

We're Number 1: Price Wars for Market Share Leadership Appendix

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In this appendix, I consider various extensions of the basic model presented in the main text.

A. Demand driven #1 effects

In the main text I considered the case when managers derive extra utility from being market leaders; but an equally compelling observation is that consumers enjoy purchasing from a market leader. According to Simon (2009),

Some companies use their world market leadership as an advertising message. For example, Wanzl, the worldwide leader for shopping carts, says, “The size of a world market leader creates security.” Being the biggest, the first or the best has always been an effective advertising message.

Consumer #1 effects may result from a rational Bayesian process (Caminal and Vives, 1996) or simply because it's less risky to buy from a market leader: as the saying goes, “no one ever got fired for buying IBM” (that is, when IBM was a clear market leader). Consistent with this view, recent research suggests that demand responds to ordinal rankings in the case of books (Sorensen (2007)), iPhone apps (Carare (2012)) and movies (Cabral and Natividad

(2013)).¹

I now extend the model to consider the possibility that consumers benefit from purchasing from the market leader. Specifically, I assume an additional term in consumer utility from buying from firm i given by $\lambda \Delta(i)$, where $\lambda \geq 0$ and $\Delta(i)$ is defined as before, that is, $\Delta(i) = 1$ if $i > j$, $\Delta(i) = -1$ if $i < j$, and $\Delta(i) = 0$ if $i = j$.

At state i , an active consumer chooses firm i if and only if

$$\zeta_i + \lambda \Delta(i) - p(i) > \zeta_j + \lambda \Delta(j) - p(j) \quad (21)$$

or simply

$$\xi_i \equiv \zeta_i - \zeta_j > x(i)$$

where

$$x(i) \equiv p(i) - p(j) - \lambda \Delta(i) + \lambda \Delta(j) \quad (22)$$

As before, my focus is on the equilibrium price function, as well as the resulting probability of a sale and stationary distribution of market shares. Suppose that $\theta = 0$, that is, firms do not derive any special direct benefit from being the market leader.

Proposition 5. *Suppose that $\theta = \psi = 0$, whereas $\lambda > 0$. There exists a unique equilibrium in the neighborhood of $\delta = 0$. Moreover,*

$$\lim_{\delta \rightarrow 0} q(i) = \begin{cases} 1 - q' & \text{if } i < i^* \\ 1 - q' < q(i) < q' & \text{if } i = i^* \\ q' & \text{if } i > i^* \end{cases}$$

$$\lim_{\delta \rightarrow 0} p(i) = \begin{cases} p' & \text{if } i < i^* \\ p' < p(i) < p'' & \text{if } i = i^* \\ p'' & \text{if } i > i^* \end{cases}$$

where $q' > \frac{1}{2}$ and $p' < \frac{1}{2\phi(0)} < p''$. Finally, if λ is large enough then the stationary distribution of market shares is bimodal.

