ensures that the stability ratio is lower than one even in the neighborhood of q^c. This condition is stronger than the usual $qP''(q)/P'(q) > -2$ (which ensures the concavity of the revenue function).

D Proof of Proposition 5

The quantity $q_H^{\mathcal{AC}}$ is characterized by

$$MR(q) = AC(q\,;\gamma,\phi) \text{ as in Appendix A, it writes } R(q) = H(q\,;\gamma) + \phi \tag{17}$$

with

$$H(q\,;\gamma) + \phi = (-P'(q))q^2 + C(q\,;\gamma) + \phi$$

which behaves like a cost function. In the following we use the notation $H'(q\,;\gamma) = \partial H(q\,;\gamma)/\partial q$, and similarly for C'. Differentiating once w.r.t. ϕ gives

$$\frac{\partial q}{\partial \phi}\left(R'(q) - H'(q\,;\gamma)\right) = 1 \tag{18}$$

Differentiating (18) w.r.t. ϕ establishes

$$\frac{\partial^2 q}{\partial \phi^2}\left(R'(q) - H'(q\,;\gamma)\right) + \left(\frac{\partial q}{\partial \phi}\right)^2 \left(R''(q) - H''(q\,;\gamma)\right) = 0$$

thus $\frac{\partial^2 q_H^{\mathcal{AC}}}{\partial \phi^2} < 0$, using that for $q = q_H^{\mathcal{AC}}$, $R' - H' < 0$ and under the general assumption that $R'' - H'' < 0$.

Similarly, differentiating (17) once w.r.t. γ

$$\frac{\partial q}{\partial \gamma}\left(R'(q) - H'(q\,;\gamma)\right) = \frac{\partial H(q\,;\gamma)}{\partial \gamma} = \frac{\partial C(q\,;\gamma)}{\partial \gamma} \tag{19}$$

Combining (18) and (19) leads to (still for $q = q_H^{\mathcal{AC}}$)

$$\frac{\partial q}{\partial \gamma} = \frac{\partial C(q\,;\gamma)}{\partial \gamma}\frac{\partial q}{\partial \phi} \tag{20}$$

Differentiating (20) w.r.t. ϕ gives

$$\frac{\partial^2 q}{\partial \gamma \partial \phi} = \frac{\partial C'(q\,;\gamma)}{\partial \gamma}\left(\frac{\partial q}{\partial \phi}\right)^2 + \frac{\partial C(q\,;\gamma)}{\partial \gamma}\frac{\partial^2 q}{\partial \phi^2} \tag{21}$$

Differentiating (18) w.r.t. ϕ establishes that $\frac{\partial^2 q}{\partial \phi^2} < 0$.

E Proof of Proposition 6

For a rational firm, 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 cost-taking firm, the equilibrium condition is (ignoring in the notation the dependence of AC on ϕ)

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

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

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

Now, we have assumed that $q^m = q_H^{\mathcal{AC}}$ and $AC'(q_H^{\mathcal{AC}};\gamma) = 0$, i.e. both type of firms produce at the minimum of the average cost, see Section 5. Moreover, if $C(q;\gamma) = C(q) + \gamma q$, then $\frac{\partial C(q_H^{\mathcal{AC}};\gamma)/q_H^{\mathcal{AC}}}{\partial \gamma} = 1$ and $\frac{\partial C'(q^m;\gamma)}{\partial \gamma} = 1$ also. Therefore

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

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 $\frac{\partial C'(q^m;\gamma)}{\partial \gamma} = C'(q^m;\gamma)$, and the same result follows.

In the general case:

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

The intuition is that if the cost shift influences more the average cost than the marginal cost, i.e. $\frac{\partial C(q_H^{\mathcal{AC}};\gamma)/q_H^{\mathcal{AC}}}{\partial \gamma} > \frac{\partial C'(q^m;\gamma)}{\partial \gamma}$ then the cost-taking firm 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 $q_H^{\mathcal{AC}} - \varepsilon$. In that case the behavioral firm would not react at all while the rational one would.

