Experimentation and Learning with Network Effects

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Abstract

This paper considers learning in an imperfectly competitive setting. By allowing an opponent a "head start," unsuccessful unilateral experimentation may jeopardize future sales and profits. We show that even in the absence of spillover and signalling effects, competition can inhibit the scope of learning, relative to a monopoly.

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1. Introduction

Consider a seller who is imperfectly informed about market demand. She can improve her information by experimenting with prices. However, experimentation is costly: charging a high price generates valuable information, but will reduce current sales and profits if demand is actually low. Therefore the seller's optimal learning policy must balance the costs of experimentation against the potential gains. In a seminal paper, Rothschild (1974) examined the optimal dynamic learning strategy of a monopoly seller. He showed that the cost of experimentation will typically inhibit complete learning, even though through sufficiently extensive experimentation, the true state of demand can be learned with arbitrarily high probability. More recent studies of the optimal learning problem include McLennan (1984), Easley and Kiefer (1988), Creane (1989), Mirman, Samuelson, and Urbano (1989) and Aghion, Bolton, Harris and Jullien (1991). All of these papers considered a monopoly seller, i.e., a single optimizing decision maker.

In this paper, we consider equilibrium learning in an imperfectly competitive setting. In our setting, learning involves in addition to the costs considered in the existing literature, a novel cost. By allowing an opponent a "head start," unsuccessful unilateral experimentation involves not only the conventional loss of current profits, but may jeopardize future sales and profits. In settings where initial market shares are important for generating future profits, unilateral experimentation at the market's inception may lead to the loss of current and **future** sales. Settings in which this effect may be important include markets characterized by network externalities, switching costs or lock-in, and learning by doing.

In a competitive setting, there may be additional factors impinging upon the decision to experiment. For example, Rob (1991) has shown that spillover effects may reduce the amount of learning. Similarly signalling effects might also distort the learning process. For example, a firm might charge low prices to convince a potential entrant that demand is low, further inhibiting learning. Aghion, Espinosa, and Jullien (1990) and Mirman, Samuelson, and Schlee (1991) explore the incentives for strategic manipulation of information in duopoly settings.

In this paper, we present a simple model with two decision makers that allows us to isolate a "market share" effect, i.e., the framework has been constructed so that spillover and signalling effects are absent. In this setting, we show that there is a collectively suboptimal amount of learning which is a direct consequence of competition. In other words, there exists a set of parameters for which a monopoly seller would experiment and learn about demand, but in the competitive setting, the unique subgame perfect equilibrium is for neither firm to experiment: We term this lack of lack of learning "the strategic Rothschild effect." The message of the paper is thus that competition may exacerbate the Rothschild effect.[1]

[1]Smith (1991) finds that the Rothschild effect is mitigated by the presence of multiple decision makers. His

2. An Experimentation Model

The market opens in two periods. In each period, a new consumer cohort enters the market. The size of each cohort is normalized to one. Consumers are homogeneous and demand one unit, at the most. Consumers knows their reservation values, but the firms are ex ante uncertain whether demand is high or low: each firm assigns the prior q $(1-q)$ that the common consumer reservation value is v_h (v_l), where $v_h > v_l$.

There are two firms, each of whom can supply an unlimited amount of the product at zero cost. The firms are risk neutral, and there is no discounting.

Consumers must make actual contact with a seller in order to learn its price and it is assumed to be too costly to contact two firms in the same period. This grants the firms market power to set prices.[2] Therefore first period consumers choose a firm at random, and buy from that firm if the price does not exceed the reservation value.[3] Thus, in the presence of complete information about demand, firms would have full monopoly power. As discussed in the following paragraph, the only competitive "liability" arises from the strategic inhibition to learn about demand, i.e., to experiment in prices in the markets' formative stage.

In the second period, there is a network effect based on the firms' realized first period market shares. We make the simplifying assumption that the network effect is so important that no second period consumer is willing to purchase from the firm with a smaller installed base at any positive price.[4] Thus if a firm realizes a smaller market share in the first period, it faces zero demand in the second period. If the firms achieve equal first period market shares, second period demand for each firm is identical to that of the first period.

At the beginning of the second period, firms simultaneously set prices. We assume that they do so before learning which firm has achieved the larger first period market share or learning their rival's first period price. This assumption eliminates the presence of any learning externalities, i.e., it eliminates the possibility of free-riding on learning achieved by one's rival. Thus the case for experimentation is as compelling as possible.