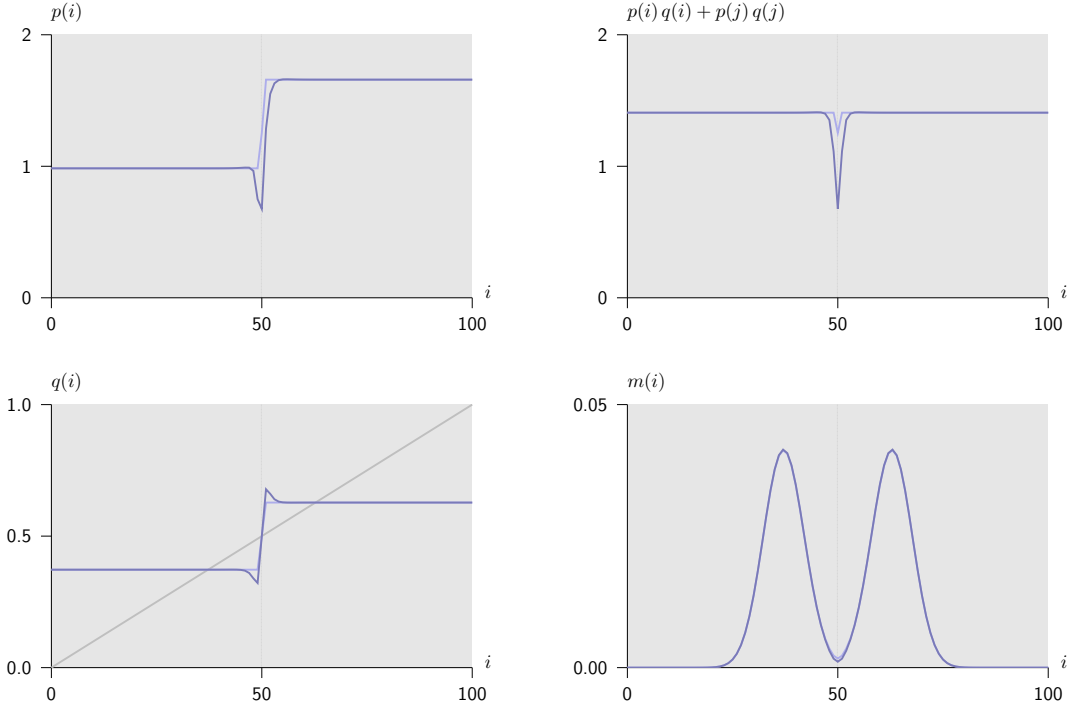
Proof of Proposition 5: Suppose that $\delta = 0$. Since $\theta = 0$, (7) becomes

$$w(i) = 0$$

1. At a theoretical level, Caminal and Vives (1996) provide a Bayesian foundation for an equilibrium where market shares signal quality, and thus consumers are willing to pay more for products with greater market share. However, they do not explain why there would be ordinal effects. Glenn Ellison has suggested a reason why ordinal effects may be present. Suppose that consumers have no initial information about product quality and try products sequentially (at a cost) until they find something they are happy with. To the extent that there is some correlation across consumer preferences, consumers strictly prefer to start with the leading product, thus creating an ordinal effect in market demand.

Figure 7

Equilibrium when $\lambda=5$ and $\delta = 0$ (lighter lines) or $\delta = 0.7$ (darker lines). (In both cases $\theta = 0$.)



Noting that $\lambda \Delta(i) - \lambda \Delta(j) = 2 \lambda \Delta(i)$, (13) may be re-written as

$$x(i) + \frac{2 \Phi(x(i)) - 1}{\phi(x(i))} = -2 \lambda \Delta(i)$$

where the left-hand side is increasing in $x(i)$ and equal to zero if $x(i) = 0$ (see the proof of Lemma 1. Let x' be the solution of the above equation when $i > i^*$, so that the right hand side equals -2λ ; and let $q' \equiv 1 - \Phi(x')$. The results for $q(i)$ and $p(i)$ then follow.

Finally, from Lemma 2, we know that

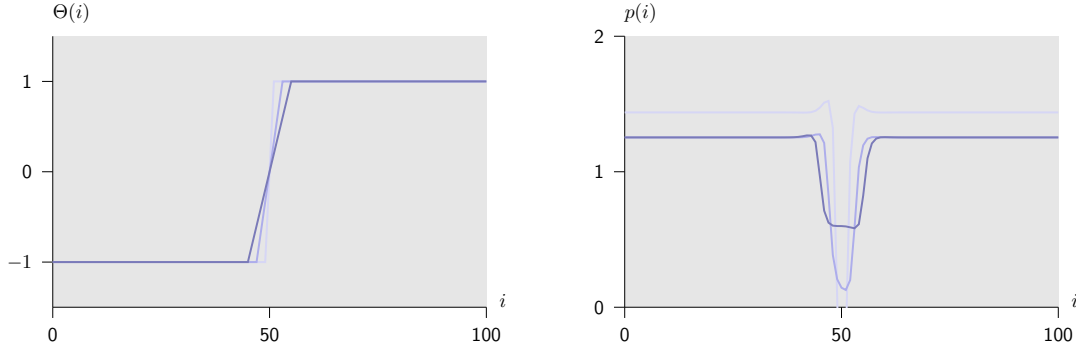
$$M(i-1, i) m(i-1) = M(i, i-1) m(i)$$

As $\lambda \rightarrow \infty$, $q(i^* - 1) \rightarrow 0$ and $q(i^* + 1) \rightarrow 1$. This implies that $M(i^* - 1, i^*) \rightarrow 0$, whereas $M(i^*, i^* - 1) = \frac{1}{4}$ for all values of λ . This in turn implies that $m(i^*) < m(i^* \pm 1)$ for λ large enough. ■

