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Technology adoption, brand strength and consumption externalities

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Abstract
We study a vertically differentiated duopoly with snob consumption externalities. Initially, the firm with the stronger brand identity, namely the ‘branded firm’, has a technology which is superior to that of its competitor, namely the ‘unbranded firm’. When a new superior technology becomes available, each firm must decide whether to adopt it or to continue producing with its old one. High snob consumption externalities, strong brand identity and small technological step may limit the adoption of the branded firm and favor the adoption of the unbranded one. With welfare analysis, we observe not only that excessive inertia or excessive momentum could exist but also that reverse adoptions are possible. Our findings suggest that there is no a general policy recommendation in snob markets and selective policies must be put into actions to increase the market efficiency including discouraging adoption.

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Snobby markets and technology adoption

Abstract

We study a vertically differentiated duopoly with snob consumption externalities. Initially, the firm with the stronger brand identity, namely the ‘branded firm’, has a technology which is superior to that of its competitor, namely the ‘unbranded firm’. When a new superior technology becomes available, each firm must decide whether to adopt it or to continue producing with its old one. High snob consumption externalities, strong brand identity and small technological step may limit the adoption of the branded firm and favor the adoption of the unbranded one. With welfare analysis, we observe not only that excessive inertia or excessive momentum could exist but also that reverse adoptions are possible. Our findings suggest that there is no a general policy recommendation in snob markets and selective policies must be put into actions to increase the market efficiency including discouraging adoption.

Keywords: Vertical differentiation; Technology adoption; Consumption externalities; Excessive momentum / inertia; Reverse adoption.
1 Introduction

There is a general consensus that top-class branded products receive a price premium due to their superior technology. Think, for example, to a Ferrari sport-car, or to a Burberry coat, or to Bose speakers. Additional characteristics, such as design, material, reliability, post-sale assistance also concur to justify a higher price of the product. This compound explanation for top-class branded product price premium is consistent with the characteristic approach to consumer theory (Lancaster, 1966): consumers assign a positive value to product characteristics so that a branded product with superior attributes receives a higher evaluation and therefore it is sold at a higher price.

However, there are other top-class branded products that receive a price premium although produced with an inferior technology. Also in this case, examples are abundant. Rolex incorporates a mechanical movement which does not reach the accuracy even of the cheapest watches based on a quartz movement. Similarly, a twenty century icon, such as Harley-Davidson motorbike is payed more than its closest competitors in the cruiser category, although most of them are superior for manageableness, fuel consumption, and acceleration. In other cases, the decision not to adopt has had a negative but ex-ante rational outcome. Nokia, which was the world leader in the mobile phone market from 1998 until 2012 was superseded by Samsung and Apple in the next few years.

In order to gain insights on the factors that might offer an explanation for the emergence of a change in the technology leadership, we explicitly consider Snob Consumption Externalities (SCEs), i.e. when a consumer willingness-to-pay for a (branded) product becomes higher when the product is owned by a limited number of people (Leibenstein, 1950).

Most of the literature on technological adoption indeed focuses on other types of consumption externalities, i.e. network externalities (David, 1985; Katz and Shapiro, 1985; Besan and Farrell, 1994). With network externalities, the technology which initially gains a larger number of users tends to get the whole market and the winning technology is not necessarily the one with superior characteristics. Indeed, a larger base of users of the inferior technology may be sufficient to offset the better characteristics of the other. As a result, the market is locked in the inferior technology and overall welfare is not maximized. Network externalities are also responsible for other inefficiencies deriving from a wrong timing in the adoption (Farell and Soloner, 1985): excessive momentum, when firms adopt too early, i.e. the immediate adoption of the technology is welfare reducing; and excessive inertia when they adopt too late, i.e. firms do not adopt now a technology which is welfare enhancing.
SCEs usually arise from conspicuous consumption: a person shows his wealth and income by spending money on visible items and, in turn, receives a utility from being esteemed, respected and envied (Veblen, 1899). Literature on snob externalities and innovation usually focuses on fashion and luxury markets, where brands are used to signal status or group membership (Pesendorfer, 1995). However, Heffetz (2011, 2012) has found that conspicuous consumption may concern not only good or service categories such as cars, jewelry and clothing, but also categories such as furniture, recreation services, barbers and cigarettes.

