Some Implications of Search Costs for the Price Dynamics of Electronic Markets

Pedro Pereira[1]

Autoridade da Concorrência, R. Laura Alves, nº4, 7º, 1050-138 Lisboa, Portugal
e-mail: ppereira@autoridadedaconcorrencia.pt; phone: 21-790-2040; fax: 21-790-2099

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Abstract: This paper develops a model based on switching costs and technological uncertainty, which explains some aspects of the price dynamics of e-commerce. Switching costs and intertemporal cost correlation lock-in consumers. Firms initially charge low prices to build a customer base. If firms fail to reduce costs, and reservations prices are low, firms exit the industry. Over time, prices increase if no exit occurs, and decrease if exit occurs. Prices may also decrease over time, if the proportion of low search cost consumers increases.

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1 Introduction

1.1 The Recent Evolution of Electronic Commerce

In this sub-section, I review the recent evolution of electronic commerce.

The Internet allowed the creation of a new retailing technology: *electronic commerce*.[2] Initially, the creation of new markets suggested a big growth potential. Between January 1998 and July 2000, venture capital invested $65 billion in Internet companies (*Fortune*, October 30, 2000). In 1999, Internet firms carried out 55% of the initial public offerings. And during 1999 and 2000, first-day returns on initial public offerings for Internet firms averaged 88%, whereas first-day returns on initial public offerings averaged 17% in 1996, 69% in 1999, and 56% in 2000 (Ljungqvist & Wilhelm (2002)). Between June 1998 and July 1999, firms that changed their names to Internet related dotcom names, had cumulative abnormal returns of 74% on their stock valuation (Cooper, Dimitrov & Rau (2001)).

But in spite of all this investment euphoria, firms had small revenues. One reason was that firms deliberately charged very low prices. This behavior was justified as an investment in consumer acquisition (Hoffman & Novak (2000) and Reichheld & Schefter (2000)). Whatever consumer acquisition means, it suggests the existence of consumer inertia or *switching costs*.[3] "Most notable was the general assumption that the deployment of the Internet would increase switching costs and create strong network effects, which would provide first-movers with competitive advantages and robust profitability", Porter (2001, p. 68). "[Amazon] sells music CD's at an average price of $12.99 while incurring costs of $14 per unit. (…) But there was a rationale: build a customer base of loyal site users and profitability will follow", Rayport (1999). Lieberman (2002) using data from early 1999 to September 2002, for 206 publicly traded firms, in 46 Internet markets, found that early entrants in the market maker and broker segments, or with patented innovations, earned a premium on their stock market valuation, relative to their peers. He was unable to develop direct measures of switching costs. But Chen & Hitt (2001) report evidence of switching costs for the broker segment, discussed in sub-section 1.2.

[Insert Figure 1 here]

After the fall of the NASDAQ in April 2000, capital markets closed for most Internet companies, which then faced one of three options: survive on their own revenues, often minimal, sell out, or go bankrupt. In either case, a wave of consolidation started, and it is expected that of the large number of entrants, few will survive. In new

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[2] Trading goods based on the processing and transmission of digitized data over the network of computers that use the Transmission Control Protocol/Internet Protocol.

[3] A s*witching cost* is a one-time product specific cost, a consumer must bear in order to consume a product, e.g., learning to use a word processor, or finding a new store.

industries, a build up in the number of firms followed by a shakeout is a well-documented phenomenon (Gort & Klepper (1982) and Klepper & Graddy (1990)). Geroski (1995) conjectured that the likelihood of firm survival is lower, in industries in which the innovative opportunities available to small firms are large. Audretsch (1995) provides evidence that supports this hypothesis. Internet technologies allow firms to operate on a small scale, due to their modularity, and offer many innovation opportunities. This suggests a severe *shakeout*.[4] In fact, according to Webmergers.com, between January 2000 and February 2002, 804 Internet companies shut down or declared bankruptcy (Figure 1). And between January 2001 and April 2002, about $43 billion were spent to buy more than 1,600 firms. Bughin (2002) using data from mid 2001, of 121 worldwide Internet retailing firms, reports the following: **(i)** about 20% of firms were profitable, **(ii)** the average profitable firm had a profit margin of 30%, **(iii)** the average non-profitable firm had a profit margin of –40%, and **(iv)** the bottom half of non-profitable firms reached profit margins of –110%. Since these firms also had a low and declining conversion of online visitors to customers, it is unlikely that they will ever be profitable.

It is premature to know the intertemporal profile of prices online, or to infer its causes. Price dynamics will certainly vary across industries. However, some evidence starts to emerge. Kwak (2001) reports that online book prices, decreased between the spring and fall of 1999, were flat for several months, and started to *increase* in 2000, when Amazon raised prices by 10-20%. Clay et al. (2001) also report an upward trend for prices of online books. Brown & Goolsbee (2002) found that the spread in Internet use *decreased* the price of term life insurance by 8–15%, after price-comparison search engines were introduced, and for insurance types covered by the search engines.

1.2 The Building Blocks: Switching Costs and Technological Uncertainty

In this sub-section I discus the building blocks of the paper.

I develop a model to explain some aspects of the price dynamics of electronic commerce. The model has two phases.[5] First, a phase in which the product is introduced, firms experiment with the new technology, consumers try to locate a low cost firm taking into account future purchases, and there is intense price competition. And second, a

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[4] An industry *shakeout* consists in a joint: **(i)** *decrease* in the number of firms, **(ii)** *increase* in total output, and **(iii)** *decrease* in prices. Klepper & Miller (1995) showed that during their early evolution, new industries commonly experience a shakeout period, during which the number of producers declines by 50%, and in extreme cases by 80%, in ten to fifteen years. The automobile industry in the United States started in 1894 with 4 producers (Klepper & Simons (1997)). The number of firms increased to 274 in 1909, fell to 121 by 1918, and fell to 7 by 1955. Entry was concentrated in the years preceding the peak, with 490 entrants before 1909, and 233 entrants after 1909.

[5] Klepper & Graddy (1990) argue that the history of a product can be divided into three stages. In the first stage the number of firms in the industry grows. In the second stage there is a decline in the number of firms. In the third stage the number of firms stabilizes.

phase in which firms learn their true cost, and there is possibly a shakeout. The two building blocks of this process are: **(i)** *switching costs*, and **(ii)** *technological uncertainty*. Since there are switching costs that lock in consumers, firms are prepared to initially charge low prices to build a customer base for the future, where they hope to have low costs.[6] If however firms fail to reduce costs, they exit the industry. Over time, prices increase if no exit occurs, and decrease if exit occurs. Prices may also decrease over time, if the proportion of low search cost consumers increases.

Regarding *switching costs*, electronic commerce reduces search and switching costs compared with physical shop retailing, but it does not eliminate them. Browsing Web sites is not costless, and it is easier to learn the current price of a previous supplier, than the price of another firm. Shoppers can bookmark the site of their previous supplier, or can be e-mailed price updates by their current vendor, while they have to search to learn the price of a new supplier. Opening an account with a Web merchant, or learning how to use its website, also creates switching costs. It is revealing that Amazon tried to patent the "1-Click-Shopping".[7] An emerging empirical literature supports this perspective. Hong & Schum (2001) using data collected from Pricescan.com for electronics and books, estimate for several model specifications, median search costs that range from 3% to 40% of the median observed price. Consider for example a Palm Pilot Vx. The median observed price was $299, and the median estimated search cost was $25.03, for one of the model specifications. The average hourly wage for an engineer was $28.97 in 1998.[8] Chen & Hitt (2001) using data provided by MediaMetrix from July 1999 to June 2000, on the eleven largest retail brokers, report evidence on *switching costs* for the online brokerage industry.[9]

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[6] Clay et al. (2002) report that on April 1999 some lowest priced firms may have charged prices close to cost. Shopping.com and books.com offered discounts of 40% on both hardcover and paperback bestsellers.

[7] The "1-Click-Shopping" ordering system allowed clients to shop without reentering their shipping and billing information every time they purchased from the firm. Amazon was awarded US patent 5,960,411 for the "1-Click-Shopping" technology on September 29, 1999. On October 21, 1999, Amazon filled a patent-infringement suit against Barnes&Noble.com alleging that it "willfully infringed" of the "1-Click-Shopping" ordering system, with its "Express Lane" ordering system. In December 1999, a Federal District Court in Seattle granted an injunctive relief barring Barnes&Noble.com from using the "Express Lane" ordering system. In February 2001 a Federal Appeals Court in Washington overturned the preliminary injunction until a trial, scheduled for September 2001, took place. In March 2002, Amazon announced it had settled the case with Barnes&Noble.

[8] According to the National Compensation Survey collected by the Bureau of Labor Statistics

[9] Other studies present evidence of consumer inertia or loyalty online. **(i)** Hann & Terwiesch (2000) use data from a German online reverse buying retailer, similar to Priceline.com, which however allows consumers to increase their bid if their earlier bid has failed. By increasing their bid by 1 cent in each consecutive round, consumers can identify the minimum price for which the seller is willing to sell, at the cost of incurring the utility loss of placing additional bids. They estimate that consumers placing bids for PDAs prefer paying an average of €5.51, over keying in an extra bid. **(ii)** Smith & Brynjolfsson (2001) documented the importance of brand, for homogeneous products, and among users of price-comparison search engines, who are presumably the most price sensitive consumers online. Using data for searches for books conducted at Dealtime.com in late 1999, they report that while price is the strongest predictor of customer choice, only 49% of customers choose the lowest priced vendor. Among consumers who do not choose the lowest priced offer, the average selected offer was 20% higher than the lowest priced offer. Consumers were willing to pay 5% more to purchase from Amazon, rather than from the lowest priced vendor, and 3% more to purchase from Barnes & Noble or Borders. **(iii)** In Brynjolfsson & Smith (2000), the authors use a cookie number to track the loyalty of customers to retailers they had selected on previous visits. They find that retailers who were selected on a previous visit by a particular customer hold a 7% price advantage over other retailers on subsequent visits by that customer. **(iv)** Johnson et al. (2001) using data from Media Metrix from July 1997 through June 1998, report that 70% of CD shoppers, 70% of the book

Regarding *technological uncertainty*, electronic commerce allows cost savings compared to physical shop retailing. These cost savings vary across industries, and conceivably are more relevant for *digital goods*.[10] But since the technology is new, achieving these cost reductions is uncertain, and firms only learn over time, by producing, if they succeeded or not. The creation of a new production process involves a process of experimentation, learning, and failure. To learn their true cost function, firms have to experiment with different bundles of production factors, to identify which are efficient. This process of trial and error requires time (Ericsson & Pakes (1995), Hopenhayn (1992), Jovanovic (1982), Klepper & Graddy (1990), Lippman & Rumelt (1982), and Zeira (1987)). In line with this perspective, Bughin (2002) reports that for his dataset, the number of customers and revenue per customer was not statistically significantly different between profitable and unprofitable firms. However, the cost per customer was statistically significantly different, and *four* times lower for profitable firms than for unprofitable firms.