Figure 7 illustrates Proposition 5. The price function no longer exhibits the “trenchy” pattern observed Proposition 3. Instead, the market leader, enjoying a preference in the

Figure 8

Effect on changing κ in the generalized #1 effect mapping. Left panel: market leadership benefit. Right panel: equilibrium price function. In both cases, lines are increasingly dark as κ increases from 2 to 6 to 10. Other parameter values: $\delta=.7$, $\theta=1$.



eyes of the consumer, is able to price higher than the laggard. Despite a higher price, the leader sells with a higher probability than the laggard, as shown in the bottom left panel of Figure 7. The top right panel shows that, similarly to the manager #1 effect case, average price, that is, $p(i)q(i) + p(j)q(j)$, is lower when the state is near the symmetric state i^* .

Finally, as the bottom right panel shows, equilibrium pricing results in a bi-modal stationary distribution of market shares. The idea is that the consumer’s preference for market leaders creates a self-reinforcing process whereby a leader, even if it enjoys a small lead, is able to sell with probability greater than 50% and thus cement its lead. If that lead becomes very large, then reversion to the mean dominates and the leader reduces its market share in expected terms. Together this implies a stationary distribution with modes strictly between 0 and 50% and between 50 and 100%, respectively.

Notice finally that, since $\theta = 0$, there is no divergence between the firm’s and the shareholders’ value: $v(i) = s(i)$. Both functions are increasing in market share: to the extent that consumers enjoy buying from the market leader, the market leader is able to set a higher price and sell with higher probability.

In sum, Proposition 5, together with Proposition 3, suggests that the effect of “the importance of being Number 1” depends on whether it’s buyers or sellers who care about relative firm position.

B. Alternative #1 effect mappings

How much do the results in Section 4 depend on the fact that market leadership is such a “discontinuous” mapping, that is, switches from $-\theta$ when $i < j$ to $+\theta$ when $i > j$? In order to address this question, I consider a general mapping $\Theta(i)$ whereby the benefits from market leadership ramp up from $-\theta$ to $+\theta$ as i increases from i' to i'' , where

$$\begin{aligned} i' &\equiv \frac{\eta - \kappa}{2} = i^* - \frac{\kappa}{2} \\ i'' &\equiv \frac{\eta + \kappa}{2} = i^* + \frac{\kappa}{2} \end{aligned}$$

Note that $\kappa = i'' - i'$ measures the width of the “price war” region, that is, the region of the state space where a firm transits from being a laggard to being a leader. The generalized market leadership benefit function is then given by

$$\Theta(i) = \begin{cases} -\theta & \text{if } i < i' \\ \left(-1 + 2 \frac{i-i'}{\kappa}\right) \theta & \text{if } i' \leq i \leq i'' \\ +\theta & \text{if } i > i'' \end{cases} \quad (23)$$

I will say that firm i is a market leader if $i \geq i''$ and a market follower if $i \leq i'$. The extreme $\kappa = 2$ corresponds to the case when a firm is a market leader even if its market share advantage is minimal. Higher values of κ correspond to more gradual transitions from laggard to leader.

The left panel in Figure 8 shows the $\Theta(i)$ mapping for three values of κ (specifically, $\kappa = 2, 6, 10$). The right panel, in turn, shows the equilibrium pricing function for each of these values of κ . As expected, a more gradual #1 effect mapping leads to lower price cuts that are spread over a wider region of the state space. In other words, the equilibrium pricing function is still “trenchy” but not in such a pronounced way as when $\kappa = 2$. In the limit when $\kappa = \eta$, there is no “trench” at all: the benefits from being a market “leader” (which are now, really, the benefits from a high market share) lead to uniformly lower prices.