For those goods that are affected by conspicuous consumption, a firm can obtain an extra value by limiting the number of users (Basu, 1989, Katz and Spiegel, 1996). Basu (1989) shows that when SCEs are sufficiently high, a firm creating an exclusive club has higher profits. When explicit exclusion is not feasible, high prices are an alternative way to limit participation and increase profits (Katz and Spiegel, 1996). When SCEs are particularly strong, the demand curve can become upward-sloping (called the 'Veblen effect'). With a different perspective, Becker (1991) has shown that exclusiveness can be created when the number of units to be sold is limited (e.g. seats at the restaurant) by under-pricing in such a way that the demand is rationed.

We study technology adoption in *snob markets* through a model of vertical product differentiation with SCEs. The initial assumptions of the model captures the outcome of a technological race. In the past, now well established firms have gained a premium position by producing with a better technology of its opponents. For example, in the age of mechanical watches, the use of the tourbillon mechanism guaranteed a more precise measurement of time with respect to the pin-lever movement.\(^1\) In more recent years, in face of an innovation (e.g. the invention of the quartz movement), well-established branded firms decided to maintain the old technology (Rolex) while almost all unbranded firms have moved to the new and superior one. Harley-Davidson demonstrated its superiority dominating most of the US (dirt-track) races at the expenses of its national competitor (Indian). Nokia was a major contributor to the mobile telephone industry, having, among the others, introduced the mobile gaming, reduced the phone size, and contributed to introduce and spread the global system for mobile communications (GSM) and long term evolution (LTE) standards.

At the beginning of the game, thus, the firm with the stronger brand identity, namely the ‘branded firm’, has a technology which is superior to that of its competitor, namely the ‘unbranded firm’. When a new superior technology becomes available, each firm must

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\(^1\)The tourbillon as well as the pin-lever movements are oscillators introduced in portable watches to contrast the bias induced by gravitation forces and increase accuracy of the measurement. For a detailed economic history of watches, see: Landes (1991).
decide whether to adopt it or to continue producing with its old one. In our examples, Rolex after developing one of the best quartz mechanisms preferred to sell mechanical watches (see also Section 2). Similarly, after a period of crisis, new investors acquiring Harley-Davidson brand decided to maintain all the distinguishable characteristics of previous models, even if this choice would have had negative implications for manageableness, fuel consumption, and acceleration of its bikes. Finally, Nokia decided not to move to the free-available superior technology, the Android system, and continue to develop its proprietary system, Symbian.

In the baseline case (no SCEs), we have the following results. If brand strength is high (or technological step is small), both firms will adopt the new superior technology. For intermediate values of brand strength only the branded firm will adopt the new technology. When brand strength is small, there are two asymmetric equilibria where one firm adopts the new technology and the other stays on its previous one: asymmetric adoption allows firms to soften price competition and escape from the Bertrand competition trap. We cover three different types of snob markets: high-tech markets, where SCEs are larger when the branded firm has the better technology (smartphones); vintage markets where SCEs are larger when the branded firm has the older technology (old motorcycle); exclusive markets where SCEs are larger when the branded firm has a different technology (watch).

The presence of SCEs modifies the outcome of the baseline model, at least in two respects. First, the parameter set from which the unbranded firm adopts the new technology enlarges: SCEs make the branded firm less aggressive. Second, excluding the case of high-tech markets, for intermediate to high values of brand strength and for high values of SCEs only the unbranded firm will adopt the new technology. This result comes from the will of the branded firm to distinguish its product from that of the opponent and to make it more snobbish. In this case, the branded firm loses its technological leadership but it gains from having larger SCEs. For a large set of parameter values, the branded firm continue to be patronized by high value consumers but in some cases (medium brand strength and medium to high SCEs), high value consumers start patronizing the unbranded one. Note that for low values of brand strength there are two possible equilibria where only one of the two firms innovates and the other firm holds the old technology. This result is similar to that described in the baseline case. Thus, snob markets have a different behaviour only when one firm has a sufficiently strong brand identity.