Although the classical example of the electric dynamo refers to a general-purpose technology, rather than to a consumer product, it illustrates the process of learning how to use a new technology (David (1990)). The deployment of electricity started by the 1890s, but its impact on productivity was negligible until the 1920s. Initially firms replaced the power source, but left the way production was organized unchanged. But by taking advantage of the new technology's characteristics, production could be reorganized in more flexible and productive ways. It took several years and experiments to discover this.[11]

1.3 Overview of the Paper

In this sub-section I give an overview of the model and the main results.

I develop a model related to Benabou (1993), Fishman & Rob (1995), MacMinn (1980), and Reinganum (1979), where firms set prices, and consumers search for prices. The model was developed having in mind the price dynamics of e-commerce, and more generally, the price dynamics of retailing industries.

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shoppers, and 42% of the travel shoppers, were observed as being loyal to just one site through the duration of the his data. On average, households that browsed a category, visited only 1.1 book sites, 1.2 CD sites, and 1.8 travel sites.

[10] *Digital goods* are products that can be stored and transmitted as zeros and ones.

[11] Initially, firms only replaced steam or water powered motors by electric motors. This allowed fuel savings and improved machine speed control. However, instead of a primary motor turning separate shafting sections and driving related groups of machines, individual electric motors could be used to run machines of all sizes. Furthermore, electric wires could replace power transmission through shafts and belts. The reduction of friction in transmission allowed further fuel savings. Factories could also be redesigned, with lighter single-story structures replacing costly multistory structures. This allowed savings in fixed capital. But more importantly, single-story, linear factory layouts, allowed a reconfiguration of materials handling, of machine placement, and of handling equipment. These changes in product and process design were the largest source of the productivity gains. See Goldfarb (2001) for an alternative perspective.

Firms have different marginal costs, which may change over time. Initial low costs help predict future low costs, and high costs may lead to exit. These assumptions about costs are intended to reflect the stochastic learning about the new technology. However, they agree with stylized facts on intra-industry microeconomic dynamics. Foster et al. (2000) using U.S. data from the manufacturing sector from 1977 to 1992, and from some service sector industries from 1987 to 1992, report that: **(i)** there are large and persistent differences in productivity levels across firms, and **(ii)** low, firm specific productivity levels, help predict exit.[12]

In the model, since search is costly, consumers accept prices above the minimum charged in the market. This gives firms market power.[13] Switching costs lock in consumers to their period 1 suppliers. And since production costs in period 1 are *positively correlated* with production costs in period 2, in period 1 consumers conduct a more thorough search than they would for a single purchase, i.e., in period 1 they hold a lower reservation price than in the period 2.

Low cost firms charge the lowest price. Thus, they are not constrained by consumer search, and charge their monopoly price. High cost firms may also benefit from the market power generated by costly search. If the consumers' reservation price is higher than their marginal cost, they charge the reservation price. If the reservation price is lower than their marginal cost, in period 2 they *exit* the industry. But in period 1, due to the lock-in effect, they remain active to secure a larger consumer share in period 2.

Over time, prices increase if no exit occurs, and decrease if exit occurs. When consumers are heterogeneous with respect to the search cost, prices may also decrease over time, if the proportion of low search cost consumers increases.

Exit is also associated with: **(i)** an *increase* of both the output per firm, and the industry output, and **(ii)** a *decrease* of the industry average price. These last predictions are in line with evidence on the evolutionary trends of industry variables, reported by Agarwal (1998).

My results contrast with the switching costs literature (Farrell & Klemperer (2001)) for three reasons. First, although consumers have switching costs, prices need not increase over time. Second, if prices do increase, it is not because firms exploit locked-in consumers, but because the consumers' reservation prices increase over time. In the switching costs literature consumers are perfectly informed of prices, and reservation prices are exogenous. Initial

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[12] The model is intended to apply to the retail industry. I use the manufacturing industry as an example due to data availability.

price lure consumers. And after consumers are locked-in, firms increase prices. In my model consumers are imperfectly informed about prices. Initial prices cuts occur, because initially consumers conduct a more thorough search and hold a low reservation price, which forces prices down. As the consumers' reservation prices increase over time, firms that are constrained by consumer search are able to raise their prices. Price movements are driven by endogenous changes in the reservation price. And third, intertemporal cost correlation alone locks-in consumers, and leads to price cuts followed by price hikes. If production costs are positively correlated, finding a low cost firm in period 1 is valuable for both periods, even if there are no switching costs. Thus, consumers hold a lower reservation price in period 1 than in period 2, which leads to prices increasing over time.

This paper's results about some implications of search and switching costs for price dynamics of electronic markets, are derived in a context where firms may exit the industry, i.e., in a context where a shakeout may occur. But, to be sure, the paper is not intended to explain the process that generates the shakeout. Rather, the paper explains the underlying price dynamics, and in a way other papers fail to do so, namely those associated with the switching costs literature.

I also discuss four generalization of the model. I consider: **(i)** consumer heterogeneity, **(ii)** cost reducing investment, **(iii)** entry, and **(iv)** phases of unequal length.

Section 2 presents the model, and section 3 characterizes its equilibria. Section 4 conducts the analysis. Section 5 discusses generalizations, and section 6 concludes. Proofs are in the appendix.

2 The Model

In this section I present the model, which is simple to lighten the exposition. In section 5 I discuss 3 generalizations: **(i)** consumer heterogeneity, **(ii)** cost reducing investment, **(iii)** entry, and **(iv)** phases of unequal length.

2.1 The Setting

Consider a market for a perishable, homogeneous good, that opens 2 periods. Subscript t refers to time.

Each of the game's 2 periods consists of 2 stages. Each period, in *stage* 1 firms choose prices, and in *stage* 2 consumers search for prices. Then agents receive their period payoffs.

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[13] *Market power* is the ability to raise price above marginal cost.

2.2 Consumers

There is a unit measure continuum of risk neutral, identical consumers. A consumer who buys at price p on $\Re_0^+$ demands $D(p)$, where $D(.)$ is a twice differentiable, bounded function, with a bounded inverse, and decreasing for p on $\left[0, D^{-1}(0)\right]$. Denote by $S(p) := \int_p^{+\infty} D(x)dx$, the surplus of a consumer who pays p.

Consumers do not know the prices charged by individual firms. However, they hold common beliefs about the price distribution. Cumulative distribution function, $F_t(.)$, gives the consumers' beliefs about the period t price distribution; the lowest and highest prices on its support are $\underline{p}_t$ and $\overline{p}_t$.

Consumers search sequentially with recall, and have a constant marginal *search cost*, $\sigma > 0$.[14] Within each period, search is instantaneous, and consumers may observe any number of prices. Consumers pick randomly which firm to sample, from the set of firms whose price they do not know.

In period 2, consumers learn for free *only* the period 2 price of their period 1 supplier. This creates a *switching cost*, equal to the expected search expenditure. In sub-section 3.3 I weaken this assumption. This way of modeling switching costs has 2 attractive features. First search and switching costs are related in a natural way. And second, switching costs, rather than assumed, are explained by the model.

A consumer's *information set* just after his *k*-th search step, consists of all previously observed prices. A consumer's *strategy* for stage 2 of period t is a stopping rule, s_t, that says if search should stop or continue, for every search cost, beliefs about the price distribution, and sequence of observations. A consumer's *payoff* is the sum of expected period surpluses, net of the search expenditure.

2.3 Firms

There is a unit measure continuum of risk neutral firms.[15] I could add a stage 0, in which firms decide if they enter the market for a fixed set-up cost, and normalize the measure of firms that enter to 1. In sub-section 5.3 I discuss additional entry in period 2. My focus is not on entry, but rather on *price dynamics* and *exit*.[16]

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[14] Arguably the Internet realizes its full potential to reduce search costs through price-comparison search engines. Search engines provide a sample of between 20 to 40 prices at a fixed cost, which is the opportunity cost of the time required to download software, learn to use the search engine's interface, configure the interface, wait for the data to be downloaded, etc (Pereira (2003)). Searching through search engines is seemingly inconsistent with my assumption that consumers search sequentially. My point in this paper is that low search costs online lead consumers to only accept low prices, which in turn forces firms to charge low prices. And this does not depend on the assumptions about the search technology. Besides, the available evidence does not suggest a widespread use of price-comparison search engines, at least yet. A Media Metrix study found that during July 2000 less than 4% of Internet users used a price-comparison search engine, while over 67% visited an online retailer (Montgomery et al. (2001)). And a Jupiter Communications survey found that 28% of the respondents where unaware of the existence of price-comparison search engine (Iyer & Pazgal (2001)).

