Market Skimming in a Hotelling Model of Overlapping Innovators*

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Abstract

Whereas new products of higher quality always benefit consumers, the newness itself benefits some consumers, but not others, and for some, it is even a disadvantage. We capture these features in a Hotelling model of OverLapping Innovators (HOLI model), entailing a sequence of static Stackelberg-Hotelling games of horizontal product differentiation, that we extend by vertical product differentiation. The HOLI model predicts that entry skimming (pricing above established products of comparable quality) tends to occur in young markets, while exit skimming is the preferred strategy in mature markets. Using advanced dynamic hedonic regression methods, we verify the model's predictions for the laser printer market.

Keywords: Dynamic duopoly; horizontal differentiation; vertical differentiation; hedonic regression; laser printer market

JEL classification: L11, L63, C23

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1 Introduction

Many markets are characterized by regular product innovations and improvements. As a rule, when new products of higher quality enter the market, they do not immediately replace all older ones. Therefore, at any point in time, product variants of different quality and vintage coexist and only the products with the worst price-performance ratio exit the market.

However, higher quality is not the only difference between new and old products. A second distinctive feature of new products is their novelty. Most consumers would still differentiate between new and old products, even if they were of the same quality. Some prefer tried and tested products, while others choose products for their newness.

Products that have been introduced long ago, may be considered as no longer up-to-date or simply “boring”. Consumers may fear that buying these products will make them seem dull to others, whereas consumers buying a newly introduced product may expect to be regarded as modern and interesting. According to this signaling theory, firms should introduce new products into the market at prices above those of the older products of comparable quality, and during the later stages of the product's life cycle, price it below newer products of comparable quality. This strategy is commonly referred to as market skimming, but for the sake of clarity, we prefer to speak of *entry skimming*.

Other consumers, however, may prefer established products, if they are doubtful about the quality and the ease of use of the new product. These consumers continue to buy the time-tested products as long as they are available. The seller of a new product can counter such initial scepticism not only by advertising but also by an aggressive pricing policy during the early stages of the product life cycle. Once a sufficiently large customer base has been established, in the later stages of the product life cycle, the price is set above those of newly entering rival products of comparable quality. This strategy we denote as *exit skimming*.

In summary, whereas new products of higher quality always benefit consumers, their newness benefits some consumers, but not others, and for some, it is even a drawback. Therefore, the analysis of markets characterized by continuous technical improvements should account for both quality and novelty. In the industrial organization literature, competition between products of different quality is generally modeled as vertical product differentiation, whereas differentiated consumer tastes are commonly captured by horizontal product differentiation in the tradition of Hotelling (1929). This suggests that markets characterized by technical progress should be studied by means of models that combine horizontal differentiation (capturing different preferences for novelty) with vertical differentiation (capturing product quality differences).

In the literature, horizontal and vertical product differentiation are usually studied in isolation (Lambertini, 2006). An early exception is Ireland (1987) who studies the price setting of a duopoly in which there are two types of differentiated consumers. The first Vertically Extended Hotelling (VEH) model is proposed by Neven and Thisse (1990). In their duopoly model, consumers are differentiated with respect to both the horizontal characteristic and quality valuation. The two competing firms decide on the horizontal characteristic, the quality, and the price of their respective products. Building on Launhardt's (1885) seminal work, Dos Santos Ferreira and Thisse (1996) propose a VEH model in which product quality is interpreted as its versatility. Consumers are differentiated with respect to some arbitrary horizontal characteristic. The duopolists decide on product quality and price.

In the present paper, we are concerned with maturing markets, characterized by regular product turnover and technical progress. Therefore, we specify a particularly simple VEH model that can easily be embedded into a dynamic context. In our VEH model, consumers differ in their preferences for novelty, the horizontal characteristic. The degree of product novelty is exogenously given. That is, the incumbent offers an established product of zero novelty that competes against the entirely novel product introduced by the entrant.

Due to technical progress, the entrant's product is of better quality than the incumbent's. The absolute difference in quality is assumed to be exogenous, implying that the duopolists compete only on price. All consumers appreciate the difference in quality in the same way. We formalize this similarly to Deltas and Zacharias (2006). They consider the sub-game perfect equilibrium of a two-period game in which every consumer buys only one unit of the product, but must choose between period 1 in which only one product is available, and period 2 in which there is a choice between the old product and a better new one.

In common with almost all Hotelling models of horizontal differentiation, the models described above utilize the Nash equilibrium. An early exception to this rule is Anderson (1987), who applies the Stackelberg equilibrium. This is also the obvious choice for our VEH model in which an incumbent (the Stackelberg leader) competes against an entrant (the Stackelberg follower).

Finally, our Stackelberg-VEH model is implemented in a dynamic context. For this purpose, we assume that the Stackelberg game is played repeatedly and today's entrant is the incumbent of the next period, while today's incumbent leaves the market and is replaced by a new entrant with a still better product. The absolute quality improvements are assumed to be constant over time, capturing the declining rate of technical progress in maturing markets.

In sum, our assumptions generate an infinite-horizon model with overlapping firms, in the same manner as common overlapping generation models. Therefore, we refer to our model as the Hotelling model of OverLapping Innovators (HOLI model). This model is complex enough to account for the key aspects of markets with product turnover and technical progress. At the same time, it is sufficiently simple to generate, for each level of market maturity, a unique Stackelberg equilibrium. The findings of the HOLI model provide a clear picture of the relationship between market maturity and the relative profitability of entry and exit skimming. It turns out that entry skimming occurs in young markets, while exit skimming is the preferred strategy in mature markets.

In addition to the analytical contribution, this paper also provides an empirical case study, verifying the analytical predictions of the HOLI model. The laser printer market is an important example of a mature market with rapid changes in the availability of product variants (printer models). Being a mature market, the HOLI model predicts exit skimming. Laser printer prices tend to decline substantially over their life cycle, which *prima facie* is in stark contrast to exit skimming. However, the observed prices are not the relevant ones, as model verification requires quality-adjusted prices of laser printers. Using advanced dynamic hedonic regression methods, we derive such quality-adjusted prices. It emerges that, on average, established printer models are sold at a higher quality-adjusted price than novel printer models. In other words, exit skimming prevails, as predicted by the HOLI model.

The paper is organized as follows. Section 2 introduces the HOLI model, and in Section 3, we derive the evolution of the Stackelberg equilibrium prices as product quality improves over time. A discussion of the results can be found in Section 4, while Section 5 presents the case study of the laser printer market and relates it to the predictions of the HOLI model. Section 6 concludes.

2 The HOLI Model

We consider a VEH model featuring two producers (*incumbent* and *entrant*) that compete on price (Bertrand competition). The incumbent is assumed to be the Stackelberg leader. The product of the entrant (Product E) is offered at price P_E and the product of the incumbent (Product I) at price P_I. For simplicity, there are no production costs.