The comparison of the market equilibrium to the first-best solution leads to new and composite welfare considerations. In the absence of consumption externalities the first-best solution is always the adoption of the new technology from both firms. Thus, market

\footnote{In a sequential game, the adopter is always the first mover.}
outcome inefficiency is due to excessive inertia, i.e. one firm will decide not to adopt. Consequently, the standard policy to cure the market failure is to provide incentives to innovators. When consumption externalities are sufficiently large, indeed, the first-best solution is that only one firm innovates. We find that for different snobbish markets, it can be optimal to that only the branded firm adopts (high-tech), only the unbranded firm adopts (vintage) and either the branded or the unbranded adopts (exclusive). From a welfare point of view, all the three different snobbish markets may display reverse adoption, i.e. the adopter in the market equilibrium should have maintained the old technology and the firm deciding not to adopt the new technology should have used the new technology. Moreover, in the high-tech case, we can observe excessive momentum, i.e. one firm (unbranded) adopts even if it is socially inefficient. Finally, in the other snobbish markets, we may observe excessive inertia also for high consumption externalities. These results suggest that there is no a general policy recommendation in snob markets and selective policies must be put into actions to increase the market efficiency including discouraging adoption.

The remaining of the paper is organized as follows. Section 2 offers a brief description of the Rolex case, which is related our exclusive snob markets. Rolex decided not adopting the quartz movement, also if it spent 15 years to obtain one of the best quartz watch movement in the world. In the remaining part of the Section, we also mention the Nokia case and Harley-Davidson case, that are, respectively, an example of high-tech and vintage snobbism. Section 3 describes the main assumptions of the model and the pricing stage equilibrium. Section 4 shows the main findings. Section 5 concludes.

2 The Rolex case

At the beginning of the sixties, two Swiss watchmaking firms, Rolex and Omega, covered about 85% of the market. Both leading brands were very famous and renowned for the quality of their mechanical movements.

In 1958, a new watch producer located in Japan, Seiko, began to develop a quartz movement. The potential advantage of this technology is that the quartz crystal can vibrate at a frequency that is about 10,000 times higher than a mechanical oscillator, making the quartz movement potentially much more accurate for measuring time (Walt, 2007). In 1962, twenty Swiss firms, including Rolex and Omega, cooperate through the Center Electronique Horloger (CEH) to develop a quartz watch movement. The CEH

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3The first quartz movement was patented by a US producer in 1928, although its economic development was limited because of high costs of semiconductor technology until 1960s.
was organized around two research teams, called Alpha and Beta. Only the latter had significant results. In 1966, Seiko announced the development of a prototype of quartz wristwatch and, a few months later, CEH presented two prototypes, called Beta 1 and Beta 2. In 1968, CEH developed the Beta 21 technology, which was used by sixteen of the twenty Swiss firms (including Rolex and Omega).

In 1972, Rolex abandoned the Beta 21 technology and began to develop its own 5035/5055 quartz movement for a new wristwatch line called Oysterquartz. Advancements in technology have yielded quartz modules with superior accuracy, but when it debuted, the 5035/5055 quartz movement only had one rival from a technological standpoint: the 2.4Mhz Omega 1516 movement used in the famous Marine Chronometer wristwatches. After a limited number of pieces (25,000), Rolex decided to stop the production of quartz watches in 2001.

Rolex’s decision of not adopting cannot derive from the features of the technology itself, as quartz movement is technically preferable to the mechanical one. Moreover, this decision cannot be justified by informational asymmetries or excessive investment costs. Indeed, Rolex was a market leader and it had already developed this new technology: 21 out of 50 patents on electrical mechanisms were filled by Rolex from 1960 to 1990. Our explanation for this apparent contradiction is that consumers in the watch market are willing to pay for being one of the few having a distinctive product, i.e., in our terminology, they are exclusive.