[Insert Figure 2 here]

Marginal costs are constant with respect to the production level, and can be *low*, c_l, or *high*, c_h, where $0 \le c_l < c_h < D^{-1}(0)$. In period 1 a firm has a low marginal cost with probability μ on $(0,1)$. In period 2, a firm that had cost c_i in period 1, has cost c_s with probability υ_{is} ($i,s=l,h$) (Figure 2). A period 1 low cost firm is more likely to have a low cost in period 2, than a period 1 high cost firm, $\upsilon_{hl} < \upsilon_{ll}$, i.e., costs are *positively correlated* across periods. The unconditional probability of a firm having a low cost in period 2 is: $\mu\upsilon_{ll} + (1-\mu)\upsilon_{hl}$. I assume that the cost distribution is the same in both periods, $\mu = \mu\upsilon_{ll} + (1-\mu)\upsilon_{hl}$. Every period, each firm observes only its cost level before choosing its price. To simplify notation, I assume that the realized value of a random variable equals its expectation.

In sub-section 5.2 I discuss cost reducing investment, and argue that period 1 low cost firms have a no smaller incentive to invest in cost reduction, than period 1 high cost firms. This provides an explanation for positive cost correlation, complementary to the stylized facts on intra-industry microeconomic dynamics, reported by Foster et al. (2000). For expository reasons, I assume that: **(i)** there are only 2 costs levels, and **(ii)** a simple intertemporal cost correlation structure. The results of section 4 generalize to a continuum of marginal costs, and to richer correlation structures, as in Tommasi (1994), with no added economic insights.

Denote by p_{ti} on $\Re_0^+$, the period t price of a cost c_i firm, and denote by $\pi(p_{ti};c_i) := (p_{ti} - c_i)D(p_{ti})$, the period t per consumer profit of a cost c_i firm. Let $\hat{p}_i := argmax_p \, \pi(p;c_i)$; I will refer to $\hat{p}_i$ as firm i's *monopoly price*. I assume that $\pi(.)$ is strictly quasi-concave in p. Denote by $\varphi_t(p_{ti})$, the period t expected consumer share of a cost c_i firm; denote by $\Pi_t(p_{ti};c_i) := \pi(p_{ti};c_i)\varphi_t(p_{ti})$, the period t expected profit of a cost c_i firm; and denote by $V^i := \Pi_1(p_{1i};c_i) + [\upsilon_{il}\Pi_2(p_{2l};c_l) + \upsilon_{ih}\Pi_2(p_{2h};c_h)]$, the sum of the expected period profits of a period 1 cost c_i firm.

Instead of modeling explicitly the firms' entry and exit decisions, I follow an equivalent, but more parsimonious approach, in line with the literature, e.g., Benabou (1993) and MacMinn (1980). I assume that all firms

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[15] Assuming that there are "many firms" may seem awkward in the context of Industrial Organization. This assumption is not essential. The model can be reinterpreted as a duopoly, at the risk of straining a bit the restrictions on the consumers' beliefs required to construct the equilibrium. But the assumption does have the virtue of making it clear, that in this context, costly search is the source of the firms' market power.

[16] Audretsch (1995) found that the variance of the survival rates across industries is considerably larger than the variance of the entry rates across industries. Geroski (1995, p. 23) commented that: "Entry appears to be relatively easy, but survival is not". And Klepper & Simons (1997) showed that in product industries entry nearly stops with shakeouts.

are in the industry. However, firms may price themselves in or out of the market. More specifically, a firm may charge a price higher than the maximum consumers are willing to pay, their *reservation price*, in which case I say that the firm is *inactive*; otherwise the firm is *active*. When indifferent between being active and inactive, a firm chooses the latter. Consumers know if a firm is active without search, which seems appropriate for electronic markets.[17]

[Insert Figure 3 here]

I assume that high cost firms lose money if they charge $\bar{p}_l$, i.e., $\bar{p}_l < c_h$ (Figure 3). One can interpret this assumption as meaning that cost heterogeneity among firms is large. In sub-section 3.1.2 I comment this last assumption.

A firm's period t information set, consists of its previous prices, costs, and consumer share realizations. A firm's stage 1 *strategy* for period t is a pricing rule, p_{ti}, that says which price a firm should charge, for every possible history. A firm's *payoff* is the sum of the expected period profits.

2.4 Equilibrium

An *equilibrium* is: a stopping rule for each period, consumer beliefs, and a pricing rule for each period and cost type, $\left\{ s_t^*, F_t^*, p_{ti}^* \middle| t = 1,2; i = l,h \right\}$, such that:[18]

(E1) Given σ and F_t, consumers choose s_t^* to maximize the net sum of the expected surpluses;

(E2) Given s_t^* and $(\mu, \upsilon_{is}, c_i)$, firms choose p_{ti}^* to maximize the sum of the expected period profits;

(E3) Beliefs F_t^* agree with the price distributions induced by p_{ti}^* and (μ, υ_{is}).

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[17] Thus, F gives the consumers' beliefs about the prices of active firms. In my approach, assuming that consumers know which firms are active, is equivalent to assuming that consumers know which firms are in the market, when the firms' entry or exit decisions are modeled explicitly. The search literature usually assumes that consumers: **(i)** know which firms are *active*, i.e., which firms are *in* the industry, **(ii)** know the price distribution, but **(iii)** don't know the prices of individual firms. There is a branch of the search literature going back to Rothschild (1974), where consumers learn through search, both individual prices, and the price distribution. This literature addresses different issues from those addressed in my paper.

[18] The equilibrium concept is related to a sequential equilibrium (Kreps & Wilson's (1982)), and requires that the consumers' beliefs about the price distribution satisfy **(i)** *sequential rationality*, and **(ii)** the *independent prices conjecture*, which generalize subgame perfection to incomplete information games. The first restriction implies that consumers behave optimally, at every information set, given their beliefs about the firms' strategies. The second restriction implies that consumers do not change their beliefs upon observing the price of any finite set of firms, and that on the equilibrium path, consumers' beliefs agree with the price distribution induced by the firms pricing strategies. See Bagwell & Ramey (1994) and Pereira (2001).

3 Characterization of Equilibrium

In this section I construct the equilibrium by working backwards. The consumers' equilibrium search behavior consists of holding reservation prices. Low cost firms are always active and charge their monopoly price. High cost firms in the first period are always active; in the second period, sometimes they are active, and other times they are inactive. When active, high cost firms charge the consumers' reservation price.

3.1 Second Period
3.1.1 Second Stage: The Search Game

In this sub-section I characterize the search equilibrium for period 2.

In period 2, consumers can either accept the offer received for free from their period 1 supplier, i.e., "recall" the current offer of their previous period supplier, or alternatively, incur in the search cost and visit another firm chosen at random. The consumers' optimal strategy consists of visiting first their period 1 supplier, and holding a reservation price, ρ_2, which equates the expected marginal benefit of search to the search cost (Benabou (1993) or Reinganum (1979)):[19]

$$\int_{\underline{p_2}}^{\rho_2} \left[S(p) - S(\rho_2) \right] dF_2(p) = \sigma \tag{1}$$

That is, the consumers' optimal strategy is to visit first their period 1 supplier and buy, if and only if, offered a price is no higher than ρ_2; and otherwise, continue to search.

Consumers that patronized in period 1 a low cost firm, hold the same reservation price as consumers that patronized in period 1 a high cost firm. This occurs because the optimal strategy for sequential search with recall is *stationary*, i.e., it does not depend on the sequence of observed prices (DeGroot (1970), Kohn & Shavell (1974), or Yahav (1966)).

The next Lemma groups 2 results that will be useful later.

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[19] Search occurs if either consumers get the first price quote for free, or the search cost is "small enough". Given *sequential rationality* (see footnote 18), consumers optimize with respect to beliefs, which given the *independent prices conjecture*, do not depend on observed prices. Thus, the consumers' search problem can be solved through dynamic programming. Under my assumptions sequential search is optimal (Morgan & Manning (1985), Prop. 3).

Lemma 1: (i) For all strictly positive search costs, the period 2 reservation price is higher than the lowest price charged in the market. **(ii)** The period 2 reservation price is increasing in first-order stochastic dominating shifts of the price distribution. §

Costly search, $\sigma > 0$, gives firms market power, since it leads consumers to accept prices above the minimum charged in the market, $\underline{p}_2 < \rho_2$. Higher prices decrease the marginal benefit of search, which leads consumers to hold a higher reservation price.

3.1.2 First Stage: The Pricing Game

In this sub-section I characterize the equilibrium prices for period 2.

Denote by n_t, the measure of active firms in period t, and denote by ΔC, the measure of consumers searching in period 2, i.e., consumers that in period 1 patronized a firm inactive in period 2. If a firm charges a price higher than the period 2 reservation price, it makes no sales; if it charges a price no higher than the period 2 reservation price, it keeps its period 1 consumers φ_1, and gets an expected consumer share of $\Delta C/n_2$. Thus:

$$\varphi_2(p) = \begin{cases} 0 & \Leftarrow \rho_2 < p \\ \varphi_1 + \Delta C/n_2 & \Leftarrow p \le \rho_2 \end{cases}$$

The next Lemma characterizes the equilibrium prices for period 2. As mentioned in sub-section 2.3, I focus on $\rho_2 < \widehat{p}_h$.[20]

Lemma 2:[21] In period 2: **(i)** Low cost firms charge their monopoly price. If the period 2 reservation price is no smaller than the high cost level, high cost firms charge the period 2 reservation price; otherwise, high cost firms are inactive. **(ii)** If the period 2 reservation price is no smaller than the high cost level, then each firm's price is $\widehat{p}_l$ with probability μ, and ρ_2 with probability $1 - \mu$; if the period 2 reservation price is lower than the high cost level, then each firm's price is $\widehat{p}_l$:

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[20] Or equivalently, I focus on σ on $(0, \bar{\sigma})$, where $\bar{\sigma}$ is defined by $\int_{\underline{p}}^{\hat{p}_h} [S(p) - S(\bar{p}_h)] dF_2(p) - \bar{\sigma} \equiv 0$.