The firms are initially imperfectly informed about market demand. Clearly this information is of value to them. Specifically, under conditions of complete information about demand, each firm would charge the true reservation price in each period. This is because, by assumption, each first period consumer accepts any price not exceeding its reservation

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result is due to the absence of any strategic interaction among agents: In his setting the payoff of each agent is independent of the actions of other agents. Our goal is precisely to address the inhibitory strategic effects on equilibrium learning associated with multiple **competing** agents.

[2]Actually, in the framework considered here, even a small search cost will be sufficient to grant firms full market power with respect to pricing. See Diamond (1971).

[3]Consumers are not dynamically strategic, i.e., they do not delay purchasing in the hope of realizing a lower future price. This is a common assumption in the network literature. See Katz and Shapiro (1986) for example.

[4]Our results remain qualitatively unchanged as long as there is some network effect.

price. Thus by charging the actual reservation price, a firm is assured of not suffering any adverse networks effects in the future. Conversely, it cannot obtain any network advantage by charging less than this price. Therefore, in the absence of any incomplete information about demand, each firm would enjoy complete monopoly power over its segment of the market.

Given incomplete information, a firm can become perfectly informed by charging the high price in the first period: acceptance of price v_h perfectly reveals that demand is high, while its rejection reveals that demand is low. This represents the potential benefits from experimentation.

Experimentation is costly, however. In our framework, this cost has two components. The first is the standard one, the potential loss of sales in the first period. The second and novel component, which our model is constructed to address in the starkest possible way, is a **strategic** cost. The source of this cost is the loss of future sales via an adverse network effect, which occurs if unilateral experimentation causes that firm to realize a smaller first period market share.

A natural benchmark which is useful to assess the significance of the second component, is comparison with monopoly learning in the same context. A monopoly also faces the first cost associated with experimentation. However, the strategic cost is absent because there is no rival who can capture its future sales. Because there is no scope for any **direct** price competition in our framework, the absence of a network effect would effectively transform each firm into a monopoly.

In the following section, we derive conditions under which learning is the monopolist's optimal strategy. This serves a benchmark with respect to which we subsequently identify the effect of competition on the optimal learning strategy.

3. Optimal Monopoly Learning

If the monopolist chooses to experiment in the first period, i.e., if it charges v_h, it becomes perfectly informed. If the consumer does not purchase in the first period, the monopoly concludes that the reservation price is v_l and charges this price in the second period. Otherwise v_h is charged in the second period. From the perspective of the first period, the expected second period profits are $qv_h + (1-q)v_l$. Thus the expected total profits from experimenting (charging price v_h in the first period) are $qv_h + (qv_h + (1-q)v_l)$, where qv_h are the expected first period profits. Therefore a monopolist will experiment if and only if $qv_h + (qv_h + (1-q)v_l) \geq 2v_l$, where $2v_l$ are the total profits earned by the monopolist if it does not experiment in the first period and hence charges v_l in both periods.[5] Rearranging

[5]If the monopolist has no incentive to experiment in the first period, it will not experiment in the second period either.

terms in the above equation, the monopolist will experiment if and only if

$$q \geq \frac{v_l}{(2v_h - v_l)} \equiv q^m. \tag{1}$$

If $q < q^m$, the monopolist gains no new information in the first period and consequently continues to charge the low price in the second period. Even if demand is actually high, the monopolist will persist in its belief that demand is low if the initial belief in high demand is below q^m. This effect has been termed the persistence of error by Rothschild. In the following section we how strategic considerations may exacerbate this effect.

4. Duopoly Analysis

We now turn to the analysis of the duopolists' equilibrium learning strategies. The solution concept is subgame perfect equilibrium. We solve the extensive form game described earlier through backwards induction, beginning with the second period. Let (p_i, p_j) be the first period prices chosen by firms i and j respectively. Since first period consumers will accept any price up to their true reservation value, no firm will ever charge a price less than v_l or a price between v_l and v_h. Thus the four possible subgames are (I) (v_l, v_h), (II) (v_l, v_l), (III) (v_h, v_h), and (IV) (v_h, v_l).