The strategy of not adopting a superior technology is not limited to watches. The twenty century icon of the motorcycle market, Harley-Davidson, is exceeded by Japanese competitors in terms of manageableness, fuel consumption, and acceleration in the segment of the cruise motorbikes. Nevertheless, its price is significantly larger than its competitors. According to Friedman (2009), Harley-Davidson V-RON priced $16,995 has an inferior quarter-mile acceleration (11.91 sec.) with respect to Yamaha V-MAX (11.62 sec.) whose price is about 36 per cent lower ($10,899). In this case, we guess that consumers are interested in being one of the few having a traditional branded product. In our terminology, consumers in motorbike market are vintage snobs.

In other cases, consumers are willing to pay a premium for being one of the few having a technologically advanced product. In such markets, that we call high-tech snob markets, firms not investing in a superior technology are rare. One notable example is Nokia. The Finnish company was the world leader in the mobile phone market until 2012. With the diffusion of smartphones, Nokia decided not adopting the Android system, and continued to develop its own proprietary operating Symbian system. Within a few years, it was superseded by Samsung and many other firms, which adopted the new technology.
3 The model

We study the technology adoption in a vertically differentiated market (Shaked and Sutton, 1983), where there are two single-product firms: a branded one, called 1; and an unbranded one, called 0. Both firms independently choose whether to switch to a new technology \( \tau_2 \), or to maintain their respective technologies \( \tau_1 \) and \( \tau_0 \). Let \( \tau_j \) be both the technology adopted by a firm and, with a little abuse of notation, the corresponding level of technology. We assume that before the adoption choice the branded firm has a superior technology, and that the new technology dominates the previous ones, or: \( \tau_2 > \tau_1 > \tau_0 > 0 \).

Moreover, we assume that the perceived quality of the product of firm \( i \) employing technology \( \tau_j \) is \( \theta_{ij} = \beta_i + \tau_j \), where \( \beta_i \) (the brand identity) accounts for all tangible and intangible attributes of the product except technology (e.g. design, assistance, etc.). We set \( \beta_1 = \beta > 0 \) and \( \beta_0 = 0 \), supporting the fact that branded firms have a superior quality, even if the same technology is in place. Production and adoption costs are null.

Consumers are atomistic and indexed by \( v \in [0,1] \), with total mass normalized to one. There are consumption externalities, meaning that consumer overall evaluation of a product does depend not only on product quality (technology and brand) but also on the choice of other consumers (e.g. whether other consumers have a product with the same or other technology, whether the branded product is acquired by many or by a few consumers). We focus on a particular type of consumption externalities, which is caused by a snobby attitude of consumers, the SCEs. Following Leibstein (1950), consumers are snob if the smaller the people making their choice, the larger their utility. The utility that a snobby consumer \( v \in [0,1] \) receives from buying a product from firm \( i = 0, 1 \) employing technology \( \tau_j \) when firm \( i' = 1 - i \) produces with technology \( \tau_{j'} \) is:

\[
\begin{align*}
 u (v, i, j, j') &= \theta_{ij}v + s (j, j') (\bar{s}_i - \mu (V_i))^+ - p_i; \\
\end{align*}
\]

where \( p_i \) is the price charged by firm \( i \), \( \theta_{ij} > 0 \) is the above measure of the quality of the product; \( \mu (X) = \int_{x \in X} dx \) is a Lesbegue measure; \( V_i \subset \mathcal{V} \), with \( \mu (\mathcal{V}) = 1 \), is the set of consumers buying the product \( i \); \( s (j, j') \geq 0 \) is a measure of the intensity of the consumption externalities which depends on the technology employed by the two firms and by the consumer snobby attitude (explanation will follow); and \( \bar{s}_i \in [0,1] \) is the threshold from which, consumption externalities are at work. We set \( \bar{s}_i = i \) meaning that (un)branded products (never) always obtain a premium from being consumed by a small

\[\text{4}\text{The unmodeled part of the story comprises a situation in which there are initially two unbranded firms producing with the same technology } \tau_0 \text{, and, at a certain point in time, the branded one vertically differentiates by adopting a superior technology } \tau_1 \text{, while the unbranded one was not able to follow. In the modeled part, a new technology } \tau_2 \text{, which is better to the previous ones, becomes available.} \]
number of people. Thus, consumption externalities do not concern unbranded products.