[21] The firms' consumer shares depend on history. However, prices are independent of consumer shares, and hence of history, because marginal costs are constant.

$$F_2^*(p;\rho_2) = \begin{cases} \begin{cases} 0 \Leftarrow p < \widehat{p}_1 \\ \mu \Leftarrow \widehat{p}_1 \le p < \rho_2 \Leftarrow c_h \le \rho_2 \\ 1 \Leftarrow \rho_2 \le p \end{cases} \\ \begin{cases} 0 \Leftarrow p < \widehat{p}_1 \\ 1 \Leftarrow \widehat{p}_1 \le p \end{cases} \Leftarrow \rho_2 < c_h \end{cases}$$

§

Low cost firms charge the lowest price. Costly search, $\sigma > 0$, leads consumers to accept prices above the minimum charged in the market, $\underline{p}_2 < \rho_2$. Thus, low cost firms are never constrained by consumer search and charge their monopoly price, $\widehat{p}_l$. Due to costly search, low cost firms gain no additional consumer share by charging a price lower than their monopoly price. And by definition of monopoly price, low cost firms have no incentive to charge a higher price either.

High cost firms may also benefit from the market power generated by costly search, by charging a higher price than low cost firms. They are, nevertheless, disciplined by consumer search. If the period 2 reservation price is *high*, $c_h \le \rho_2$, high cost firms charge the reservation price, ρ_2. If the period 2 reservation price is *low*, $\rho_2 < c_h$, high cost firms are inactive, i.e., charge a price on $(\rho_2, +\infty)$ (Figure 4).

Since this is a 2 period model, a firm being inactive in period 2 is equivalent to *exiting* the industry.

To have positive sales, firms have to charge a price no higher the consumers' reservation price. By definition, only firms that are inactive, i.e., that exit the industry, fail to do so. Thus, on the equilibrium path, only consumers that patronized in period 1 a firm that exits in period 2, search actively. For consumers that patronized in period 1 a firm active in period 2, the option to search serves only as a credible, out of equilibrium threat, constraining high cost firms' pricing behavior.

I assumed that $\widehat{p}_l < c_h$. Under the alternative assumption that $c_h \le \widehat{p}_l$, high cost firms are always active in period 2. Whereas if $\widehat{p}_l < c_h$, high cost firms may or may not be active in period 2, depending on ρ_2. Thus, case $\widehat{p}_l < c_h$, considered by Benabou (1993) and MacMinn (1980), is more encompassing than the alternative case $c_h \le \widehat{p}_l$, considered by Reinganum (1979).

For some search cost values, the equilibria for which high cost firms are *active*, overlaps with the equilibria for which high cost firms are *inactive*, i.e., there is multiplicity of equilibria.[22]

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[22] See Pereira (2004b).

From Lemma 2:

$$n_2 = \begin{cases} 1 & \Leftarrow c_h \le \rho_2 \\ \mu \upsilon_{ll} + (1-\mu)\upsilon_{hl} & \Leftarrow \rho_2 < c_h \end{cases}$$

I focus on equilibria in symmetric pure strategies. However, the equilibria described in Lemma 2 are unique for $\rho_2 \neq c_h$.[23]

3.2 First Period
3.2.1 Second Stage: The Search Game

In this sub-section I characterize the search equilibrium for period 1.

Denote by $G(p)$, the period 2 maximum expected surplus, net of search expenditure, of a consumer whose best available offer in period 1 is p, and behaves optimally.

The next Lemma characterizes the search equilibrium for period 1.

Lemma 3: In period 1, if consumers search, their optimal period 1 strategy consists of holding a reservation price, ρ_1, which equates the sum of the expected marginal benefit of search for periods 1 and 2, to the search cost:

$$\int_{\underline{P}_1}^{\rho_1}[S(p) - S(\rho_1)]dF_1(p) + \int_{\underline{P}_1}^{\rho_1}[G(p) - G(\rho_1)]dF_1(p) = \sigma \tag{2}$$

§

Consumers learn for free the period 2 price of their period 1 supplier. Thus, they tend to buy at the same firm in both periods. With the prospect of buying twice from the same firm, the consumers' period 1 incentives to search depend on current savings, $[S(p) - S(\rho_1)]$, and also on future savings, $[G(p) - G(\rho_1)]$.

3.2.2 First Stage: The Pricing Game

In this sub-section I characterize equilibrium prices for period 1.

The period 1 expected consumer share of a firm that charges p is:

---

[23] Case $\rho_2 < c_h$ is obvious. For case $\rho_2 < c_h$, uniqueness follows from the strict quasi-concavity of the profit function, and the *independent prices conjecture* (see footnote 18). For $\rho_2 \neq c_h$, there are two other types of equilibria. In both of these equilibria low cost firms play the same strategy as in Lemma 2. In one of these additional equilibria, high cost firms play asymmetric pure strategies; some firms charge $p_{2h}^* = c_h$, and others are inactive. In the other equilibrium, high cost firms mix between charging $p_{2h}^* = c_h$, and being inactive. Since, $\underline{p}_2 = \hat{p}_l < \rho_2 \le p_{2h}^*$, as in Lemma 2, neither of the conclusions of section 4 are affected. The same reasoning applies to the equilibrium of sub-section 3.2.2.

$$\varphi_1(p) = \begin{cases} 0 & \Leftarrow \rho_1 < p \\ 1/n_1 & \Leftarrow p \leq \rho_1 \end{cases}$$

To ensure that high cost firms are active in period 1, let: $0 \leq \pi(\widehat{p}_l, c_h) + v_{hl}\pi(\widehat{p}_l, c_l)/\mu$.[24]

The next Lemma characterizes the equilibrium prices for period 1. Again I focus on $\rho_1 < \widehat{p}_h$.

Lemma 4: In period 1: **(i)** Low cost firms charge their monopoly price. High cost firms charge the period 1 reservation price. **(ii)** Each firm's price is $\widehat{p}_l$ with probability μ, and ρ_1 with probability $1 - \mu$:

$$F_1^*(p;\rho_1) = \begin{cases} 0 & \Leftarrow p < \widehat{p}_l \\ \mu & \Leftarrow \widehat{p}_l \leq p < \rho_1 \\ 1 & \Leftarrow \rho_1 \leq p \end{cases}$$

§

Due to the lock-in effect, even if in period 2 a firm charges a price acceptable to consumers, on the equilibrium path, it will only sell either to its period 1 customers, or to consumers that are searching. Thus, when the period 1 reservation price falls below the high cost level, $\rho_1 < c_h$, a high cost firm sells below marginal cost in period 1, but secures a larger consumer share for period 2.[25]

From Lemma 4 $n_1 = 1$ and

$$\Delta C = \begin{cases} 0 & \Leftarrow c_h \leq \rho_2 \\ 1 - \mu v_{ll} - (1-\mu)v_{hl} & \Leftarrow \rho_2 < c_h \end{cases}$$

3.3 The Equilibrium Reservation Prices

In this sub-section I establish the equilibrium reservation prices. I also relax the assumption that in period 2 consumers learn for free the current price of their period 1 supplier.

Let:

$$\varpi := \begin{cases} [1 - (v_{ll} - v_{hl})]\sigma & \Leftarrow c_h \leq \rho_2 \\ [1 - (v_{ll} - v_{hl})\mu]\sigma & \Leftarrow \rho_2 < c_h \end{cases}$$

---

[24] If $\pi(\widehat{p}_l, c_h) + [v_{hl}\pi(\widehat{p}_l, c_l) + (1-v_{hl})\pi(\widehat{p}_h, c_h)] < 0$ a high cost firm is inactive in period 1 if ρ_1 is low enough, and there is a level of ρ_1, p^s, for which a high cost firm is indifferent between being active and inactive in period 1. The analysis of this paper corresponds to case $p^s \leq \rho_1$. Case $\rho_1 < p^s$ allows more intertemporal profiles, but adds no economic insights.

[25] High cost firms can price below marginal cost in period 1, and by doing so, earn higher profits in period 2. This is not predatory pricing (Areeda & Turner (1975)). The purpose of period 1 high cost firms is not to expel rivals, but to build a customer base for period 2, which is necessary, since consumers do not move freely between firms.

The next Lemma uses Lemmas 2 and 4 to restate the equilibrium conditions for the reservation prices in a more useful way.

Lemma 5: The period 2 and period 1 equilibrium reservation prices are determined by, respectively:

$$\begin{cases} \mu[S(\widehat{p}_l) - S(\rho_2)] - \sigma = 0 & \Leftarrow \quad c_h \le \rho_2 \\ \ [S(\widehat{p}_l) - S(\rho_2)] - \sigma = 0 & \Leftarrow \quad \rho_2 < c_h \end{cases}$$

(4)

$$\mu[S(\widehat{p}_l) - S(\rho_1)] - \varpi = 0$$

(5)

§

Denote by σ_r, the cost of a consumer learning the period 2 price of its period 1 supplier. I assumed that $\sigma_r = 0$. Next I relax this assumption. Let:

$$\alpha_i := \begin{cases} \upsilon_{il}/\mu & \Leftarrow \quad c_h \le \rho_2 \\ 1 - \mu + \upsilon_{il} & \Leftarrow \quad \rho_2 < c_h \end{cases}$$

The next Lemma identifies the search cost values for which the lock in effect holds.

Lemma 6: If σ_r belongs to $[0, \alpha_i \sigma]$, then clients of a period 1 cost c_i firm are better off visiting first in period 2 their period 1 supplier, than visiting first another firm chosen at random. §

The lock-in effect is transparent when it is costless to observe the period 2 price of a period 1 supplier. However, the lock-in effect holds under weaker conditions. Besides, it depends also on the intertemporal cost correlation. Consider, for example, the case of a consumer that patronized a low cost firm in period 1, and let $\upsilon_{ll} = 1$. Then $\sigma_l > 1$, and in period 2 the consumer will be prepared to pay more than σ, to return to its period 1 supplier, before visiting another firm chosen at random. Also, since $\upsilon_{hl} < \upsilon_{ll}$, the lock-in effect is stronger for clients of a period 1 low cost firm, than for clients of a period 1 high cost firm, $\alpha_h < \alpha_l$.