The consumers are of mass 1 and uniformly distributed along the interval $[0, 1]$. The consumer's location is equivalent to her taste parameter $x \in [0, 1]$. Each consumer can buy either one unit of Product I or one unit of Product E or no unit at all. The established Product I exactly matches the taste of the consumer located at $x = 0$ and the novel Product E exactly matches the taste of the consumer located at $x = 1$ (horizontal product differentiation). More specifically, the consumer rents derived from the Products I and E are defined by

$$U_I(P_I) = V - tx - P_I$$
$$U_E(P_E) = V + \Delta - t(1 - x) - P_E ,$$

where V is consumer x's willingness to pay for a product that conforms precisely to her own taste and has the same quality as Product I. The difference in quality between Products E and I is indicated by Δ (vertical product differentiation). The parameter $t > 0$ measures the sensitivity of consumer rent with respect to the distance between the consumer's location x and the product's location ($x_I = 0$ and $x_E = 1$). The larger t, the greater the extent to which consumers dislike a given distance between their own and the product's location.

Without loss of generality, the consumer rents can be expressed in units of t:

$$u_I(p_I) = v - x - p_I \quad (1)$$
$$u_E(p_E) = v + \delta - (1 - x) - p_E \quad (2)$$

where $u_I(p_I) = U_I(P_I)/t$, $u_E(p_E) = U_E(P_E)/t$, $v = V/t$, $\delta = \Delta/t$, $p_I = P_I/t$, and $p_E = P_E/t$.

The diagonal solid lines in Figure 1 (a)-(c) show the consumer rents u_E and u_I for given prices as a function of the taste parameter x. The slopes of these consumer rent lines are -1 and $+1$, respectively. Technical progress, represented by δ, is assumed to be exogenous. For $\delta = 0$, the new product has the same quality as the old one, so that the absence of vertical differentiation is a special case. Recall, however, that horizontal differentiation remains present, since both products still differ as to their novelty.

Last period's entrant is the present incumbent. As in the previous period, she offers a product of quality v. The present entrant is new to the market and so is his

Product E of quality $v+\delta$. At the end of the period, the present incumbent and her Product I will exit the market, and the present entrant will become the incumbent of the next period. His product's quality will be unchanged at $v' := v+\delta$. He will compete with a new entrant whose product will have the quality $v'+\delta$. Therefore, the market structure during the new period is exactly the same as in the previous period, the only difference being the improved basic quality of the Products I and E (v' instead of v). Since the quality improvement δ is time invariant, the percentage change in quality from one period to the next, and thus the relevance of technical progress, will decline. In sum, we have developed a highly stylized model that captures the typical evolution of technical progress in the context of horizontal as well as vertical product differentiation.

The consumer who is indifferent between Products I and E is denoted as the marginal consumer $\bar{x}$. Equations (1) and (2) imply that the marginal consumer is located at

$$\bar{x} = \frac{1}{2}\left(p_E - p_I + 1 - \delta\right) \ . \tag{3}$$

The consumer rent (1) of the marginal consumer (3) is nonnegative, if

$$p_E \leq 2v + \delta - p_I - 1 \ . \tag{4}$$

If this condition is satisfied, each consumer will buy either of the two products. Therefore, inequality (4) is the condition of complete market coverage. In the following analysis, we distinguish between *strict market coverage*, when the inequality in (4) is strict, and *marginal market coverage*, when (4) is satisfied as an equality.

Figure 1(a) depicts the case of incomplete market coverage. Consumers with medium taste parameter x neither buy Product E nor Product I. In Figure 1(b), the consumer rents (solid lines) intersect exactly at the abscissa. This is the case of marginal market coverage. Finally, Figure 1(c) shows a situation of strict market coverage, where the consumer rents (solid lines) intersect strictly above the abscissa.

We denote the demand for I and E with D_I and D_E. When the prices p_I and p_E

are sufficiently high or the quality v sufficiently low, the consumer rent is negative for some consumers, and condition (4) is violated, resulting in incomplete market coverage. In this situation, Products I and E are bought only by consumers who derive a positive consumer rent $u_I(p_I)$ or $u_E(p_E)$ from their purchase. This yields the demand functions

$$D_I = v - p_I \tag{5}$$

$$D_E = v + \delta - p_E \; . \tag{6}$$

With complete market coverage, the demand functions of I and E directly follow from the marginal consumer $\bar{x}$:

$$D_I = \frac{1}{2}(p_E - p_I + 1 - \delta) \tag{7}$$

$$D_E = \frac{1}{2}(p_I - p_E + 1 + \delta) \; . \tag{8}$$

The complete market coverage demand functions (7) and (8) depend on both prices p_E and p_I. A price increase from the incumbent will increase the customer base of the entrant and *vice versa*. In contrast, each producer can ignore the competitor's price in the case of incomplete market coverage.

3 Stackelberg Equilibrium

In order to stress the evolutionary character of technical progress, we assume that $\delta \in [0, 1]$. This also ensures that by choosing a sufficiently low price, each producer could always ensure a positive demand for his product and therefore a positive profit. Furthermore, negative prices and prices $p_I \geq v$ and $p_E > v + \delta$ will never generate a positive profit. Therefore, we can confine our attention to prices $p_I \in (0, v)$ and $p_E \in (0, v + \delta)$. Since the outcome of the present period has no influence on the starting conditions of the next period, each period can be analyzed separately from all other periods.

3.1 Profit Functions

Incomplete Market Coverage: The relevant demand functions are (5) and (6), and the profit functions are

$$\pi_I = p_I (v - p_I) \tag{9}$$
$$\pi_E = p_E (v + \delta - p_E) \ .$$

The rectangle π_I in Figure 1(a) shows the profit of the incumbent when setting the price $p_I = v/2$. Since there are no production costs, marginal profits equal marginal revenue,

$$\frac{\partial \pi_I}{\partial p_I} = (v - p_I) - p_I \tag{10}$$
$$\frac{\partial \pi_E}{\partial p_E} = (v + \delta - p_E) - p_E \ . \tag{11}$$

A price increase has the two standard effects on revenue. The first components in (10) and (11), $(v - p_I)$ and $(v + \delta - p_E)$, reflect the revenue gains from the existing customer base (*inframarginal effects*). The second components, p_I and p_E, reflect the revenue losses caused by the contraction of the customer base (*marginal effects*).

With incomplete market coverage, both producers act as monopolists. Figure 1(a) illustrates the marginal effect of a p_E-increase by $\mathrm{d}p_E$. The price rise causes the consumer rents to fall from the solid line to the dotted line. Evidently, the entrant's customer base (the interval to the right of the intersection of the consumer rent line and the abscissa) shrinks by $\mathrm{d}p_E$.

Complete Market Coverage: The relevant demand functions are (7) and (8), and the profit functions are

$$\pi_E = p_E \left(\frac{1}{2} (p_I - p_E + 1 + \delta) \right) \tag{12}$$
$$\pi_I = p_I \left(\frac{1}{2} (p_E (p_I) - p_I + 1 - \delta) \right) \ , \tag{13}$$

where $p_E(p_I)$ indicates that the entrant is the Stackelberg follower.