In analogy to our modeling choice on product quality decomposition, we assume that the intensity of SCEs, \( s(j, j') = b + t(j, j') \), is affected by two components: the brand component, \( b > 0 \), and the technological component, \( t(j, j') \geq 0 \), which is jointly determined by the technology adopted by firm 0, \( \tau_j \), firm 1, \( \tau_{j'} \), and by the class of consumers, that we are considering.

We distinguish three classes of consumers with respect to their snobby attitude. Exclusive consumers \( E \) receive extra utility when technology employed in the branded product differs from that of other product. Examples of this class of consumers are in the watch or fashion markets. Vintage consumers \( V \) get extra utility from buying a branded product based on a technology which is older than the unbranded one. Examples of this class of consumers are in the old motor or music markets. High-tech consumers \( H \) get extra utility from buying a branded product based on a technology which is newer than (and therefore superior to) that of the unbranded product. Examples of this last class of consumers are in the phone or computer markets. Table 1 summarizes the value of technological component depending on the technology choice of the two firms and the three different consumer classes.

The sequence of the game is as follows. First, firms decide whether or not to update their technology. Second, firms simultaneously charge their prices. Third, consumers choose whether to buy or not the product, and in the latter case, which firm to patronize. We assume that consumers have perfect foresight, i.e. they are able to correctly anticipate the behavior of the others and therefore they correctly evaluate the impact of the snob effect. We will show that under this hypothesis, consumer demand is uniquely determined; there is no risks of multiple equilibria; and we can focus on the reduced game (where the third stage is replaced by the demand function of branded and unbranded products), which is one of perfect information. The appropriate solution concept is Perfect Nash

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<tr>
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<th>Firm 1 does not adopt ( (\tau_1 \rightarrow \tau_1) )</th>
<th>Firm 1 adopts ( (\tau_1 \rightarrow \tau_2) )</th>
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<tr>
<td>Firm 0 does not adopt ( (\tau_0 \rightarrow \tau_0) )</td>
<td>( t_H = t )</td>
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<tr>
<td>Firm 0 adopts ( (\tau_0 \rightarrow \tau_2) )</td>
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Equilibrium. We solve the game by backward induction.

3.1 Demand for branded and unbranded products

In markets with SCEs, consumer choice is affected by the buying decision of other players. We assume that consumers are rational, they correctly anticipate the equilibrium outcome (perfect foresight), and they decide accordingly. Thus, for any couple of prices charged by the two firms, demand for the branded product under perfect foresight is reached when each consumer has no incentive to modify her choice.

Let \( V^m \equiv \{ v \mid \theta_1 v + s (1 - m) - p_1 \geq (\theta_0 v - p_0)^+ \} \) be the set of consumers buying the product offered by firm 1 when prices charged by the two firms are \( p_0 \) and \( p_1 \) and consumers expect that the share of consumers buying a branded product is \( m \).\(^5\) We derive the demand for branded and unbranded products when \( p_0 \in [0, \theta_0] \) and \( p_1 \in [0, s + \theta_1] \).

We start considering the case in which firm 1 serves some consumers, i.e. \( \theta_1 > \theta_0 \), when richest consumers patronize firm 1. For \( \theta_1 v + s (1 - m) - p_1 > (\theta_0 v - p_0)^+ \), firm 1 serves some consumers, i.e. \( V^m \neq \emptyset \). Let \( v^m_1 = \inf V^m \in [0, 1] \). Since firm 1 always serves the richest segment \( V^m = [v^m_1, 1] \). Moreover, \( -v^m_1 \) and hence \( \mu(V^m) \) are decreasing and continuous in \( m \). Monotonicity and continuity of \( \mu \) imply that \( V_1 \), under perfect foresight, the set of consumers that will buy the product 1, when firms 0 and 1 respectively charge \( p_0 \) and \( p_1 \), exists and is uniquely determined by:\(^6\)

\[
V_1 = \{ v \mid \theta_1 v + s (1 - \mu(V_1)) - p_1 \geq (\theta_0 v - p_0)^+ \} .
\]

Let \( v_1 = \inf V_1 \). From (2) and previous considerations, it follows that \( V_1 = [v_1, 1] \) with \( v_1 \in [0, 1] \), and \( \mu(V_1) = 1 - v_1 \). We denote \( v_1 = 1 \) and \( V_1 = \emptyset \) the case in which firm 1 does not supply any consumer.