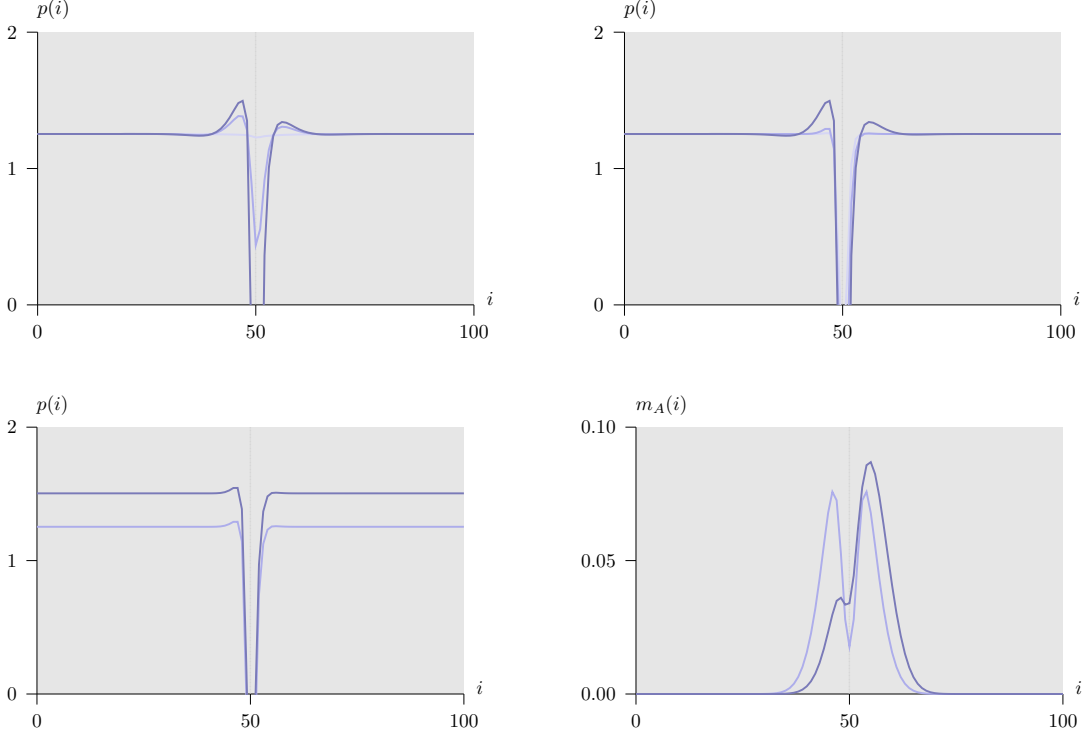
Although the mapping (23) generalizes my initial assumption regarding #1 effects, it is still subject to kinks at $i = i'$ and $i = i''$. However, my results are not dependent on this feature. To confirm this, I also tried a manager benefit function given by

$$\Theta(i) = \theta \left(\frac{1 - \exp(i^* - i)}{1 + \exp(i^* - i)} \right)$$

which basically corresponds to an S shaped curve that effectively smooths out the kinks in (23). The results for the equilibrium pricing function are very similar.

Figure 9

Comparative dynamics. Effects on equilibrium pricing of (a) $\theta=.01, .1, 1$ with $\delta=.9$ (top left panel); (b) $\delta=.5, .7, .9$ with $\theta=1$ (top right panel); (c) $\sigma=1,1.2$ (bottom left panel); and effect on stationary distribution of $\mu=0,0.25$ (bottom right panel). (Lines are increasingly dark as relevant parameter value increases).



C. Comparative dynamics

The two crucial parameters in my model are θ , the intensity of the #1 effect, and δ , the discount factor. How do my results depend on the precise value of these parameters? From the analysis in the previous section, one is led to suspect that the qualitative nature of the results is fairly robust. Figure 9 shows the equilibrium pricing function for different values of θ (top left panel) and δ (top right panel). I tried other values for these parameters and the general conclusion is that the shape of $p(i)$ varies “smoothly” with the θ and δ .

In my numerical simulations I assume that ξ is normally distributed with $\mu = 0$ and $\sigma = 1$. The bottom left panel in Figure 9 shows the effect of increasing σ . As expected, prices are uniformly higher as a result of an increase in σ , which effectively corresponds to an increase in product differentiation. In fact, in the limit as $\delta \rightarrow 0$, the equilibrium value of price in a “peace” state is given by $1/(2\phi(0))$, which in the normal ξ case is equal to $\sigma\sqrt{2\pi}/2$ (assuming that $\mu = 0$).