4 Price Dynamics

In this section I discuss price dynamics.

The next Lemma establishes a useful result about reservation prices.

Lemma 7: If there is no exit, the period 1 reservation price is lower than the period 2 reservation price. §

Since period 1's costs are positively correlated with period 2's costs, $\upsilon_{hl} < \upsilon_{ll}$, period 1's costs are *informative* of period 2's costs. And, since high cost firms charge higher prices than low cost firms, period 1's prices are also *informative* of period 2's prices.

Consumers tend to buy at the same firm in both periods. In addition, period 1's prices are *informative* of period 2's prices. Finding a low cost firm in period 2 is valuable only for period 2, whereas finding a low cost firm in period 1 is valuable for period 1 and also for period 2. Thus, if there is no exit, and hence the measure of active firms is the same in both periods, in period 1 consumers conduct a more thorough search than they would for a single purchase. That is, in period 1 consumers hold a lower reservation price than in period 2, $\rho_1 < \rho_2$.[26]

The next Proposition establishes the results about price dynamics.

Proposition 1: (i) If high cost firms are active in period 2, then the period 2 price distribution first-order stochastically dominates the period 1 price distribution. **(ii)** If high cost firms are inactive in period 2, then the period 1 price distribution first-order stochastically dominates the period 2 price distribution. **§**

[Insert Figure 4 here]

When active, high cost firms charge the reservation price. Since in period 1 the reservation price is lower than in period 2, if high cost firms are active in period 2, $c_h < \rho_2$, prices *increase* from period 1 to period 2, $F_2^* \leq F_1^*$ (Figure 5 (a)). If high cost firms are inactive in period 2, $\rho_2 < c_h$, prices *decrease* from period 1 to period 2 $F_1^* \leq F_2^*$ (Figure 5 (b)). The measure of inactive firms in period 2, n_2, is non-increasing in the search cost, and decreasing in the probability of a firm having a low cost in period 1.

To sum up, switching costs and the intertemporal correlation of production costs, which emerges as firms learn about the new technology, lock-in consumers. Hence, firms are prepared to initially charge low prices to build a customer base for the future, where they hope to have low costs. If however firms fail to reduce costs, and reservation price is low, perhaps because the search cost is small, firms exit the industry. Over time, prices increase if no exit occurs, and decrease if exit occurs.

---

[26] If $\upsilon_{hl} = \upsilon_{ll}$, period 1's costs and prices are *not Informative* of period 2's costs and prices, hence $\rho_1 = \rho_2$. If $\upsilon_{hl} < \upsilon_{ll}$ and exit occurs, the period 2 price distribution suffers a first-order stochastic dominated shift, which pushes ρ_2 down. However, if $\mu > 1/(\upsilon_{ll} + \upsilon_{hh})$, $\rho_1 < \rho_2$ still holds.

I can now state, without proof, the next Corollary about industry variables.

Corollary 1: If there is exit, then from period 1 to period 2: **(i)** both the output per firm and the industry output increase, and **(ii)** the industry average price decreases.   §

The case in which search costs are *low*, and therefore the period 2 reservation price is *low*, $\rho_2 < c_h$, corresponds to a *shakeout* scenario, in which output expands and prices decrease. A shakeout like the one which occurred in electronic markets after April 2000, emerges in my model when search costs are *low*. This is in line with the common wisdom that electronic markets reduce search costs. According to an estimate, finding a high interest rate certificate of deposit requires 25 minutes using the telephone, 10 minutes using the Internet, and less than a minute using a price-comparison search engine (Butler et al. (1997)).

When search and switching costs are *high*, emerges an intertemporal pattern of increasing prices. Initial low prices correspond to the case of penetration pricing, identified, e.g., by the switching costs literature (Farrell & Klemperer (2001)).

The evidence reported in sub-section 1.1 is inconclusive about which of the 2 intertemporal price patterns will characterize the evolution of e-commerce. Most likely, price dynamics will vary across industries. The price decrease identified by Brown & Goolsbee (2002), occurred due to the spread in search engines use, and therefore is not accounted for by Proposition 1. In sub-section 6.1 I discuss consumer heterogeneity, which explains the price decrease identified by Brown & Goolsbee (2002).

Exit leading to lower, rather than to higher prices, in a context in which firms have market power, is seemingly counter-intuitive. In the model, market power is not determined by the number of rivals, but rather by how costly it is for consumers to observe prices, and the consumers' beliefs about the prices charged in the industry. Exit reduces prices for two reasons. First, because it has a *selection effect*. High cost firms exit the industry. And second, because it gives consumers information about the remaining firms. If exit occurs, only low cost firms remain in the industry, which leads consumers to hold lower reservation prices.

5 Generalizations

The model laid out in section 2 captures some of the aspects I wanted to discuss in this paper in a simple way. However, expository simplicity was obtained at the expense of imposing some limitations on the model. In this section I consider four generalizations, which address these limitations.

5.1 Consumer Heterogeneity

In this sub-section I discuss consumer heterogeneity.

Pereira (2004a) and Pereira (2002) explore some consequences of consumer heterogeneity. Next, I explain briefly how consumer heterogeneity can be introduced. This extension will allow prices to decrease over time, as a result of an increase in low search cost consumers, and thereby explain the price decrease identified by Brown & Goolsbee (2002).

Consider section 2's model, except for the following. There are 2 types of consumers, which differ only with respect to their search cost. Some consumers have a *low search cost*, and other consumers have a *high search cost*. For simplicity I will focus on the case where there is no exit.

In either period, low search cost consumers hold a lower reservation price than high search cost consumers. There are 2 types of equilibria. In both, low cost firms charge their monopoly price, and sell to both types of consumers. At a *competing* equilibrium, high cost firms charge the reservation price of low search cost consumers, and compete with low cost firms for both types of consumers. At a *segmentation* equilibrium, high cost firms charge the reservation price of high search cost consumers, and sell only to these consumers; low search cost consumers buy from low cost firms. The higher is the proportion of low search cost consumers, the more willing are high cost firms to lower their price to sell to low search cost consumers.

Suppose that in period 1 the proportion of low search cost consumers is small, and as a consequence, the model is at a *segmentation* equilibrium. Then, an increase in the proportion of low search cost consumers from period 1 to period 2, can cause the model to switch from a *segmentation* to a *competing* equilibrium. In other words, an increase in the proportion of low search cost consumers can cause prices to decrease over time.

Price-comparison search engines allow consumers to easily observe and compare the prices of several firms, effectively reducing search costs for consumers that use them. If one interprets the spread in search engines use, as an increase in the proportion of low search cost consumers, then the price *decrease* identified by Brown & Goolsbee (2002) emerges.

Consumer homogeneity imposes an additional limitation. Consumers only switch of firms if exit occurs. Pereira (2002) shows that consumer heterogeneity with respect to the search cost, also allows consumer turnover even without exit.

5.2 Cost Reducing Investment

In this sub-section I discuss cost reducing investment.

Even if the creation of a new production process involves uncertainty, that can only be resolved over time, firms can influence, possibly at a cost, their technological type, as in Bagwell et al. (1997). However, except in the implausible case where cost-reducing investment completely eliminates uncertainty about future costs, the question of whether the cost distribution is exogenous or endogenous, is marginal to the issues I raise in this paper. The insights of section 4 apply, as long as firms face *some* uncertainty about their future cost, inherent to the process of learning the new technology. Next, I explain briefly how cost-reducing investment could be introduced, and which additional insights could be gleaned from this exercise.

Consider section 2's model except for the following. In period 2, first firms simultaneously make an investment that increases their likelihood of having a low cost, c_l. I assume that the probability that a firm who had cost c_i in period 1 has a low cost in period 2, $\upsilon_{il}(a_i)$, is twice differentiable, strictly increasing, and concave, in the firm's *cost reducing* expenditure, $a_i \geq 0$. Let $m := \mu \upsilon_{ll} + (1 - \mu) \upsilon_{hl}$. I drop the assumption that $\mu = m$.

At an interior solution, optimal investment, a_i^*, equates the marginal benefit to the marginal cost:

$$\upsilon_{il}'(a_i^*)\left[\pi(\overline{p}_l; c_l)\varphi_2(\overline{p}_l) - \pi(p_{2h}^*; c_h)\varphi_2(p_{2h}^*)\right] = 1$$

The equation above defines implicitly $a_i = A_i(\rho_2)$. And since $m = m(a_l, a_h, \mu)$, the period 2 reservation price and investment levels, (ρ_2, a_l^*, a_h^*), are determined jointly.[27] Multiple equilibria cannot be ruled out in general.

It is possible to show that at equilibria *locally stable* with respect to the Cournot tâtonnement process (Pereira (2001)), lower search costs lead to lower period 2 prices, both because: **(i)** the measure of period 2 low cost firms increases, and **(ii)** the period 2 high cost firms' price decreases: $\partial a_i^*/\partial \sigma < 0 < \partial \rho_2/\partial \sigma$.

---

[27] The period 2 reservation price best response function is continuous and strictly decreasing in a_i, and $A_i(\rho_2)$ are non-increasing and continuous in ρ_2, except for $\rho_2 = c_h$, where they have downward discontinuities: $\lim_{\rho_2 \to c_h^+} A_i(\rho_2) < A_i(c_h)$. Existence of equilibrium follows from Tarski's fixed point theorem.

A decrease in the search cost, given the investment level, i.e., given the measure of period 2 low cost firms, m, reduces the period 2 reservation price. The fall in the period 2 reservation price increases investment, through 2 effects. First, if high cost firms are active in period 2, a fall in the period 2 reservation price forces them to lower their price, and earn a smaller per consumer profit. This increases the marginal benefit of investment. Second, if the fall in the period 2 reservation price forces high cost to exit, then the consumer share of period 2 low cost firms rises. This also increases the marginal benefit of investment. The rise in investment, in turn, increases the measure of low cost firms in period 2, m, which leads consumers to hold a lower reservation price in period 2.