Let \( V_0 \) be the set of consumers buying from firm 0 under perfect foresight. From (1) and (2), it follows that:

\[
V_0 = \begin{cases} [v_0, 1] \setminus V_1 = [v_0, v_1) & \text{if } v_1 > v_0 \\ \emptyset & \text{otherwise} \end{cases} ,
\]

where \( v_0 = p_0 / \theta_0 \) is the marginal consumer for product 0. Now, when both firms sell a positive quantity, i.e. \( (\theta_1 + s) p_0 / \theta_0 < p_1 < p_0 + \theta_1 + s - \theta_0 \), \( v_1 = (p_1 - p_0) / (\theta_1 + s - \theta_0) \). When only firm 1 is active, i.e. \( p_1 \leq (\theta_1 + s) p_0 / \theta_0 \), then \( v_1 = p_1 / (\theta_1 + s) \); while when

\(^5\)To simplify the notation, we do not explicitly show the dependence of the variables on \( p_0 \) and \( p_1 \).

\(^6\)Intuitively, for small values of \( m \), consumers, who want to buy the product are larger than \( m \) and therefore this is not the consumers’ equilibrium. Similarly, for large values of \( m \), the size of consumers is too small. By continuity and monotonicity, there exists only one \( m \) for which there is an equilibrium.
only firm 0 is active, i.e. \( p_1 \geq p_0 + \theta_1 + s - \theta_0 \) then \( v_1 = 1 \). Previous considerations imply that the demand for products 0 and 1 are, respectively:

\[
D_0 = \mu([v_0, v_1]) = \left( \min \left\{ 1 - \frac{p_0}{\theta_0}, \frac{1 - p_0}{\theta_1 - \theta_0 + s} - \frac{p_0}{\theta_0} \right\} \right)^+ ,
\]

\[
D_1 = \mu([v_1, 1]) = \left( \min \left\{ 1 - \frac{p_1}{\theta_1 + s}, \frac{1 - p_1}{\theta_1 - \theta_0 + s} - \frac{p_0}{\theta_0} \right\} \right)^+ .
\]

We now consider the case in which \( \theta_1 \leq \theta_0 \). Here, the solution is reversed: the branded product is bought by the poor segment and the unbranded one by the rich one. More specifically, following the previous reasoning it is easy to show that firm 0 serves consumers with higher evaluation i.e. the segment \([v_0, v_1], v_1 \in (0, 1)\) and firm 1 will serve the remaining segment \([v_0, v_1], v_0 \in [0, v_1]\).

When both firms sell a positive quantity, i.e. \((s + \theta_1) (\theta_1 - \theta_0 + p_0) / \theta_1 < p_1 < s + \theta_1 p_0 / \theta_0\), the consumer who equally evaluate both products is: \( v_1 = (s (1 + v_0) - p_1 + p_0) / (\theta_0 - \theta_1 + s) \). Similarly, the consumer having zero utility from buying from firm 1 is: \( v_0 = (p_1 - s (1 - v_1)) / (s + \theta_1) \). Combining previous expressions, when both firms are active, we obtain:

\[
v_0 = \frac{(\theta_0 - \theta_1) p_1 - s (\theta_0 - \theta_1 - p_0)}{\theta_1 (\theta_0 - \theta_1) + s \theta_0} , v_1 = \frac{\theta_1 (p_0 - p_1) + s (\theta_1 + p_0)}{\theta_1 (\theta_0 - \theta_1) + s \theta_0}
\]