I also consider the case when $\mu \neq 0$. This implies that the model is not symmetric — even if both firms have the same value of θ . The bottom right panel of Figure 9 shows the effect of making $\mu > 0$, where I assume that a positive value of μ favors firm a . The stationary distribution of market shares is still bimodal. However, the mode corresponding to firm a being the large firm has greater density than the mode corresponding to firm b being the market leader.

To conclude this section, I show different simulations of price and market share dynamics for different model parameterizations. Figure 10 considers two alternative cases with respect to the case considered in Figure 5.² Specifically, the left panel considers the case when the #1 effect ramps up as market shares increase from 45 to 55% (as opposed to the base case, where a firm with 51% market share reaps the total market leadership benefit). The left panel in Figure 8 shows that the more gradual the #1 effect is, the wider the price war region — but also the shallower it is. The left panel in Figure 10 confirms this prediction in terms of actual price dynamics: longer price wars take place in equilibrium. This particular panel also shows a very high correlation between firm a and firm b prices.

The right panel in Figure 10 depicts the case when there are no firm level #1 effects ($\theta = 0$), but instead there are consumer level #1 effects ($\lambda > 0$). One first important difference is that firm prices are quite different, with the leading firm charging a higher price and the laggard firm charging a lower price. A second important difference is that a price war consists of a convergence of the two firms' prices (with the high-price firm leading the price shift). The particular simulation shown in the right panel in Figure 10 suggests that these price wars are significantly less frequent and less pronounced than in the “supply side” #1 effects case.

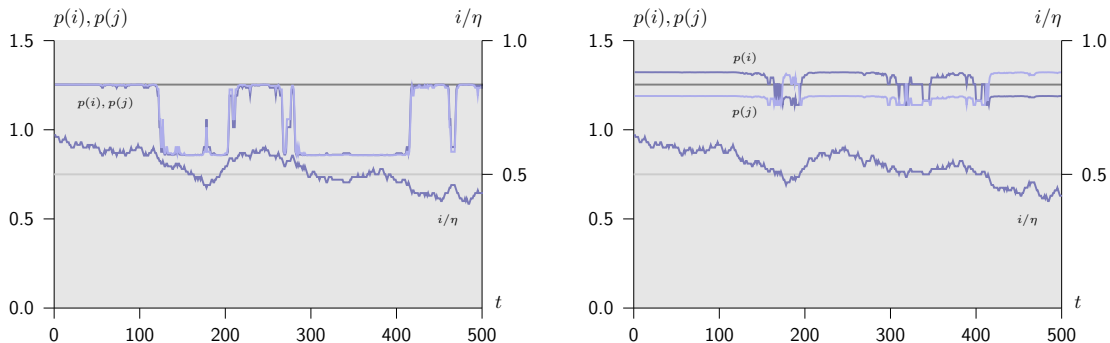
One feature shared by both panels in Figure 10 which is different from Figure 5 is the fact that there is tipping, that is, during the 500 periods simulation under consideration, the initial leader becomes a laggard. Given my assumptions regarding the distribution of ξ (in particular, part (ii) of Assumption 1), the stochastic process of market shares is ergodic, and so with probability 1 the leader becomes a laggard in finite time. Whether “finite time” means a short period or a long period depends on parameter values. I should note that I used the same sequence of values of ξ to generate the paths in Figures 5 and 10. The fact that the latter features a leadership switch whereas the former does not is primarily due to the higher value of δ used in Figure 5.

2. In addition to the parameter values consider in the figure's caption, I maintain $\eta=100$, $\mu=0$, $\sigma=1$

Figure 10

Price and market share dynamics for different model parameter values.