The marginal profit of the entrant is

$$\frac{\partial \pi_E}{\partial p_E} = \underbrace{\frac{1}{2}\left(p_I - p_E + 1 + \delta\right)}_{\text{inframarginal}} - \underbrace{\frac{1}{2}p_E}_{\text{marginal}} \quad . \tag{14}$$

The marginal effect of a p_E-increase is depicted graphically in Figure 1(c). A price rise of $\mathrm{d}p_E$ lowers consumer rent from the solid to the dotted line. Hence, the position of the marginal consumer $\bar{x}$ shifts to the right by $\mathrm{d}p_E/2$. As a consequence, the entrant's customer base is reduced only by $\mathrm{d}p_E/2$ and not by $\mathrm{d}p_E$, as in the case of incomplete coverage. Setting (14) equal to zero yields the entrant's reaction function

$$p_E(p_I) = \frac{1}{2}\left(p_I + 1 + \delta\right) \ . \tag{15}$$

Noting from (15) that $\mathrm{d}p_E/\mathrm{d}p_I = 1/2$, the marginal profit of the incumbent can be written as

$$\frac{\partial \pi_I}{\partial p_I} = \underbrace{\frac{1}{2}\left(p_E - p_I + 1 - \delta\right)}_{\text{inframarginal}} - \underbrace{\frac{1}{2}p_I}_{\text{marginal}} + \underbrace{\frac{1}{4}p_I}_{\text{complementary}} \quad . \tag{16}$$

As before, the first two components are the inframarginal and marginal effects. The last component, $\frac{1}{4}p_I$, is the positive effect of the entrant's price reaction (as a response to a unit price increase of the incumbent) on the customer base of the incumbent (*complementary effect*). The complementary effect occurs only in the case of strict market coverage. If the price increase from the incumbent starts from a situation of incomplete or marginal market coverage, the customer base of the entrant remains unaffected.

The nature of the resulting Stackelberg equilibrium depends on the maturity of the market, that is, on the level of the quality parameter v. It turns out that there are four different stages that have to be dealt with as quality v increases over time: (I) incomplete market coverage, (II) marginal market coverage at lower values of v, (III) marginal market coverage at higher values of v, and (IV) strict market coverage. We will consider these four stages in turn. Formal proofs of the propositions are presented in the appendix. In Section 4 the findings of the four stages are put together, generating the overall picture of pricing in maturing markets.

3.2 Stage I: Incomplete Market Coverage

In the absence of any competitors, it is always profit-maximizing for a firm to set the monopoly price. At this price, the positive inframarginal effect of a further price increase is exactly offset by the negative marginal effect. Therefore, the incumbent and the entrant set the monopoly prices $p_I = v/2$ and $p_E = (v + \delta)/2$, as long as they lead to incomplete market coverage. However, over time, quality v increases twice as much as the monopoly prices. Therefore, consumer rents increase, leading to consistently growing customer bases. Finally, complete market coverage arises and monopoly pricing may no longer be profit-maximizing.

Proposition 1 *For*

$$v \leq \frac{1}{2}(2-\delta) \tag{17}$$

the Stackelberg equilibrium is given by the monopoly prices

$$p_I = \frac{1}{2}v \tag{18}$$

$$p_E = \frac{1}{2}(v+\delta)\ . \tag{19}$$

3.3 Stage II: Marginal Market Coverage at Lower Values of *v*

If there were no entrant, the incumbent would of course continue to set the monopoly price (18), even if $v > \frac{1}{2}(2-\delta)$. We demonstrate that the optimal response of the entrant is to increase his own price p_E beyond its monopoly level (19) until marginal market coverage is restored. In other words, the incumbent can act as if there were no entrant. This situation remains valid until the quality v crosses the borderline to Stage III.

In order to understand this result intuitively, assume that quality increases from $v = \frac{1}{2}(2 - \delta)$ to $v' = v + \delta$ and that the incumbent sets the new monopoly price $p_I = v'/2$. Should the entrant increase his price above last period's monopoly price $p_E = (v + \delta)/2$? The entrant's customer base has increased, and so too has the positive inframarginal effect of a p_E-increase. At the same time, due to strict market coverage, the negative marginal effect of a p_E-increase has halved ($\mathrm{d}p_E/2$ instead of $\mathrm{d}p_E$). Therefore, a p_E-increase is profitable for the entrant. This price increase is the complementary effect of the incumbent's p_I-increase.

Should the entrant raise the price to the new monopoly price, $p_E = (v' + \delta)/2$? Under the old monopoly price, $p_E = (v + \delta)/2$, the positive inframarginal effect of a p_E-increase exactly outweighed the negative marginal effect. With the new monopoly prices, both consumer rent lines would shift upward by $\delta/2$, leading to strict market coverage. The customer base of the duopolists, and therefore, the positive inframarginal effect of an additional p_E-increase, would be the same as in the previous period. However, the negative marginal effect of an additional p_E-increase would be smaller than before. Although lost revenue per customer increases slightly (due to the increased monopoly price), the number of customers lost would be halved, as compared to the previous period ($\mathrm{d}p_E/2$ instead of $\mathrm{d}p_E$). In sum, at the new monopoly prices, the smaller negative marginal effect of an additional p_E-increase no longer outweighs the unchanged positive inframarginal effect. Therefore, the entrant increases his price above the new monopoly price $p_E = (v' + \delta)/2$.

In fact, for the v-values covered by Stage II, the entrant will find price increases profitable, until marginal market coverage is restored. Price increases beyond marginal coverage are not profitable, as the negative marginal effect of a p_E-increase returns to its full size ($\mathrm{d}p_E$ instead of $\mathrm{d}p_E/2$) and any further p_E-increases would over-compensate for the positive inframarginal effect.

To summarize, when the incumbent continues to set the monopoly price, the entrant raises his own price above the monopoly level, such that marginal market coverage is restored and the incumbent's expansion of her customer base remains unchallenged. Thus, the incumbent can ignore the entrant and continue to act as a monopolist. However, the eroding customer base of the entrant also erodes the positive inframarginal effect of a p_E-increase. Ultimately, in the situation of marginal market coverage, the inframarginal effect is eroded to such a degree that it no longer exceeds the marginal effect but merely equals it. The proof of Proposition 2 below demonstrates that this situation occurs when v reaches the level $\frac{2}{5}(3-\delta)$. As v increases above this level, the entrant will price more aggressively, eating into the incumbent's customer base (see Stage III).

Proposition 2 *For*

$$\frac{1}{2}(2-\delta) \leq v \leq \frac{2}{5}(3-\delta) \tag{20}$$

the Stackelberg equilibrium is given by

$$p_I = \frac{1}{2}v \tag{21}$$

$$p_E = \frac{3}{2}v + \delta - 1 \; . \tag{22}$$

3.4 Stage III: Marginal Market Coverage at Higher Values of v

When quality improves above $v > \frac{2}{5}(3-\delta)$, the entrant would no longer react to the incumbent's monopoly pricing by raising his own price until marginal market coverage is restored. Instead, the entrant would choose a smaller price increase leading to strict market coverage and broadening the entrant's customer base at the expense of the incumbent. Consequently, it is no longer optimal for the incumbent to act as a monopolist.

Assume that quality improves from $v = \frac{2}{5}(3-\delta)$ to $v' = v + \delta$. If the incumbent were still to set the monopoly price $p_I = v'/2$, the entrant would increase his own price above the new monopoly level $p_E = (v' + \delta)/2$. However, the negative marginal effect of the p_E-increase would cancel out the positive inframarginal effect before marginal market coverage is restored. The resulting strict market coverage has repercussions for the incumbent's situation. As depicted by the upper dotted line in Figure 1(b), the negative marginal effect of a further p_I-increase is suddenly halved (from $\mathrm{d}p_I$ to $\mathrm{d}p_I/2$), such that it no longer outweighs the positive inframarginal effect. Therefore, the incumbent will increase her price above the monopoly price. In turn, the entrant will implement an additional price increase. This is the incumbent's positive complementary effect of her latest p_I-increase.