When only firm 0 is active, \( v_1 = v_0 = p_0 / \theta_0 \), and when only firm 1 is active, \( v_1 = 1 \) and \( v_0 = p_1 / (\theta_1 + s) \). Therefore:

\[
D_0 = \mu([v_1, 1]) = \left( \min \left\{ 1 - \frac{p_0}{\theta_0}, 1 - \frac{\theta_1 (p_0 - p_1) + s (\theta_1 + p_0)}{\theta_1 (\theta_0 - \theta_1) + s \theta_0} \right\} \right)^+ ,
\]

\[
D_1 = \mu([v_0, v_1]) = \left( \min \left\{ 1 - \frac{p_1}{\theta_1 + s}, \frac{\theta_1 p_0 + \theta_0 (s - p_1)}{\theta_1 (\theta_0 - \theta_1) + s \theta_0} \right\} \right)^+ .
\]

### 3.2 Pricing stage

Revenue functions of firms 0 and 1 are respectively \( R_0 = D_0 p_0 \) and \( R_1 = D_1 p_1 \). From (4)-(7), it emerges that revenue functions are both continuous and quasi-concave and therefore there is an equilibrium in pure strategies (Nash, 1950; Dasgupta and Manskin, 1986). Simple reasoning can be applied to show that both firms are active in equilibrium.
for any parameter range, and therefore there is a unique and interior price solution:

\[
p_0 = \begin{cases} 
\theta_0 (s + \theta_1 - \theta_0) & \text{if } \theta_1 > \theta_0 \\
\frac{4s + 4\theta_1 - \theta_0}{4s\theta_0 + 4\theta_0\theta_1 - \theta_1^2} & \text{if } \theta_1 \leq \theta_0
\end{cases}
\] (8)

\[
p_1 = \begin{cases} 
\frac{2(s + \theta_1)(s + \theta_1 - \theta_0)}{4s + 4\theta_1 - \theta_0} & \text{if } \theta_1 > \theta_0 \\
\frac{(s + \theta_1)(2s\theta_0 - \theta_1^2 + \theta_0\theta_1)}{4s\theta_0 - \theta_1^2 + 4\theta_0\theta_1} & \text{if } \theta_1 \leq \theta_0
\end{cases}
\] (9)

Some considerations directly emerge from the inspection of (8) and (9). First, when \( s = 0, \) and \( \theta_0 = \theta_1, \) we go back the Bertrand outcome: \( p_0 = p_1 = 0. \) Interestingly, the presence of SCEs, even in the absence of product differentiation \( (\theta_1 = \theta_0), \) allow firms to price above marginal costs. Market power of both firms increases with the strength of SCEs. Since costs are null, profit functions of firms 0 and 1 are respectively:

\[
\Pi_0 = \begin{cases} 
\frac{\theta_0 (s + \theta_1)(s + \theta_1 - \theta_0)}{(4s + 4\theta_1 - \theta_0)^2} & \text{if } \theta_1 > \theta_0 \\
\frac{\theta_0^2 (s + \theta_1)(2s\theta_0 - \theta_1^2 + \theta_0\theta_1)^2}{(s\theta_0 - \theta_1^2 + \theta_0\theta_1)(4s\theta_0 - \theta_1^2 + 4\theta_0\theta_1)^2} & \text{if } \theta_1 \leq \theta_0
\end{cases}
\] (10)

\[
\Pi_1 = \begin{cases} 
\frac{4(s + \theta_1)^2(s + \theta_1 - \theta_0)}{(4s + 4\theta_1 - \theta_0)^2} & \text{if } \theta_1 > \theta_0 \\
\frac{\theta_0 (s + \theta_1)^2(2s\theta_0 - \theta_1^2 + \theta_0\theta_1)^2}{(s\theta_0 - \theta_1^2 + \theta_0\theta_1)(4s\theta_0 - \theta_1^2 + 4\theta_0\theta_1)^2} & \text{if } \theta_1 \leq \theta_0
\end{cases}
\] (11)

Note that profits are continuous in \( \theta_0, \theta_1 \) and \( s. \)

4 Results

Before discussing the results of the model, we first introduce some simplifying assumptions. We first consider the case where there are no consumption externalities. Finally, we will discuss the three cases emerging by the three different types of consumers. Because of the high nonlinearity of the profit functions when we deal with SCEs, the results of the model are computed by simulations. In order to simplify the discussion of the results, we introduce the following assumptions:

(a) Proportional technological step: \( \tau_0 = 1, \tau_1 - \tau_0 = \tau_2 - \tau_1 = \tau, \) with \( \tau \in [0,1]. \)

(b) Normalization: \( \tau + \beta = 1. \)
(c) Symmetry: \( t = \sigma \tau; b = \sigma \beta \), with \( \sigma \in [0, 1] \).