Left panel: $\theta=1, \lambda=0, \delta=0.7, \kappa=10$. Right panel: $\theta=0, \lambda=.1, \delta=0.7$



D. Multiple simultaneous active agents

For analytical tractability, I assume one consumer makes a decision at a time. I conjecture that the model's main qualitative features remain valid if we were to allow for multiple active consumers each period. If there were n active consumers, then, for given $p(i), p(j)$, we would have a binomial distribution of changes in i , which I denote by Δi . For some values of $\Delta i < i - j$, this would imply a shift from i being the leader to j being the leader. This implies that, even for δ equal or close to 0 a price war would take place whenever $i - j < n/2$. The depth of the price war, however, would be smaller as the value of $|i - j|$ increases. This is because the value of θ in the pricing first order condition is multiplied by the binomial probability of a large number of j sales. In other words, the effect of $n > 1$ would be to smooth out price dynamics with respect to Proposition 3, in way that is similar to the smoothing out effect of a higher value of δ . In Section 6, I consider still another reason why price wars may be smoother than Proposition 3, namely a smoother market leadership payoff function.

E. N firms

So far, all of my analysis has centered on the duopoly case. Some of the examples I motivated the paper with are indeed duopolies (e.g., Boeing and Airbus); but many feature more than two firms (e.g., IBM, HP and others). Suppose that there are $N > 2$ firms. Let the state space now be described by $\mathbf{x} = (x_i)$, where x_i is firm i 's installed base, $i = 1, \dots, N$.

An active consumer chooses firm i if and only if $\zeta_i - p_i(\mathbf{x}) > \zeta_j - p_j(\mathbf{x})$ for all $j \neq i$:³

$$q_i(\mathbf{x}) = \mathcal{P}\left(\zeta_i - p_i(\mathbf{x}) > \zeta_j - p_j(\mathbf{x})\right) \quad \forall j \neq i$$

Define

$$\hat{\mathbf{x}}_k^j \equiv \mathbf{x} - \mathbf{1}_k + \mathbf{1}_j$$

where $\mathbf{1}_i$ is an N dimensional vector with 1 in the i th component, zeros elsewhere; and $\Delta_i(\mathbf{x})$ is the generalized sign function: $\Delta_i(\mathbf{x}) = +1$ if $x_i > x_j$, for all $j \neq i$; $\Delta_i(\mathbf{x}) = -1$ if $x_i < x_j$, for all $j \neq i$; and $\Delta_i(\mathbf{x}) = 0$ otherwise. Firm's value can then be written as

$$v_i(\mathbf{x}) = q_i(\mathbf{x}) p_i(\mathbf{x}) + \sum_{k=1}^N \frac{x_k}{\eta} \sum_{j=1}^N q_j(\mathbf{x}) \left(\theta \Delta_i(\hat{\mathbf{x}}_k^j) + \delta v_i(\hat{\mathbf{x}}_k^j) \right)$$

Unlike the $N = 2$ case, I now restrict the distribution of consumer preferences by assuming that ζ_i follows an extreme value distribution. This implies that

$$q_i(\mathbf{x}) = \frac{\exp(-p_i(\mathbf{x}))}{\sum_{k=1}^N \exp(-p_k(\mathbf{x}))}$$

It follows that

$$\begin{aligned} \frac{dq_i(\mathbf{x})}{dp_i(\mathbf{x})} &= \frac{-\exp(-p_i(\mathbf{x})) \sum_{k=1}^N \exp(-p_k(\mathbf{x})) + \exp(-p_i(\mathbf{x}))^2}{\left(\sum_{k=1}^N \exp(-p_k(\mathbf{x}))\right)^2} \\ &= -\frac{\exp(-p_i(\mathbf{x})) \sum_{k \neq i} \exp(-p_k(\mathbf{x}))}{\left(\sum_{k=1}^N \exp(-p_k(\mathbf{x}))\right)^2} \end{aligned}$$

and

$$\frac{dq_i(\mathbf{x})}{dp_j(\mathbf{x})} = \frac{\exp(-p_j(\mathbf{x})) \exp(-p_i(\mathbf{x}))}{\left(\sum_{k=1}^N \exp(-p_k(\mathbf{x}))\right)^2}$$

and so

$$\frac{dq_j(\mathbf{x})}{dp_i(\mathbf{x})} \bigg/ \frac{dq_i(\mathbf{x})}{dp_i(\mathbf{x})} = \frac{\exp(-p_j(\mathbf{x}))}{\sum_{k \neq i} \exp(-p_k(\mathbf{x}))}$$