The proof of Proposition 3 below demonstrates that, for $v < \frac{5}{8}(3-\delta)$, the process of alternating price increases stops only when marginal market coverage is restored. At this point, the incumbent's negative marginal effect jumps back to its full size. This full-size marginal effect overcompensates for the positive complementary and inframarginal effects of a further p_I-increase. In fact, when $v = \frac{5}{8}(3-\delta)$, the positive effects exactly outweigh the half-size marginal effect. Note that all the way through Stage III, the p_E-increases are smaller than the p_I-increases. Therefore, in each period, additional customers return from the incumbent to the entrant.

Proposition 3 *For*

$$\frac{2}{5}(3-\delta) \leq v \leq \frac{5}{8}(3-\delta) \tag{23}$$

the Stackelberg equilibrium is given by

$$p_I = \frac{1}{3}(4v+\delta) - 1 \tag{24}$$

$$p_E = \frac{2}{3}(v+\delta)\ . \tag{25}$$

3.5 Stage IV: Strict Market Coverage

As argued in the previous section, when $v = \frac{5}{8}(3-\delta)$, the prices (24) and (25) exactly balance the incumbent's negative (half-sized) marginal effect and the positive inframarginal and complementary effects of a p_I-increase. A quality increase from $v = \frac{5}{8}(3-\delta)$ to $v' = v + \delta$ would not change this situation. The customer base and therefore the incumbent's inframarginal effect are unaffected. Furthermore, the incumbent's negative marginal effect would also be unaffected, because the reference price is still (24). Similarly, the inframarginal and marginal effect of the entrant remain constant (price and customer base unchanged), implying that the complementary effect of the incumbent is also unchanged. All in all, despite the improved quality, there is neither an incentive for the incumbent nor for the entrant to increase their prices above the level that was optimal for $v = \frac{5}{8}(3-\delta)$.

Proposition 4 *For*

$$v \geq \frac{5}{8}(3-\delta) \tag{26}$$

the Stackelberg equilibrium is given by

$$p_I = \frac{1}{2}(3-\delta) \tag{27}$$

$$p_E = \frac{1}{4}(5+\delta) \ . \tag{28}$$

4 Pricing in Maturing Markets

Propositions 1 to 4 describe the four types of Stackelberg equilibria that arise in the HOLI model as quality v increases over time. Do these findings predict entry or exit skimming? To answer this question, we link the findings of the four Propositions and derive the resulting quality-adjusted equilibrium prices $\hat{p}_I = p_I/v$ and $\hat{p}_E = p_E/(v+\delta)$. When $\hat{p}_I < \hat{p}_E$, entry skimming prevails, whereas $\hat{p}_I > \hat{p}_E$ indicates exit skimming.

The lower part of Figure 2 shows the evolution of the quality-adjusted prices $\hat{p}_I$ and $\hat{p}_E$ as quality v increases over time (for parameter $\delta = 0.1$). The curves directly reveal that, as markets mature, entry skimming is replaced by exit skimming. The upper part of Figure 2 shows the evolution of the unadjusted equilibrium prices derived in Propositions 1 to 4. It is worth discussing the findings depicted in Figure 2 stage by stage.

Stage I (incomplete market coverage) represents the lowest quality range with both producers acting as ordinary monopolists. In each period, both unadjusted prices increase by $\delta/2$. Due to the higher quality of the entrant's product, his unadjusted price and customer base, and thus his profit, is larger than that of the incumbent. The quality-adjusted prices of the incumbent and entrant are equal and remain constant as quality v increases.

Of course, if no interfering competitor existed, both producers would prefer to continue their monopoly pricing. However, when quality v reaches Stage II (marginal market coverage at lower values of v), the customer bases have broadened to such an extent that at least one of the duopolists can no longer behave as a monopolist. Strategic considerations become relevant and the entrant has the second mover advantage. If the entrant wants to win over customers of the incumbent, he can set an aggressive price and the incumbent cannot counter this attack by lowering her own price. However, the incumbent has a first mover advantage, so that she can anticipate the entrant's profit-maximizing behavior and adjust her own price setting accordingly.

At the beginning of Stage II, the entrant's incentives to gain additional customers by lowering p_E is small, because the negative inframarginal effect of a p_E-decrease is large and, due to the low price level, the positive marginal effect of a p_E-decrease is small. In other words, the relevance of the entrant's second mover advantage is negligible. The incumbent can therefore exploit her first mover advantage. In fact, she can continue to set the monopoly price, because the entrant backs off by increasing his price above the monopoly level. As a consequence, the quality-adjusted price of the incumbent remains constant, whereas the quality-adjusted price of the entrant increases. This is the phase of entry skimming. As quality v improves further, the incentives for the entrant to attack the incumbent's customer base become progressively stronger, and the relevance of the second mover advantage increases.

When quality v reaches Stage III (marginal market coverage at higher values of v), the entrant no longer backs off. If the incumbent continued to charge the monopoly price, she would lose customers to the entrant. Therefore, the incumbent must choose between two options. Firstly, she can reduce her price below the monopoly level, ensuring that there is still no incentive for the entrant to attack her own customer base. Secondly, she can set a relatively high price, such that some of her customers drift to the entrant, but the remaining ones generate an acceptable average revenue. The incumbent will start with the second option, because at the beginning of Stage III, her customer base is still relatively large and the positive inframarginal effect of a p_I-increase, together with the positive complementary effect, more than compensates for the negative marginal effect.

The quality-adjusted price of the incumbent increases, whereas the quality adjusted-price of the entrant remains constant. Note also that at some quality stage, the incumbent's quality-adjusted price exceeds that of the entrant. Accordingly, entry skimming is replaced by exit skimming. Furthermore, the incumbent's customer base continues to shrink, eroding her incentives to pursue a retraction strategy. The entrant experiences two opposing effects, his customer base increases, lowering the incentives for aggressive pricing, but the revenue from each customer increases, making aggressive pricing more appealing.

Finally, when quality v reaches Stage IV (strict market coverage), the incumbent finds it more profitable to defend her remaining customer base instead of retreating further. She does not raise her price above the final level of Stage III, $p_I = \frac{1}{2}(3 - \delta)$, because such an increase would induce the entrant to win over new customers by increasing his own price by a smaller amount than the incumbent. With an unchanged price p_I, the entrant faces exactly the same situation as at the end of Stage III. Therefore, he sets the same price as back then. With constant unadjusted prices and increasing quality, quality-adjusted prices fall, with $\hat{p}_I$ exceeding $\hat{p}_E$. In other words, exit skimming also prevails in Stage IV. Only for the (unrealistic) case of $\delta > 1/3$, at very high quality levels, would the duopolists revert to entry skimming.