F Bayesian learning

We now account for shocks affecting the firm cost function, incorporating such costs within the framework of Esponda and Pouzo (2016). We assume a constant marginal cost c. While the fixed cost ϕ is deterministic, the marginal cost c is drawn from the normal distribution with mean $\bar{c}$ and variance 1, or

$$c = \bar{c} + \omega,$$

where the cost shock ω is drawn from the standard normal distribution. The true data generating process, or "objective model", for the average cost function is thus

$$AC^{\mathcal{O}}(q;\phi) = \bar{c} + \omega + \frac{\phi}{q}.$$

The behavioral firm believes that the average cost follows the Gaussian distribution of mean θ and variance 1. The subjective, misspecified model is thus

$$AC^{\mathcal{S}}(q;\phi \,|\, \theta) = \theta + \varepsilon,$$

where ε is drawn from the standard normal distribution. The firm chooses quantity q, observes the realized average cost $AC(q;\phi)$ after it has been affected by the shock ω, and infers θ from that observation.

The Berk-Nash equilibrium (θ^*, q^*) is defined by two conditions. First, the firm belief θ^* minimizes the Kullback-Leibler divergence between the objective and subjective models, i.e.

$$\theta^* = \operatorname{argmin}_\theta \, \mathbb{E}_\omega \ln \frac{\varphi\left[AC^{\mathcal{O}}(q^*;\phi) - \bar{c} - \phi/q^*\right]}{\varphi\left[AC^{\mathcal{O}}(q^*;\phi) - \theta\right]}, \tag{22}$$

where φ denotes the density function of the standard normal distribution.[17] Second, the firm optimally chooses output given its belief:

$$q^* = \operatorname{argmax}_q \, \mathbb{E}_\varepsilon \left[P(q)q - AC^{\mathcal{S}}(q;\phi \,|\, \theta^*)q\right]. \tag{23}$$

In this particular context, the minimization problem (22) is simple because $\ln \varphi\left[AC^{\mathcal{O}}(q^*;\phi) - \bar{c} - \phi/q^*\right]$ does not depend on θ. Hence the problem boils down to

$$\theta^* = \operatorname{argmax}_\theta \, \mathbb{E}_\omega \ln \varphi\left[AC^{\mathcal{O}}(q^*;\phi) - \theta\right] = \operatorname{argmin}_\theta \, \mathbb{E}_\omega \left[\bar{c} + \omega + \frac{\phi}{q^*} - \theta\right]^2 = 1 + \left[\bar{c} + \frac{\phi}{q^*} - \theta\right]^2.$$

It follows that θ^* is given by

$$\theta^* = \bar{c} + \frac{\phi}{q^*}. \tag{24}$$

[17]The numerator is the true likelihood of the average cost, while the denominator is the subjective likelihood that reflects the firm belief.

The quantity choice in (23) is equally simple as the firm objective is linear in average cost:

$$q^* = \text{argmax}_q \; P(q)q - \theta^* q,$$

hence

$$MR(q^*) = \theta^*. \tag{25}$$

Equations (24) and (25), which characterizes the Berk-Nash equilibrium, are the same as (4) in section 3.2.

Esponda and Pouzo (2016) show that the above equilibrium can be achieved as the result of a learning process where a Bayesian firm at each period myopically maximizes its profit and then updates its belief about its average production cost. Specifically, let μ_0 be the firm's prior belief about θ at date 0. Consider an iid sequence of cost shocks $(\omega_t)_{t\geq 0}$ drawn from the standard normal distribution. Let q_t be the outcome produced at date t, $t \geq 0$. For $t \geq 1$, the firm beliefs at the beginning of period t are described by the posterior distribution μ_t which, by Bayes rule, is proportional to

$$\mu_t(\theta) \propto \mu_0(\theta) \prod_{n=0}^{t-1} \varphi\left[AC^{\mathcal{O}}(q_n;\phi) - \theta\right].$$

At date t, the firm chooses output q_t to maximize its current profit

$$q_t = \text{argmax}_q \mathbb{E}_{\mu_t} \; [qP(q) - \theta q]$$

hence

$$MR(q_t) = \mathbb{E}_{\mu_t}\theta$$

Esponda and Pouzo (2016) demonstrate that the quantity q_t tends to q^* and the posterior distribution μ_t tends to the mass point at θ^* as t tends to infinity, where (q^*, θ^*) form a Berk-Nash defined by (24) and (25).

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