An increase in the probability of a firm having a low cost in period 1, μ, has a similar effects.

If in period 1 all firms have the same investment capabilities, $\upsilon'_{hl} = \upsilon'_{ll}$, then period 1 low cost firms have a no smaller marginal benefit of investment than period 1 high cost firms, $a^*_h \leq a^*_l$. This occurs because period 1 low cost firms have a no smaller consumer share than period 1 high cost firms. This last effect reinforces, or justifies, the positive intertemporal cost correlation.

5.3 Entry in Period 2

In this sub-section I discuss entry in period 2.

Consider section 2's model except for the following. In period 2, first firms that where in the industry in period 1 observe their period 2 cost. Second, a large number of firms decide if they enter the industry, for a fixed set-up cost, $F > 0$. Then firms choose prices and consumers search for prices.

I will consider 2 extreme cases, regarding how the knowledge about the new technology acquired in period 1, spills-over in the industry in period 2. Either there is a complete knowledge spill-over, or there is no knowledge spill-over at all. In the first case, firms that consider entering the industry in period 2 have a low cost level, c_l. Some firms that where in the industry in period 1 might, nevertheless, have a high cost level, due to irreversible decisions, regarding the design of their organizations. In the second case, firms that consider entering the industry in period 2 have a low marginal cost with probability μ.

Consider first the case where there is no exit, $c_h \leq \rho_2$. There will be no additional entry, independently of how the knowledge about the new technology spills-over. The reason is that on the equilibrium path, in period 2 consumers patronize their period 1 suppliers. This is an extreme case where switching costs constitute a prohibitive entry barrier. Consumer renewal, or demand expansion, would change this, and give some scope for additional entry.

Now consider the case where there is exit, $\rho_2 < c_h$. If there is a complete knowledge spill-over, then the measure of firms that enter the industry in period 2, η, is determined by the equation:

$$\left(\frac{1-\mu}{\mu+\eta}\right)\pi(\widehat{p}_l;c_l) - F = 0 \tag{6}$$

Otherwise the analysis of sections 3 and 4 remains unchanged. If there is no knowledge spill-over, then the measure of firms that enter the industry in period 2 is also determined by equation (6). Firms that enter in period 2 and find that they have a high cost level, remain inactive.

The possibility of additional entry in period 2 makes the shakeout scenario more likely.

5.4 Phases of Unequal Length

In this sub-section I allow the two phases of the game to have unequal lengths.

One of the important characteristics of the model is that there are 2 distinct phases. First a *development* phase, in which the product is introduced, firms experiment with the technology, there is intense price competition, and consumers try to locate a low cost firm, taking into account repeat purchases. And second a *maturity* phase, in which firms learn their true cost. I associated each phase with a period, so that both phases are of equal lengths. However, the two phases can be of different lengths. In particular, the development phase can be relatively short, compared with the maturity phase. Next I allow the two phases of the game to have unequal lengths, following the modeling approach of Bagwell et al. (1997).

Consider section 2's model except for the following. To allow period 2 to be long relative to period 1, let consumers and firms have a common discount factor $\beta > 1$.

Period 2, the maturity phase, unfolds as in sub-section 3.1.

In the second stage of period 1 equation (2) becomes:

$$\int_{\underline{p}_1}^{\rho_1} [S(p) - S(\rho_1)]dF_1(p) + \beta \int_{\underline{p}_1}^{\rho_1} [G(p) - G(\rho_1)]dF_1(p) = \sigma$$

The firms pricing behavior in period 1 is as described in Lemma 4.

Redefine ϖ as:

$$\varpi' := \begin{cases} [1 - \beta(v_{ll} - v_{hl})]\sigma & \Leftarrow \quad c_h \le \rho_2 \\ [1 - \beta(v_{ll} - v_{hl})\mu]\sigma & \Leftarrow \quad \rho_2 < c_h \end{cases}$$

Equation (5) becomes:

$$\mu[S(\widehat{p}_l) - S(\rho_1)] - \varpi' = 0$$

Implicit differentiation of the equation above shows that period 1 reservation price, ρ_1, is strictly decreasing in β. This result is intuitive. The larger the maturity phase, the larger the benefit of finding a low cost firm in period 1, and therefore the larger the incentives for consumers to conduct a more active search in period 1. As a consequence, the reservation price in period 1 for the case where the maturity phase is larger than the development phase, $\beta > 1$, is smaller, than the period 1 reservation price for the case where the maturity phase and the development phase are of equal lengths, $\beta = 1$.

The implications for the price dynamics of the maturity phase being longer than the development phase, $\beta > 1$, instead of both phases being of equal lengths, $\beta = 1$, are the following. When there is no exit in period 2, $c_h < \rho_2$, and prices increase over time, the price hike is larger. When there is exit, $\rho_2 < c_h$, and prices decrease from period 1 to period 2, the price cut is smaller. Otherwise, the analysis of section 4 remains unchanged.

6 Conclusions

This paper develops a model based on *switching costs* and *technological uncertainty*, intended to explain some aspects of the price dynamics of e-commerce. The model is related to Benabou (1993), Fishman & Rob (1995), MacMinn (1980), and Reinganum (1979), where firms set prices, and consumers search for prices. Firms have different marginal costs, which may change over time. Initial low costs help predict future low costs, and high costs may lead to exit.

Switching costs and the intertemporal correlation of production costs that emerges as firms learn about the new technology, lock-in consumers. Firms are prepared to initially charge low prices to build a customer base for the future, where they hope to have low costs. If however firms fail to reduce costs, and reservations prices are low, perhaps because search costs are small, firms exit the industry. Over time, prices increase if no exit occurs, and decrease if exit occurs. Prices may also decrease over time, if the proportion of low search cost consumers increases.

Appendix

Lemma 1: (i) Obvious from the inspection of (1). **(ii)** Let ρ_2' and ρ_2'' be the reservation prices associated with F_2' and F_2''. I show that $F_2'' < F_2' \Rightarrow \rho_2' < \rho_2''$. Suppose that $\rho_2'' \leq \rho_2'$. From (1), after integrating by parts, $\int_{\underline{p}_2}^{\rho_2'} D(p) F_2' dp = \sigma = \int_{\underline{p}_2}^{\rho_2''} D(p) F_2'' dp$, or, $\sigma = \int_{\underline{p}_2}^{\rho_2''} D(p)[F_2'' - F_2'] dp - \int_{\rho_2''}^{\rho_2'} D(p) F_2' dp < 0$, which is false. §

Lemma 2: (i) I proceed in 5 steps. In *step* 1 I show that $\underline{p}_2 = p_{2l}^* \le p_{2h}^* = \overline{p}_2$. Suppose that $p_{2h}^* < p_{2l}^*$. By definition: $\Pi(p_{2h}^*; \rho_2, c_l) \le \Pi(p_{2l}^*; \rho_2, c_l)$ and $\Pi(p_{2l}^*; \rho_2, c_h) \le \Pi(p_{2h}^*; \rho_2, c_h)$. Adding the inequalities one gets $(c_h - c_l)[D(p_{2l}^*)\varphi_2(p_{2l}^*) - D(p_{2h}^*)\varphi_2(p_{2h}^*)] \ge 0$, which is false, since $\varphi_2(.)$ is non-increasing and $D(.)$ is strictly decreasing. Thus $p_{2l}^* \le p_{2h}^*$. In *step* 2 I show that $p_{2l}^* < \rho_2$. Follows from *step 1* and Lemma 1: (i). In *step* 3 I show that $p_{l2}^* = \overline{p}_l$. Given *step 2* and the definition of $\varphi_2(.)$, from the c_l firms' perspective, $\varphi_2(p_{2l})$ is given. Thus, only $\pi(.)$ matters to determine p_{2l}^*. Suppose $p_{2l}^* \ne \overline{p}_l$. Consider first $p_{2l}^* < \overline{p}_l$. There is a $\varepsilon > 0$ sufficiently small such that $p_{2l}^* + \varepsilon < \rho_2$. Thus, if a c_l firm deviates and charges $p_{2l}^* + \varepsilon$, it loses no customers, and by strict quasi-concavity, $\pi(.)$ rises. Thus, $\overline{p}_l \le p_{2l}^*$. Now consider $\overline{p}_l < p_{2l}^*$. If a c_l firm deviates and charges $p_{2l} = \overline{p}_l$, by definition of $\overline{p}_l$, profit rises. Thus, $p_{2l}^* \le \overline{p}_l$, and therefore, $p_{2l}^* = \overline{p}_l$. In *step* 4 I show that $p_{2h}^* = \rho_2$ for $c_h < \rho_2$. Suppose $p_{2h} < \rho_2$. If a c_h firm charges $p_{2h}^* = \rho_2$, it loses no customers, and $\pi(.)$ rises as in *step 3*. Suppose $\rho_2 < p_{2h}$. A c_h firm makes no sales, whereas if $p_{2h}^* = \rho_2$, it has a strictly positive profit. In *step* 5 I show that $p_{2h}^* \in (\rho_2, +\infty)$ for $\rho_2 < c_h$. A c_h firm makes zero profits for any $p_{2h} \in (\rho_2, +\infty)$; otherwise it makes a negative profit. **(ii)** Obvious. §

Lemma 3: I proceed in 6 steps. In *step* 1 I show that the consumers' problem is well defined. Denote by $V_1(A_1)$, the period 1 maximum expected surplus, net of the search expenditure, of a consumer who's acceptance set is A_1 and behaves optimally. Denote by $K_1(\sigma) := -\sigma + \int V_1(A_1)dF_1$, the expected value in period 1 of paying an additional σ to draw a new price, and subsequently behaving optimally. The Bellman equation of the consumers' problem is:

$$V_1(A_1) = \max\{S(p) + G(p), K_1\}$$

The consumers' problem has a well defined and finite optimal value function, and optimal search terminates in a finite number of steps with probability 1 (DeGroot (1970), Lemma 1, p. 350 and Theorem. 1, p. 347).