The constant unadjusted prices of Stage IV imply that the technical progress benefits only the consumers, while profits remain constant. The indifferent consumer is located at

$$\bar{x} = \frac{1}{8}(3 - \delta) < \frac{1}{2}$$

and profits are $\pi_I = \frac{1}{16}(\delta - 3)^2$ and $\pi_E = \frac{1}{32}(\delta + 5)^2$ with π_E exceeding π_I for $\delta \in [0, 1]$.

5 Case Study: Laser Printer Market

The HOLI model predicts that in the early stages of a market's evolution, there is entry skimming, $\hat{p}_E > \hat{p}_I$. Due to technical progress, the quality of the products, and therefore the willingness to pay for them, increases over time. At the same time, the rate of technical progress declines. The HOLI model predicts that this process finally leads to a reversal of the original inequality of prices, $\hat{p}_E < \hat{p}_I$, that is, to exit skimming.

We now proceed to verify this prediction empirically, for a market that has been characterized by continuous technical progress, namely the laser printer market. In contrast to products such as smartphones, laser printers are not status products. When given the choice between an old and a new printer model of the same quality and price, it is unlikely that all consumers would buy the new model purely for reasons of social prestige. Therefore, it is more reasonable to assume that the continuum of consumers can be approximated by a rectangular distribution over the interval $[0, 1]$, than by a cluster near $x = 1$ (high preference for the new product). Furthermore, laser printers are mature products. Although newly introduced printers generally have better quality characteristics than older ones, the quality increments are small in relation to overall quality. In terms of the model, the ratio δ/v is small, and the model predicts exit skimming: $\hat{p}_I > \hat{p}_E$.

For various reasons, the laser printer market is a suitable field for empirical investigation. Price data is readily available and can easily be obtained from online retailers. In addition, most quality aspects of a printer can be defined and measured in terms of its technical specifications, e.g. the number of pages printed per minute, or whether duplex printing is possible. Most non-measurable quality characteristics can be subsumed reasonably well in fixed brand effects. Furthermore, the market is concentrated and dominated by a small number of large firms. Finally, the life cycle of laser printers is relatively short: the median lifetime is 33 months in our data set. It is therefore possible to observe many market entries and exits within a few years of market observation.

To investigate empirically whether the quality-adjusted prices of newly entering products are in fact lower than that of the incumbent products, one needs a method to take into account the different quality characteristics of laser printers. For this purpose, the hedonic regression approach is a powerful tool. In the following analysis, we briefly present the data set. We then describe the dynamic hedonic regression model that is used to determine quality-adjusted prices, the estimation method, and the empirical results.

5.1 Data

We collected monthly online data generated in the German market for black-and-white laser printers over the 48 months from January 2003 to December 2006.[1] The following continuously measurable attributes were recorded: print speed, processor speed, standard memory, extended memory, memory that can still be added, printing resolution, paper capacity of the multi-purpose tray, standard paper capacity of the main paper tray, supplementary paper capacity, optional paper capacity, and maintenance cost per page.

In addition, there are dummy variables for: interfaces with and without network connectivity, maximum paper size A3, equipped with network connectivity, optional upgrade with network connectivity, printer language PCL5, printer language PCL5 or PCL6, GDI-printer (Graphical Device Interface), equipped with

[1] A detailed description of the data set can be found in Auer and Trede (2011).

Postscript 2, equipped with Postscript 3, optional upgrade with Postscript, built-in duplex, upgraded with duplex, optional upgrade with duplex.

Since non-measurable quality aspects can be subsumed by brand dummies, we also included dummies for: Brother, Canon, Epson, Hewlett-Packard, Kyocera, Lexmark, Minolta, Oki, and Samsung. No other brands were included in the sample.

In order to handle lifetime effects, and to avoid bias due to left-truncated observations, the entry month of all printers was determined, even if they had entered the market before the observation period. The number of months on the market is added to the set of attributes. The total number of printer attributes is then $K = 35$.

Prices of the same product in a given month may differ from retailer to retailer. To bypass problems caused by such differing prices, an average price was computed from the individual ones offered by internet vendors.

The number of printers available in each month varies between 176 and 272. The number of different printer models is 597 and the total number of printer-month observations is 10,853. The data cover well above 95 percent of the German market.

The price data of our sample reveal that the prices of almost all laser printers fall over the duration of their market presence, measured in months since market entry. In other words, the price ratio of a printer, relative to its entry price, falls the longer the product is on the market. The thick line in Figure 3 indicates the average of these price ratios for each month for which the product is available on the market. The broken lines are pointwise 95% confidence intervals. Typically, the price falls rapidly. Six months after market entry, the price has already declined by about 5% on average. After two years, printers are about 15% cheaper than at the time of market entry.

Figure 3 suggests that entrants price their products higher than incumbents. However, this conjecture disregards the fact that new printers generally have better quality characteristics than older printers. What matters are the quality-adjusted prices and not the observed raw prices.

5.2 Dynamic Hedonic Regression

A well-established method for adjusting for quality differences is hedonic regression. Hedonic regressions have a long and lasting tradition in the economic literature (Waugh, 1928; Court, 1939; Chow, 1967; Triplett, 1969; Berndt and Rappaport, 2001; Pakes, 2003). A disadvantage of the traditional hedonic approach is its static nature. Only cross-sectional price variations over different product variants are explained by the basic hedonic regression. However, some dynamic techniques also exist: adjacent year regression (Berndt and Rappaport, 2001), continuously changing coefficients (Auer, 2007), the NTP-method (Nelson, Tanguay and Patterson, 1994), linear splines, and semiparametric approaches (see Auer, 2007, for a discussion of all these techniques). Below, we apply the dynamic hedonic regression approach of Auer and Trede (2011). A major advantage of this approach is its capability to deal rigorously with many market entries and exits.

To fix the notation, we start with the static setting. Let $\mathbf{y} = (y_1, \ldots, y_N)'$ denote the vector of log-prices of N products belonging to some product category. The K product attributes are organized in an $(N \times K)$-matrix $\mathbf{Q}$. The static hedonic regression is

$$\mathbf{y} = \mathbf{Q}\boldsymbol{\beta} + \mathbf{u} \tag{29}$$

where $\mathbf{u} = (u_1, \ldots, u_N)$ are error terms satisfying the usual OLS assumptions. Auer and Trede (2011) add a time index to (29) to make the regression dynamic. Writing $\boldsymbol{\beta}_t = (\beta_{t1}, \ldots, \beta_{tK})'$, $\mathbf{y}_t = (y_{t1}, \ldots, y_{tN_t})'$, and $\mathbf{u}_t = (u_{t1}, \ldots, u_{tN_t})'$, and collecting the attributes of all products available in period t in the matrix $\mathbf{Q}_t$, the hedonic regression model (29) at time t is:

$$\mathbf{y}_t = \mathbf{Q}_t\boldsymbol{\beta}_t + \mathbf{u}_t \ , \qquad \mathbf{u}_t \sim N(\mathbf{0}, \sigma_t^2\mathbf{I}_{N_t}) \tag{30}$$

where the matrix $\mathbf{Q}_t$ is of dimension $N_t \times K$. The number of products observed in period t is N_t which may change over time due to market entries and exits. The number of attributes K is constant.