4.1 Second Period

Case I (v_l, v_h)

First suppose that firm *i* charges v_l in the second period. With probability q demand is high and both firms made first period sales and begin the second period with equal market shares. In this case, firm i has no network advantage, so its second period profits are just v_l. With probability $1 - q$ demand is low, and firm *j*, having charged v_h, begins period two with a smaller (no) market share. In this case firm i enjoys a network advantage, and earns profits of $2v_l$. Thus firm *i*'s expected second period profits from charging v_l in that period are

$$\pi_l^I = qv_l + (1 - q)2v_l. \tag{2}$$

If firm i charges v_h in the second period, it cannot enjoy a network advantage under any circumstances. This is because if demand is high, both firms begin the second period with equal market shares. If demand is low, firm *i* makes no sales. Thus not having acquired any new information about demand, firm i's expected second period profits from charging v_h in that period are

$$\pi_h^I = qv_h. \tag{3}$$

Comparing equations (2) and (3), firm i will optimally charge v_l if

$$q < \frac{2v_l}{(v_h + v_l)}. \tag{4}$$

Case II (v_l, v_l)

In this case, there is no possibility of a network advantage because the firms have equal first period market shares regardless of the true state of demand. Thus firm *i*'s second period profits are just v_l if its price is v_l and are qv_h if its price is v_h. Therefore firm i will optimally charge v_l in the second period if

$$q < \frac{v_l}{v_h}. \tag{5}$$

Case III (v_h, v_h)

Again there is no scope for network effects: Whether the true state of demand is high or low, both firms begin the second period with equal market shares. Having experimented in the first period, firm i is perfectly informed about the true state of demand before setting its price, i.e., its price is v_h if demand was learned to be high or v_l if demand turned out to be low. Thus second period ex ante expected profits, (as perceived at the beginning of the first period) are

$$\pi^{III} = qv_h + (1 - q)v_l. \tag{6}$$

Case IV (v_h, v_l)

As in the preceding case, firm *i* is fully informed about the true state of demand before setting its second period price. If demand has been learned to be high, its optimal second period price is v_h, while if demand has been learned to be low, firm *i* is unable to make a sale at any price, because of its rivals' network advantage. Thus its second period ex ante profits (as perceived at the beginning of the first period) are

$$\pi^{IV} = qv_h. \tag{7}$$

4.2 Equilibrium

Based on the above analysis of the second period, we can state the following proposition.

Proposition 1 *If $q < v_l/v_h$, the unique subgame perfect equilibrium is that no firm experiments, i.e, each firm charges v_l in each period.*

Proof. We prove the proposition by showing that it is a dominant strategy to charge v_l in the first period.

We will first show that v_l is a best response to v_l. If firm i charges v_l in the first period, its second period profits are v_l under the condition of the proposition, since from case II, firm i will charge v_l in the second period. Thus, its expected total profits from charging v_l are $2v_l$.

If firm i charges v_h in the first period, by case IV, its expected second period profits are qv_h. Since its first period expected profits from charging v_h are qv_h, its total profits from charging v_h in the first period are $2qv_h$. Thus v_l is a best response to v_l if $2v_l > 2qv_h$, which is the case for the q under consideration.

We will now show that v_l is also a best response to v_h. From the analysis of case I, if firm i charges v_l in the first period, it will also charge v_l in the second period if $q < \frac{2v_l}{(v_h+v_l)}$, which is implied by the assumption that $q < v_l/v_h$. Its expected second period profits from charging v_l in the first period are $2v_l - qv_l$. Thus its total expected profits from charging v_l in the first period are $v_l + 2v_l - qv_l = 2v_l + (1-q)v_l$.

If firm i charges v_h in the first period, from the analysis of case III, its expected second period profits are $qv_h + (1-q)v_l$. Thus its total expected profits from charging v_h in the first period are $qv_h + qv_h + (1-q)v_l = 2qv_h + (1-q)v_l$. Comparing these profits, for $q < v_l/v_h$, v_l is a best response to v_h. *Q.E.D.*

We can now state our main result.

Proposition 2 *Suppose that $\frac{v_l}{(2v_h-v_l)} \leq q < \frac{v_l}{v_h}$. Then the monopoly always experiments and learns the true state of demand, while neither of the duopolists experiment.*

Proof. This result follows directly from Proposition (1) and equation (1). *Q.E.D.*

Thus for the relevant parameters, as specified in Proposition (2), the monopolist learns the true state of demand with probability one, while the duopolists will persist in “error," i.e., they will charge v_l with probability one, even if the true state of demand is high. Thus we have demonstrated the existence of the strategic Rothschild effect: Experimentation is less likely to occur in its presence.

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