In *step* 2 I characterize the consumers' optimal strategy. If consumers search, the expression for $V_1(A_1)$ can be written as:

$$V_1(A_1) = -\sigma + V(A_1)\left[1 - \int_{A_1} dF_1(p)\right] + \int_{A_1}[S(p) + G(p)]dF_1(p)$$

Some manipulation gives the expression bellow, which defines the optimal acceptance set A_1^*:

$$\int_{A_1^*}[S(p) + G(p) - V_1(A_1^*)]dF_1(p) = \sigma \tag{I}$$

Let: $A_1^+ := \{p|S(p) + G(p) - V_1^* > 0\}$, $A_1^0 := \{p|S(p) + G(p) - V_1^* = 0\}$, $A_1^- := \{p|S(p) + G(p) - V_1^* < 0\}$. $A_1^+, A_1^- \ne \varnothing$, since $S(+\infty) + G(+\infty) \le K_1(+\infty) < K_1(\sigma) < S(\underline{p}_1) + G(\underline{p}_1)$, for $\sigma \in (0, +\infty)$, and the value of the search problem is decreasing in σ; $A_1^0 \ne \varnothing$ by continuity of $S(.) + G(.)$. Thus, $A_1^* = A_1^+ \cup A_1^{00}$, where A_1^{00} is any subset of A_1^0, i.e., the optimal strategy for the consumer is to stop to search when he observes a price on A_1^*; otherwise continue to search.

In *step* 3 I establish an auxiliary Lemma. The expected share of consumers of a firm that charges p is:

$$\varphi_1(p, \rho_1) = \begin{cases} 0 & \Leftarrow p \in A_1^* \\ 1/n_1 & \Leftarrow p \notin A_1^* \end{cases}$$

As before $n_1 > 0$.

Lemma A: (0) $p_{1l}^* \in A_1^*$; **(i)** $p_{1l}^*, p_{1h}^* \in A_1^* \Rightarrow \underline{p}_1 = p_{1l}^* \le p_{1h}^* = \overline{p}_1$; **(ii)** $p_{1h}^* < p_{1l}^* \Rightarrow p_{1h}^* \notin A_1^*$; **(iii)** $p_{1l}^* < \sup A_1^*$; **(iv)** $p_{1l}^* = \overline{p}_l$.

Proof: (0) $A_1^* \ne \varnothing$, otherwise the left-hand side of (6) is 0 while $0 < \sigma$. Suppose that $p_{1h}^* \in A_1^*$ and $p_{1l}^* \notin A_1^*$. If $p_{1h}^* \in A_1^*$, then charging p_{1h}^* earns c_h firms a non-negative profit. Thus, if a c_l firm deviates and charges p_{1h}^*, it make a strictly positive profit, contradicting $p_{1l}^* \notin A_1^*$. **(i)** Since $\varphi_1(.)$ is constant when $p_{1l}^*, p_{1h}^* \in A_1^*$, the argument in

Lemma 2: (i) step 1 applies. **(ii)** From (i), if $p_{1h}^* < p_{1l}^*$, then $p_{1l}^* \notin A_1^*$ or $p_{1h}^* \notin A_1^*$. Using (0) the result follows. **(iii)** Case $p_{1l}^* < p_{1h}^*$ is obvious. If $p_{1h}^* < p_{1l}^*$ then $p_{1l}^* < \sup A_1^*$, otherwise the left-hand side of (6) is zero while $0 < \sigma$. **(iv)** As in Lemma 2: (i). §

In *step* 4 I establish $\text{Prob}[P_2 \le p | P_1 = q]$. Using Lemmas 2 and A, and the definition of υ_{is}, the distribution of the price a firm charges in period 2, conditional on charging price q in period 1 is:

$$\text{Pr}ob[P_2 \le p | P_1 = q] = \begin{cases} \begin{cases} 0 & \Leftarrow & p < \underline{p}_2 \\ \upsilon_{ll} & \Leftarrow & \underline{p}_2 \le p < \overline{p}_2 & \Leftarrow & q = p_{1l} \\ 1 & \Leftarrow & p \ge \overline{p}_2 \end{cases} \\ \begin{cases} 0 & \Leftarrow & p < \underline{p}_2 \\ \upsilon_{hl} & \Leftarrow & \underline{p}_2 \le p < \overline{p} & \Leftarrow & q \ne p_{1l} \\ 1 & \Leftarrow & p \ge \overline{p} \end{cases} \end{cases}$$

In *step* 5 I show that $S(.) + G(.)$ is decreasing for $\hat{p}_l \le p$. Denote by $V_2(p)$, period 2's net maximum expected surplus of a consumer whose best available offer in period 2 is p, and behaves optimally. From sub-section 3.1.1:

$$V_2(p) = \begin{cases} S(p) & \Leftarrow & \text{p} < \rho_2 \\ S(\rho_2) & \Leftarrow & \rho_2 \le p \end{cases} \tag{II}$$

Thus, $G(p_{1l}) = \upsilon_{ll} S(\overline{p}_l) + (1 - \upsilon_{ll}) S(\rho_2)$. Assuming the equilibrium refinement that when consumers observe a firm charging $p \ne \hat{p}_l$ they infer that the firm has cost c_h: $G(p \ne p_{1l}) = \upsilon_{hl} S(\overline{p}_l) + (1 - \upsilon_{hl}) S(\rho_2)$, and, $G(p_{1l}) - G(p) = (\upsilon_{ll} - \upsilon_{hl})[S(\overline{p}_l) - S(\rho_2)] > 0$.

In *step* 6 I establish equation (2), and thus that the consumer's optimal period 1 search strategy has the reservation price property. Thus, for $\hat{p}_l \le p$, $S(.) + G(.)$ is decreasing, and $A_1^0 \cap \{p | p \ge \hat{p}_l\}$ is a singleton; denote its value by ρ_l. Furthermore, $A_1^* \cap \{p | p \ge \hat{p}_l\} = [\hat{p}_l, \rho_2]$. Manipulation of (I) gives:

$$\int_{\underline{p}_1}^{\rho_1} [S(p) - S(\rho_1)] \, dF_1(p) + \int_{\underline{p}_1}^{\rho_1} [G(p) - G(\rho_1)] \, dF_1(p) = \sigma$$

Thus, the optimal period 1 strategy can be characterized as holding a reservation price, ρ_1.

This concludes the proof. See Hey (1979) for a related discussion. §

Lemma 4: (i) As in Lemma 2 for p_{1l}^*, it has a strictly positive profit. In *step* 5 I show that $p_{2h}^* \in (\rho_2, +\infty)$ for $c_h \le \rho_2$. Case $\rho_2 < c_h$ follows from assumption $0 \le p(\overline{p}_l, c_h) + \upsilon_{hl} p(\overline{p}_l, c_l)/\mu$ and s_2^*. **(ii)** Obvious. §

Lemma 5: Using Lemma 2, (4) follows directly from (1). From Lemmas 2 and 4, and the definition of v_{il}, $G(p_{1l}) = \upsilon_{ll} S(\overline{p}_l) + (1 - \upsilon_{ll}) S(\rho_2)$, $G(p \ne p_{1l}) = \upsilon_{hl} S(\overline{p}_l) + (1 - \upsilon_{hl}) S(\rho_2)$, and thus:

$$G(p_{1l}) - G(p) = (v_{ll} - v_{hl})[S(\overline{p}_l) - S(\rho_2)] \tag{III}$$

Using Lemma 4 and (III), (2) can be written as:

$$\mu\{[S(\overline{p}_l) - S(\rho_1)] + (\upsilon_{ll} - \upsilon_{hl})[S(\overline{p}_l) - S(\rho_2)]\} - \sigma = 0$$

or using (4) and ϖ, as (5). §

Lemma 6: In period 2, a customer of a period 1 cost c_i firm should visit first its period 1 supplier, rather than visit first another firm chosen at random, if $-\sigma_r + \upsilon_{il} S(\overline{p}_l) + (1 - \upsilon_{il}) S(\rho_2) \ge -\sigma + \int V_2 dF_2$, or replacing $\int V_2 dF_2$ from (II), and rearranging, if $\sigma_r \le \sigma + (\upsilon_{il} - \mu)[S(\overline{p}_l) - S(\rho_2)]$. Using (4) gives the result. §