The first order condition for firm i 's value maximization is given by

$$\begin{aligned} &\frac{dq_i(\mathbf{x})}{dp_i(\mathbf{x})} p_i(\mathbf{x}) + q_i(\mathbf{x}) \\ &+ \sum_{k=1}^N \frac{x_k}{\eta} \left(\frac{dq_i(\mathbf{x})}{dp_i(\mathbf{x})} \left(\theta \Delta_i(\hat{\mathbf{x}}_k^i) + \delta v_i(\hat{\mathbf{x}}_k^i) \right) - \sum_{j \neq i} \frac{dq_j(\mathbf{x})}{dp_i(\mathbf{x})} \left(\theta \Delta_i(\hat{\mathbf{x}}_k^j) + \delta v_i(\hat{\mathbf{x}}_k^j) \right) \right) = 0 \end{aligned}$$

3. I assume the distribution of taste shocks is continuous, so that inequalities are strict almost surely.

In a symmetric equilibrium where ζ_i follows an extreme value distribution,

$$\frac{q_i(\mathbf{x})}{dq_i(\mathbf{x})/dp_j(\mathbf{x})} = \exp(-p_i(\mathbf{x}))$$

The first-order condition can then be written as

$$p_i(\mathbf{x}) = \exp(-p_i(\mathbf{x})) - \sum_{k=1}^N \frac{x_k}{\eta} \left(\left(\theta \Delta_i(\hat{\mathbf{x}}_k^i) + \delta v_i(\hat{\mathbf{x}}_k^i) \right) - \sum_{j \neq i} \frac{\exp(-p_j(\mathbf{x}))}{\sum_{\ell \neq i} \exp(-p_\ell(\mathbf{x}))} \left(\theta \Delta_i(\hat{\mathbf{x}}_k^j) + \delta v_i(\hat{\mathbf{x}}_k^j) \right) \right)$$

Compared to the $N = 2$ case, this creates an extra layer of computational burden: even for given value functions, I need to solve the first-order conditions numerically. Moreover, the stochastic process is no longer a birth-and-death process, so the stationary distribution of market shares cannot be computed analytically. Other than that, the model is similar to what I developed in Section 3, although some new wrinkles are created by the presence of more than two firms.

Suppose for example that $N = 3$ and consider the limit as $\delta \rightarrow 0$. Suppose moreover that $i = j$, whereas $k < i - 1$. Then firm i 's first-order condition implies that, in the limit as $\delta \rightarrow 0$

$$p_i(\mathbf{x}) = \exp(-p_i(\mathbf{x})) - \theta \frac{x_j}{\eta} \left(1 - \frac{\exp(-p_k(\mathbf{x}))}{\sum_{\ell \neq i} \exp(-p_\ell(\mathbf{x}))} \right) - \theta \frac{x_k}{\eta}$$

How does this compare to the expression in Proposition 3? In the latter case, the “subsidy” term is simply equal to θ : when $i = j$, either the “active” consumer is a firm i consumer or the active consumer is a firm j consumer. In the former case, the difference between winning and losing the next sale is the difference between the status quo and becoming the laggard. In the latter case, the difference between winning and losing the next sale is the difference between becoming the leader and remaining in the current state. Either way, the difference between winning and losing the next sale corresponds to a payoff of θ (in addition to the revenue from sales).

With three firms things are a little different. Suppose that the active consumer is a firm i consumer. Then, no matter what choice this consumer makes, firm i 's leadership status does not change: if firm i makes the sale, all it achieves is to remain in the current state. If either firm j or firm k make the sale, then firm i does not become the leader — and neither does it become the laggard. Consider now the case when the active consumer is firm j 's. Then firm i becomes the leader if *either* firm i makes the sale *or* firm k makes the sale. In terms of the first order condition this implies that we multiply the derivative $\partial q_i / \partial p_i$ by the

term $1 - \exp(-p_k(\mathbf{x})) / \sum \exp(-p_\ell(\mathbf{x}))$. In words: when firm i lowers its price it increases the probability of making a sale, which in turn increases the probability that it becomes a market leader. However, to the extent that this sale is won over firm k , it has no marginal effect in terms of market leadership. Finally, if the active consumer is a firm k consumer, then firm i needs to make a sale in order to become a market leader, so we get the full θ marginal effect.