The vector $\boldsymbol{\beta}_t$ could simply be estimated for each period $t = 1, \ldots, T$ by running T separate OLS regressions. However, Arguea and Hsiao (1993) demonstrate that this approach can suffer from large standard errors and erratic changes in the estimated attribute prices from one period to the next. Auer and Trede (2011) show that the estimation can be improved by adding the assumption that the coefficients follow a random walk process:

$$\boldsymbol{\beta}_t = \boldsymbol{\beta}_{t-1} + \mathbf{v}_t, \quad \mathbf{v}_t \sim N(\mathbf{0}, \mathbf{W}) \ , \tag{31}$$

for $t = 1, \ldots, T$, where $\mathbf{W}$ is a symmetric, positive definite $(K \times K)$-matrix, and $\mathbf{v}_t$ is a random K-vector. As usual, we assume that the disturbance vectors $\mathbf{u}_t$ and $\mathbf{v}_t$ are independent. The start vector $\boldsymbol{\beta}_0$ is a random variable with distribution

$$\boldsymbol{\beta}_0 \sim N(\mathbf{m}, \mathbf{D}) \ . \tag{32}$$

Equations (30), (31) and (32) constitute a state space model (or dynamic linear model; see, for example, West and Harrison, 1997). Equation (31) is the transition equation, and (30) is the measurement equation, while $\boldsymbol{\beta}_1, \ldots, \boldsymbol{\beta}_T$ are the state vectors. Maximum likelihood estimation of the model's coefficients $\mathbf{m}, \mathbf{D}, \mathbf{W}$ and $\sigma_1^2, \ldots, \sigma_T^2$ has to rely on numerical methods and is notoriously unstable. Auer and Trede (2011) suggest estimating all coefficients of interest – $\mathbf{W}$, $\sigma_1^2, \ldots, \sigma_T^2$ and the state vectors $\boldsymbol{\beta}_0, \ldots, \boldsymbol{\beta}_T$ – simultaneously by the Markov Chain Monte Carlo (MCMC) method, and setting an uninformative prior distribution for the initial state $\boldsymbol{\beta}_0$ parameterized by $\mathbf{m}$ and $\mathbf{D}$.

Being a Bayesian method, MCMC treats both the state variables $\boldsymbol{\beta}_1, \ldots, \boldsymbol{\beta}_T$ and the other coefficients $\boldsymbol{\psi} = (\mathbf{W}, \sigma_1^2, \ldots, \sigma_T^2)$ as random vectors. Their prior distribution is assumed to be uninformative for all coefficients.

The joint posterior distribution of $\boldsymbol{\beta}_1, \ldots, \boldsymbol{\beta}_T$ and $\boldsymbol{\psi}$, given the observed data, that is, the observed prices $\mathbf{y}_t$ and the observed product attributes $\mathbf{Q}_t$ for $t =$

$1, \ldots, T$, can be computed by Gibbs-sampling (see Auer and Trede, 2011, for details). After a burn-in period of R_0 drawings, the subsequent R drawings $\boldsymbol{\beta}_1^{*r}, \ldots, \boldsymbol{\beta}_T^{*r}$, $r = 1, \ldots, R$ are stored and averaged to obtain point estimators of expectations of the posterior distribution of the state variables, $E(\boldsymbol{\beta}_1 | \mathbf{Y}_T), \ldots, E(\boldsymbol{\beta}_T | \mathbf{Y}_T)$, given the observed data $\mathbf{Y}_T = (\mathbf{y}_1, \mathbf{Q}_1, \ldots, \mathbf{y}_T, \mathbf{Q}_T)$. The estimator of $E(\boldsymbol{\beta}_t | \mathbf{Y}_T)$ is

$$\widehat{E(\boldsymbol{\beta}_t | \mathbf{Y}_T)} = \frac{1}{R} \sum_{r=1}^{R} \boldsymbol{\beta}_t^{*r} .$$

and similarly for the other parameters.

In order to quantify the uncertainty of the point estimators, we determine pointwise $(1-\alpha)$ confidence bands for the time path $\beta_{1k}, \ldots, \beta_{Tk}$ of the k-th component of the attribute price vector. The R random draws $\beta_{tk}^{*1}, \ldots, \beta_{tk}^{*R}$ of the Gibbs sampler are ascendingly ordered separately for each time period $t = 1, \ldots, T$. Denote the order statistics as $\beta_{tk}^{*(1)} \leq \ldots \leq \beta_{tk}^{*(R)}$, then

$$\left[\beta_{tk}^{*(\alpha R/2)}, \beta_{tk}^{*((1-\alpha)R/2)} \right], \quad t = 1, \ldots, T ,$$

is a pointwise $(1-\alpha)$ confidence band for the k-th attribute price.

5.3 Results

We estimate the dynamic hedonic regression (30) for the laser printer data. The printers are described by their quality characteristics, as well as by the number of months they have been on the market (*presence*). The coefficient belonging to the covariate *presence* is the coefficient of interest. A positive coefficient would indicate that the quality-adjusted price of an older printer is greater than that of a newly introduced printer or, in the terminology of the HOLI model, that the entrant's quality-adjusted price $\hat{p}_E$ is lower than the incumbent's $\hat{p}_I$. Hence, by running a dynamic hedonic regression, we can test the empirical implication of the theoretical model that laser printers are relatively cheap at the time of market entry.

The solid line in Figure 4 represents the development of the coefficient $\hat{\beta}_{t,presence}$ for $t = 1, \ldots, T$ (where $T = 48$ months), the broken lines are pointwise 95% confidence intervals. The coefficient is significantly positive in almost all periods, indicating that an older printer is more expensive than a new one with the same quality characteristics. The size of the effect is economically significant. The coefficient's value ranges from 0.002 to 0.011 with an average value of about 0.0064, implying that, on average, the quality-adjusted price of a printer rises by 0.64% per month, or about 8% per year. In other words, the price of a printer entering the market is $1/(1.08) - 1 = 7.4\%$ lower than an incumbent printer of the same quality with a market presence of one year. This conforms to the prediction of the HOLI model.

In fact, our theoretical model makes an additional prediction. In very mature markets, the price ratio between the quality-adjusted price of the entrant and that of the incumbent is below 1, but increasing. In other words, the entrant's price discount tends to decline over time. The declining trend of the solid line in Figure 4 seems to confirm this prediction for the German laser printer market.

6 Concluding Remarks

The study of markets characterized by technical progress usually relies on rather complex analytical tools. In this paper, we introduced a much simpler alternative that we refer to as the Hotelling Model of OverLapping Innovators (HOLI model). This model transforms an essentially dynamic market process into a sequence of static market situations. The model can be seen as a combination of two basic components.

The first component is Hotelling's (1929) classic model of horizontal product differentiation, extended by vertical product differentiation. Though developed in the context of industrial organization, this Vertically Extended Hotelling (VEH) model is applicable to decision problems in various fields within and beyond that of economics (e.g., political science, medical science). In this paper, we were concerned with pricing in markets with regular product turnover and technical progress. Therefore, our VEH model combines different preferences for novelty (horizontal differentiation) with quality differences (vertical differentiation). We assumed that the entrant (Stackelberg follower) introduces a new product of better quality than the established one offered by the incumbent (Stackelberg leader).

The second component is the consistent application of this Stackelberg-VEH model in a dynamic context. For this purpose, we assumed that the last period's entrant is the incumbent of the present one. This yields an infinite-horizon model with overlapping innovative firms.