Lemma 7: Follows from (4) and (5). §

**Proposition 1: (i)-(ii)** Follow from $\mu = m$, Lemmas 2, 4, and 5. §

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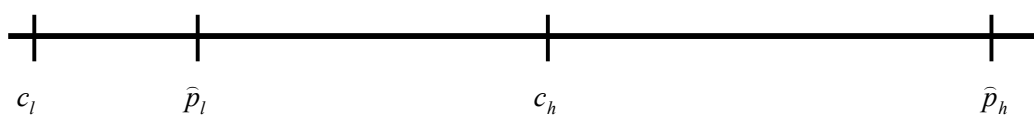
Figure 1(a): Shutdowns
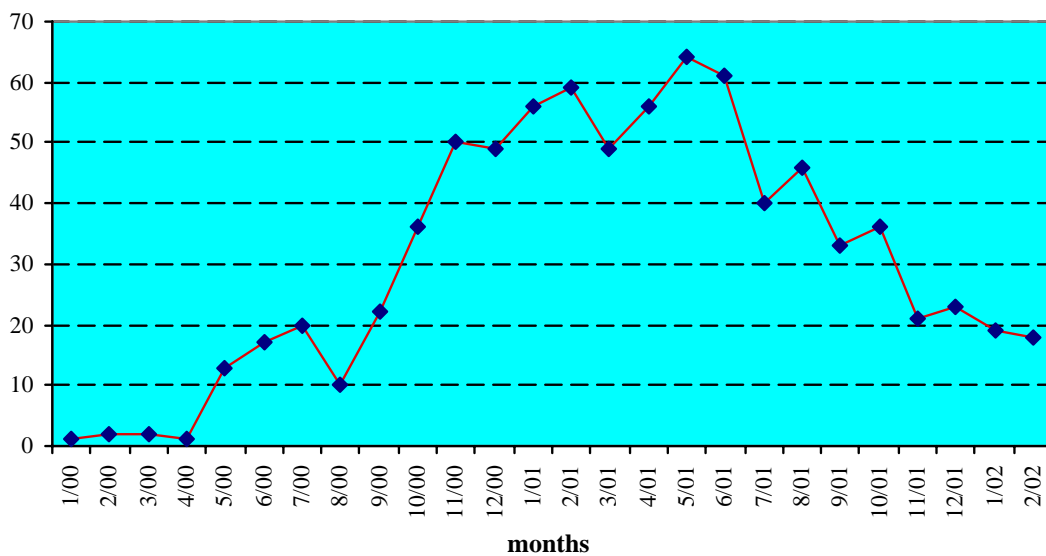
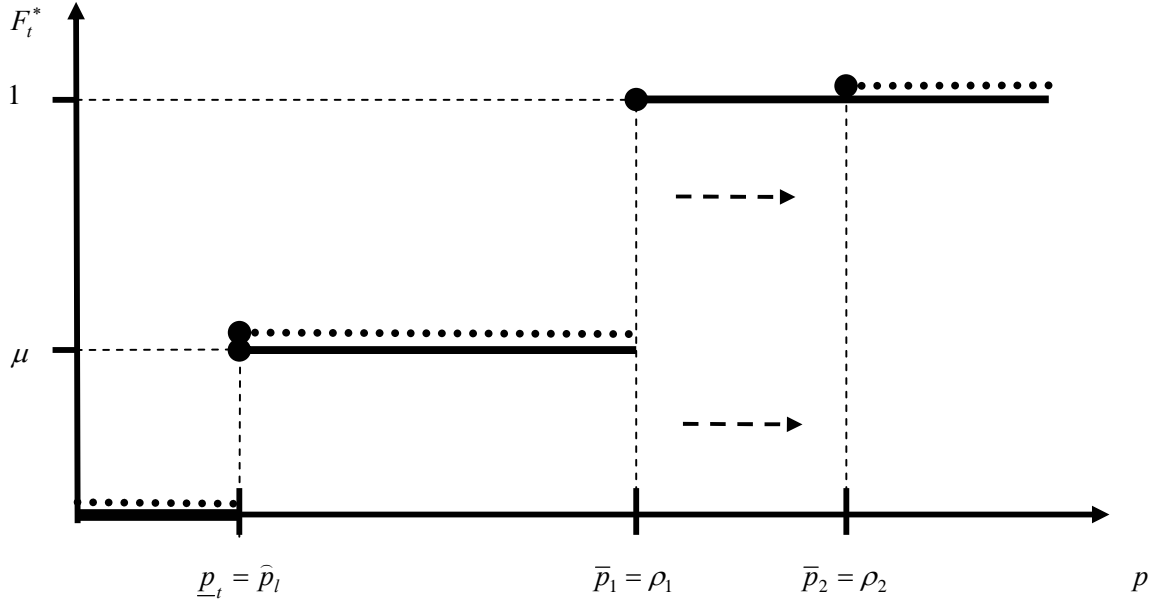**Figure 1(b): Cumulative Shutdowns**
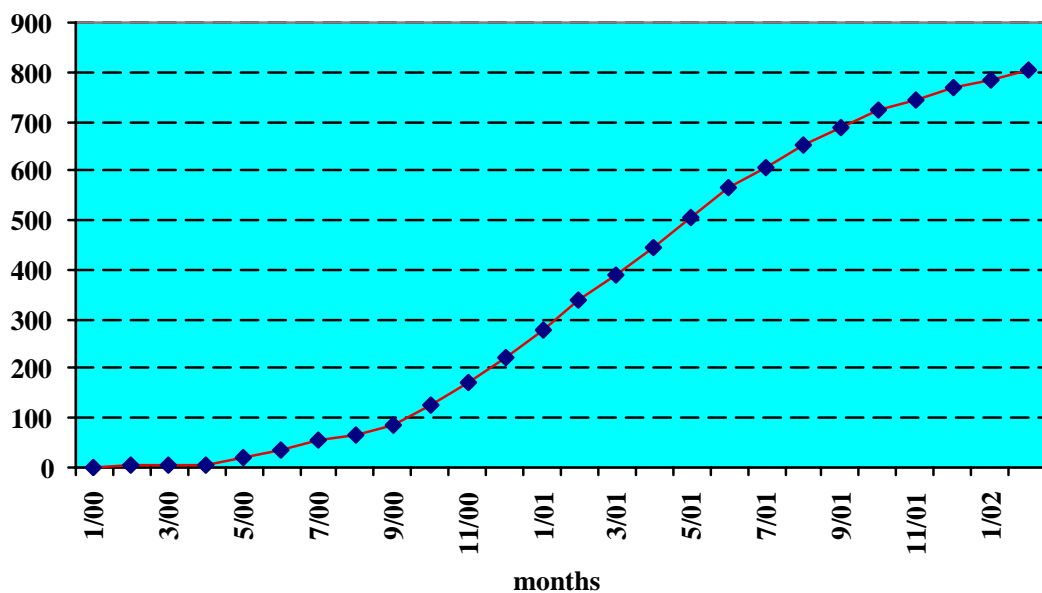
Figure 2: Cost Uncertainty
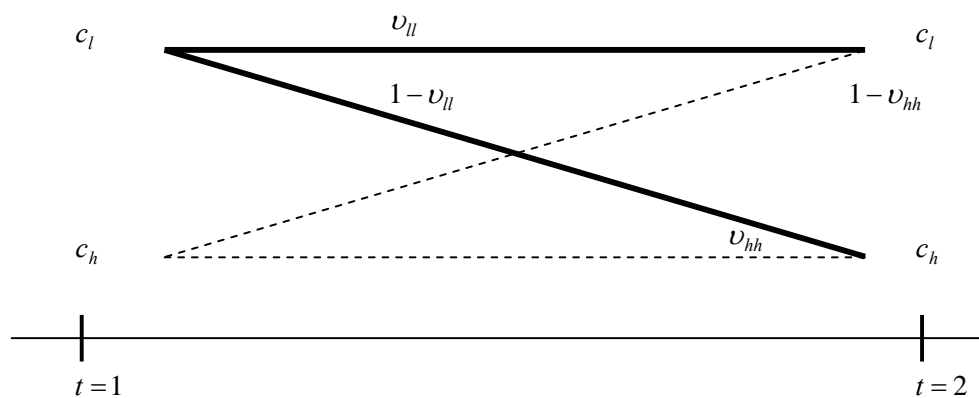
A period 1 low cost firm remains a low cost firm in period 2 with probability υ_{ll}, and with probability $1 - \upsilon_{ll} - \upsilon_{lh}$ becomes a high cost firm; similarly for a high cost firm.
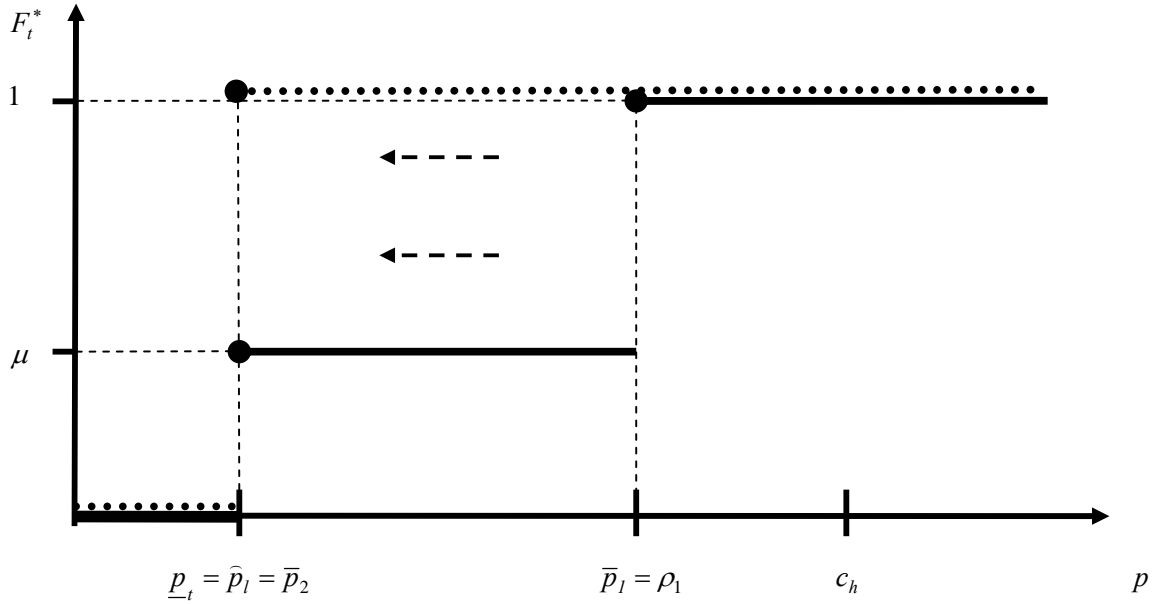
Figure 3: Cost Levels

Figure 4 (a): Prices Increase Over Time

Low cost firms always charge $\widehat{p}_l$. If high cost firms are active in period 2, prices increase over time.

The continuous line represents F_1^*, and the dotted line represents F_2^*.

Figure 4 (b): Prices Decrease Over Time

If high cost firms are inactive in period 2, prices decrease over time.

The continuous line represents F_1^*, and the dotted line represents F_2^*.