F. Corporate culture metagame

In the main text I showed that, in a symmetric equilibrium, shareholder value may be higher in some states when $\theta > 0$ than when $\theta = 0$: even though shareholders do not benefit from being market leaders, they may benefit from hiring managers who benefit from being market leaders. In this section I present two limit results that characterize shareholder value when $\theta_a > 0$, that is, when only one firm’s manager benefits from being the market leader. The first result is a simple corollary of the asymmetric version of Proposition 3: if $\delta = 0$, then the game is effectively a sequence of “static” games where future values $v_k(i)$ do not matter. As seen in the proof of Proposition 3, a positive θ_a implies lower prices in some states. Since this amounts to a deviation from the first order condition under $\theta_a = 0$, it must decrease firm value. By continuity, we conclude that the same is true for values of δ close to zero (that is, the above inequality is strict).

At the opposite extreme, I can also find sufficient conditions such that a unilateral #1 effect increases shareholder payoffs. Suppose that (a) the managers’ discount factor is very small but the shareholders’ discount factor, denoted by δ_s , is very high; (b) in addition to the “psychological” value θ , market shares have real value, that is, value that accrues to shareholders in addition to managers: specifically, firms receive a flow payoff ψi per periods, where $\psi > 0$.⁴ (Intuitively, we may think of ψ as after-sales service revenues per customer.) Then I can provide conditions such that a unilateral increase in θ_a leads to higher shareholder value. Intuitively, by an argument similar to that of Proposition 3 and the explanation for Figure 7, a unilateral increase in θ_a implies a rightward shift in the stationary distribution of market shares. A very patient shareholder only cares about the stationary distribution of market shares. Finally, a small increase in θ_a has an infinitesimal negative impact on profitability (by the envelope theorem), whereas the shift in the stationary distribution of market shares is a first-order effect.

4. Notice that I assume the market share benefit is linear. In this way, I maintain my initial assumption that industry joint payoff (aside from pricing) is constant with respect to i .

The next result summarizes the discussion in the preceding paragraphs.

Proposition 6. *There exists a $\delta' > 0$ such that:*

- (a) *If $0 < \delta \leq \delta'$ and $0 < \delta_s \leq \delta'$, then $s_a(i)$ is strictly decreasing in θ_a for $i \in \{i^* - 1, i^*, i^* + 1\}$;*
- (b) *There exist $\psi', \delta' > 0$ and $\delta'_s < 1$ such that, if $\psi \geq \psi'$, $\delta \leq \delta'$, and $\delta_s \geq \delta'_s$, then $s_a(i)$ is increasing in θ_a .*

Obviously, two can play the same game. A possible next step would to analyze the “meta-game” played by firms a and b when each can choose θ_k . The above results and numerical simulations suggest that the equilibrium of this meta-game may sometimes be $\theta_a = \theta_b = 0$; and that it sometimes have the structure of a prisoner’s dilemma, where both firms choose positive θ_k and both firms receive a lower equilibrium payoff than in the situation where both choose $\theta_k = 0$.

Proof of Proposition 6: (a) Suppose that $\delta = 0$. By an argument similar to that of Proposition 3, a positive θ_a implies strictly lower prices at states $i \in \{i^* - 1, i^*, i^* + 1\}$ and no change in prices at other states. Since equilibrium prices when $\theta_a = 0$ maximize firm profits, we conclude that shareholder value is strictly lower. Since the inequality is strict, by Lemma 1 it also holds for sufficiently small δ .

(b) Suppose that $\delta = 0$ and consider an infinitesimal increase in θ_a . By the same argument as in part (a), this leads to lower prices in states $i \in \{i^* - 1, i^*, i^* + 1\}$. By the envelope theorem, given the change in θ_a is infinitesimal, the change in per period profit is of second order. However, the increase in $q(i)$ is a first-order effect. Since per period payoff is strictly increasing in i , it follows that average payoff in the stationary state is strictly increasing. Finally, the shareholder’s value (in any given state) converges to the average stationary value as the discount factor tends to infinity. ■

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