We used our HOLI model to analyze markets in which a product starts its life cycle as a Stackelberg follower, becomes a Stackelberg leader and then exits the market. In such markets, two opposing pricing strategies appear sensible and rational: entry skimming and exit skimming. Empirically, one can observe that in some markets the sellers pursue entry skimming, while in other markets, exit skimming prevails. The HOLI model explains the coexistence of the two strategies by the differences in the maturity of the respective markets. In young markets, entry skimming should arise, while in matured markets, one expects exit skimming.

The theoretical part of this paper has been supplemented by an empirical study of the German market for laser printers. In a hedonic regression analysis based on MCMC estimation techniques, it could be shown that, on average, the quality-adjusted prices of established laser printers exceed those of novel printers. In other words, the German market for laser printers exhibits exit skimming. Since the laser printer market is mature, our empirical result conforms perfectly to the predictions of the HOLI model.

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Appendix

Proof of Proposition 1: Prices (18) and (19) are the monopoly prices. They are consistent with incomplete market coverage, as long as condition (4) is violated. Inserting prices (18) and (19) into condition (4) and reversing the inequality sign yields condition (17).

Proof of Proposition 2: Prices (21) and (22) lead to marginal market coverage, any marginal price increase leads to incomplete market coverage, and any marginal price reduction leads to strict market coverage. Given the incumbent's price (21), lowering the price below (22) reduces the entrant's profit, because inserting (21) and (22) into the entrant's marginal profit (14) yields

$$\frac{\partial \pi_E}{\partial p_E} = \frac{3}{2} - \frac{1}{2}\delta - \frac{5}{4}v \ ,$$

and this expression is positive, when the right inequality of (20) holds. The entrant should not increase his price above (22) either, because inserting (22) into (11) yields

$$\frac{\partial \pi_E}{\partial p_E} = 2 - \delta - 2v \ ,$$

and this expression is negative, when the left inequality of (20) holds. Given the reaction (22), the incumbent's monopoly price (21) leads to marginal market coverage, and is therefore profit-maximizing.

Proof of Proposition 3: Prices (24) and (25) lead to marginal market coverage:

$$p_E = 2v + \delta - p_I - 1 \ . \tag{33}$$

Any marginal price increase leads to incomplete market coverage and any marginal price reduction to strict market coverage.

Given the incumbent's price (24), lowering the entrant's price below (25) reduces the entrant's profit, because inserting (24) and (25) into the entrant's marginal profit (14) yields

$$\frac{\partial \pi_E}{\partial p_E} = 0$$

and the second derivate of the profit function becomes negative. Increasing the entrant's price above (25) also reduces his profit, because inserting (25) into (11) yields

$$\frac{\partial \pi_E}{\partial p_E} = -\frac{1}{3}(v + \delta)$$

which is always negative.

If the incumbent reduces her price below (24), complete market coverage continues to hold. Inserting (24) and (25) into the incumbent's relevant marginal profit function (16) yields

$$\frac{\partial \pi_I}{\partial p_I} = \frac{5}{4} - \frac{5}{12}\delta - \frac{2}{3}v \ . \tag{34}$$

If the second inequality of (23) holds, the marginal profit is positive and a price reduction would reduce profit.

If the incumbent increases her price above (24), incomplete market coverage arises. Lowering the price (25) to (33) restores marginal market coverage and increases the entrant's profit. The entrant's marginal profit of lowering the price from (33) towards the entrant's monopoly price is obtained by inserting (33) into (14). The resulting expression is positive, if

$$p_I > \frac{1}{3}(4v + \delta) - 1 \ .$$

Since this inequality is satisfied, the reduction of p_E below (33) would reduce the entrant's profit. Therefore, the entrant would react with price (33) and the incumbent's profit functions (9) and (13) become identical. Inserting (24) into the incumbent's marginal profit (10) yields

$$\frac{\partial \pi_I}{\partial p_I} = 2 - \frac{2}{3}\delta - \frac{5}{3}v \ .$$

This expression is negative, when the left inequality of (23) holds. Therefore, a p_I-increase above (24) would reduce the incumbent's profit.

Proof of Proposition 4: Inserting (27) into the entrant's reaction function (15) yields the entrant's price (28). Given (26), prices (27) and (28) lead to strict market coverage. Since price (28) is the interior solution of a maximization problem in which price (33) is also available, the latter price – leading to marginal market coverage – is not profit-maximizing. Inserting (28) into the incumbent's marginal profit function (16), setting the resulting expression equal to zero, and solving for p_I yields (27).

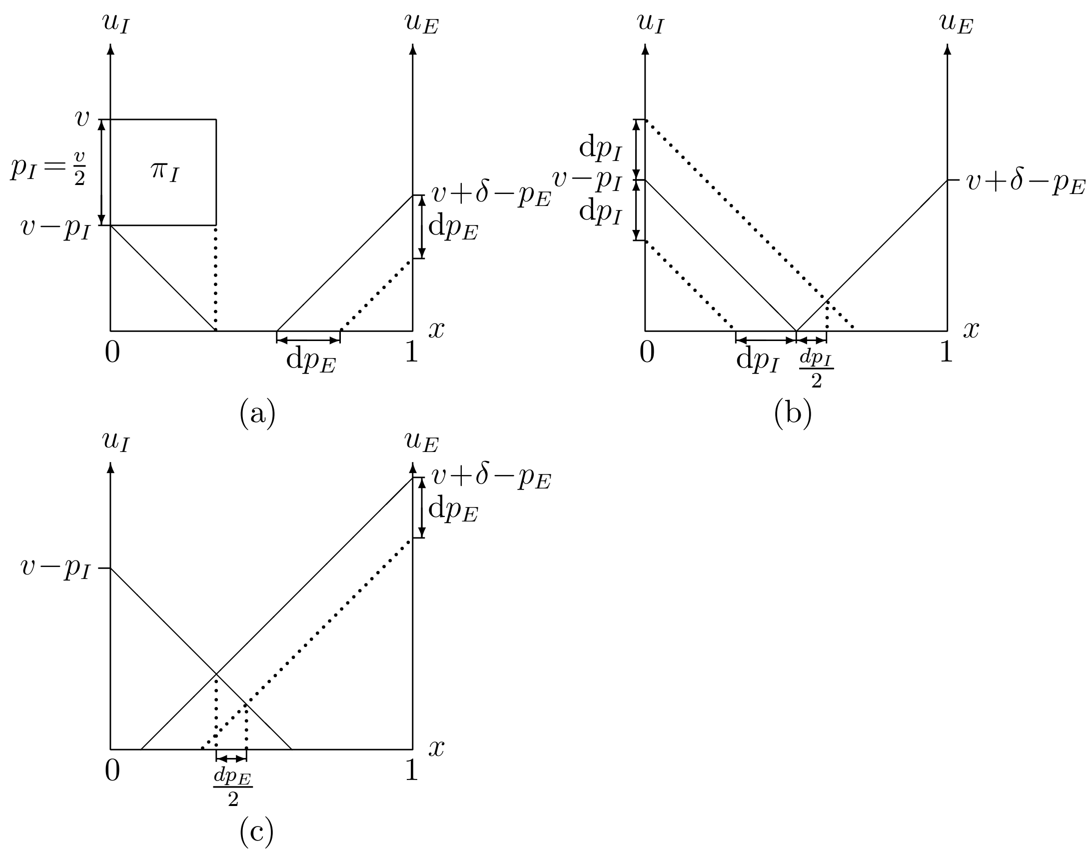

Figure 1: (a) Incomplete market coverage with $v = 0.7$ and $\delta = 0.2$, equilibrium prices are $p_E = 0.45$, $p_I = 0.35$; (b) marginal market coverage with $v = 1$ and $\delta = 0.2$, equilibrium prices are $p_E = 0.7$, $p_I = 0.5$; (c) strict market coverage with $v = 2$ and $\delta = 0.2$, equilibrium prices are $p_E = 1.3$, $p_I = 1.4$

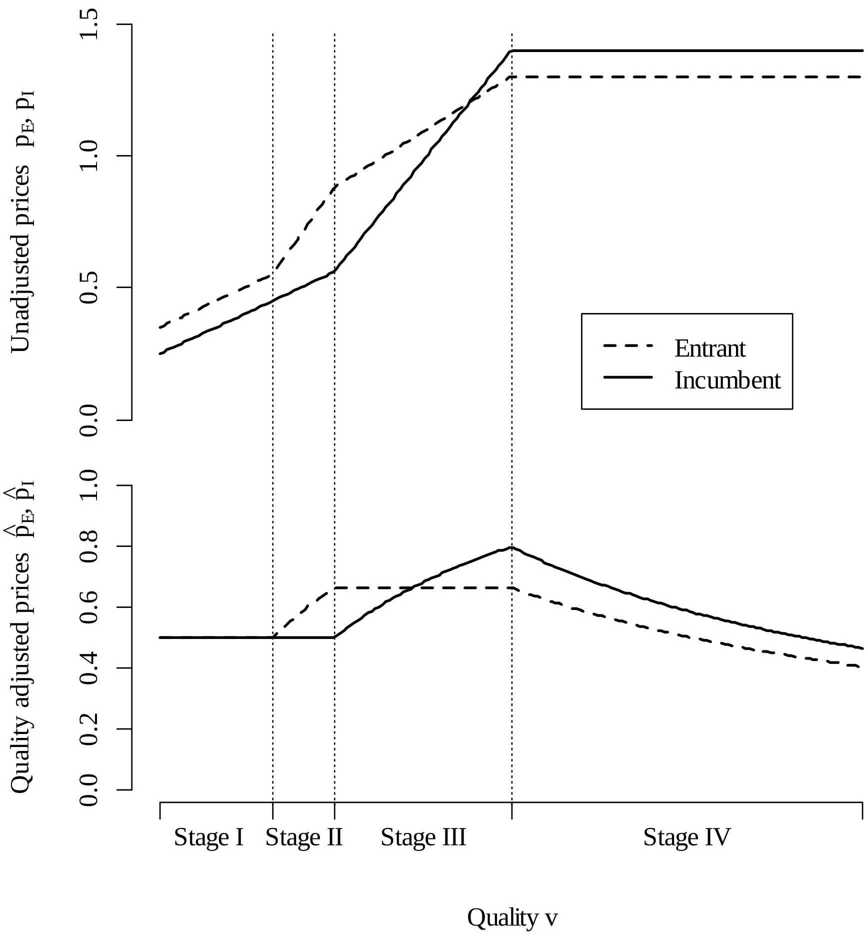

Figure 2: The evolution of unadjusted and quality-adjusted prices (for $\delta = 0.1$).

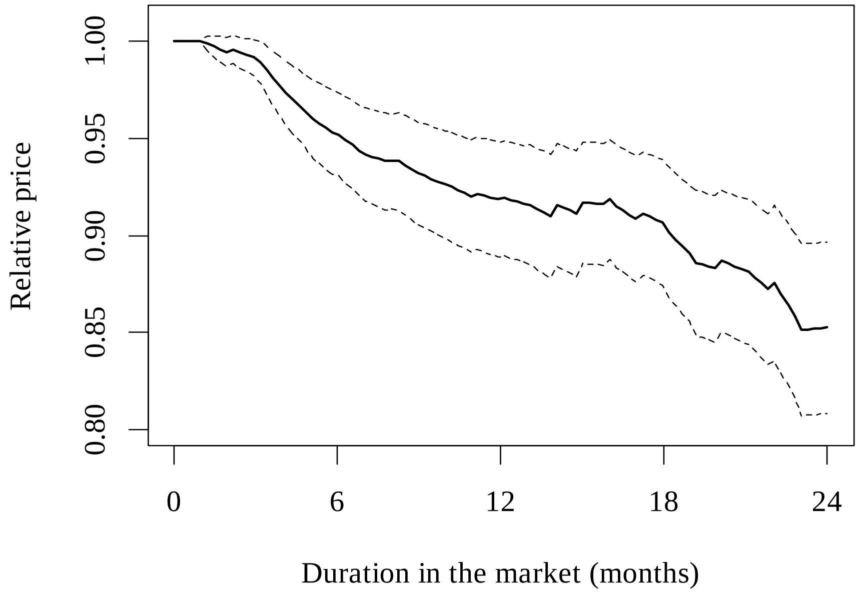

Figure 3: Price of laser printers in relation to their entry price as a function of their duration on the market (in months). The thick line is the average and the thin lines are pointwise 95% confidence intervals.

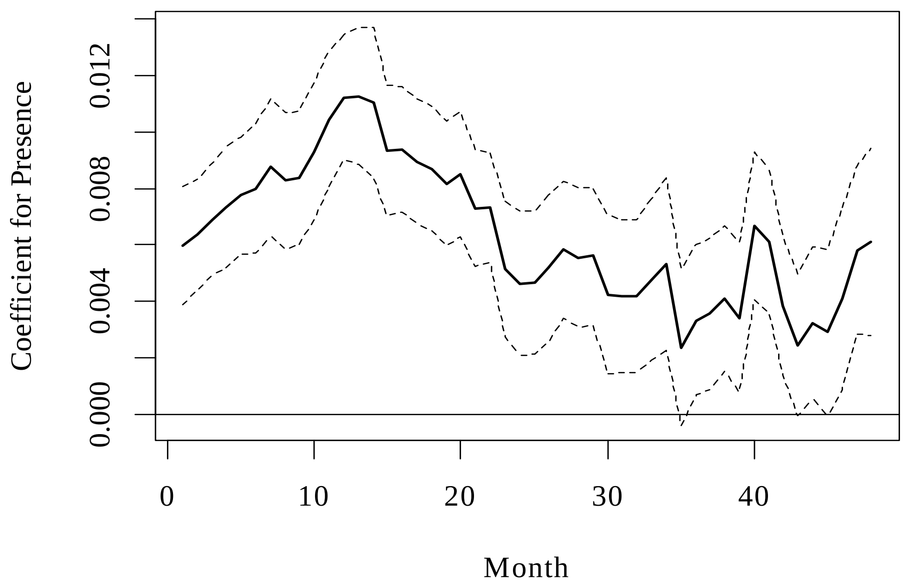

Figure 4: Development of the coefficient of the variable *presence*