Assumption (a) implies the technological difference between the two firms can be either 0 if both firms adopt the new technology, \( \tau \) if firm 1 does not adopt, and \( 2\tau \) if only firm 1 adopts. Assumption (b) introduces a normalization of the parameters such that \( \beta \) can be interpreted as the strength of brand image with respect to the extent of the technological step. We will see that when \( \beta > 1/2 \), the choice of the technology has a minor effect on the consumer choice. Richest consumers patronize firm 1 irrespective from the adoption choice. On the contrary, when \( \beta < 1/2 \) and firm 0 has a better technology than firm 1, richest consumers patronize firm 0. Finally, Assumption (c) introduces some symmetry in the model. It states that there is the same linear relation between the two components of perceived quality (brand and technology) and the corresponding effects on snob components of consumer preferences.

In the next sub-sections, we use the pair \((x, y)\) to summarize the equilibrium profile of the game, where \( x \) and \( y \) stand for the technology choices \( \tau_x \) and \( \tau_y \) respectively adopted by firms 0 and 1, with \( x = 0, 2 \) and \( y = 1, 2 \).

4.1 No consumption externalities

In the baseline model we consider the case in which there are no consumption externalities.

**Proposition 1** In the absence of SCEs \((\sigma = 0)\), there are three possible parameter regions:

- Region 1, where brand image is strong, \( \beta \in (\bar{\beta}, 1] \) and both firms will adopt, with \( \bar{\beta} \approx 0.69 \);
- Region 2, where brand image is intermediate, \( \beta \in (\bar{\beta}, \bar{\bar{\beta}}] \), and only firm 1 will adopt, with \( \bar{\beta} \approx 0.12 \); and
- Region 3 where brand image is weak, \( \beta \in (0, \bar{\beta}] \), and either one firm or the other will adopt. In Region 3, the first-mover is the adopter. High type consumers will always patronize firm 1 except in Region 3 when firm 0 is the adopter.

**Proof** See Appendix. ■

Intuitively, two effects drive the adoption choices. First, by acquiring a superior technology, a firm increases the consumer willingness-to-pay for the product. This first effect favors technological adoption. Second, by choosing the same technology of the opponent, a firm reduces vertical differentiation and competition becomes fiercer. This second effect is in favor of asymmetric adoption.

In Regions 1 and 2, the dominant strategy for firm 1 is the adoption of the new technology: it can simultaneously increase product quality and product differentiation. When brand image is strong enough, products remain sufficiently differentiated even if both firms have the same technology. Thus, firm 0 prefers to adopt the same technology.
for larger values of $\beta$ and to stay with the old technology for lower ones. In Region 3, indeed, there are two asymmetric equilibria, where one firm adopts the new technology and the other stay on the old one. Since brand image is quite low, simultaneous adoption leads too much competition. Contrary to Region 2, where firm 1 will prefer the new technology irrespective to the opponent choice, here, staying ahead may not be the better choice when the opponent has already adopted. The branded firm can indeed prefer to differentiate its product even if it losses the technological leadership and consumer high valued segment.

In order to analyze the incentive to innovate in vertical markets, we assume that a benevolent government could choose the firms’ technology and then firms are free to compete in the market. The following definitions are of help to compare the first-best outcome with the market outcome.

**Definition 1** *The first-best outcome is given by the couple of technologies which maximizes welfare, constrained to market competition in the pricing game. There is excessive inertia if at least one firm will not adopt when it should do. There is excessive momentum if at least one firm will adopt when it should not do. There is reverse adoption if we simultaneously observe excessive inertia and excessive momentum.***

**Proposition 2** *In absence of SCEs ($\sigma = 0$), the first-best outcome implies that both firms will adopt the new technology.*

**Proof** See Appendix.

Proposition 2 provides a clear and largely expected result: the welfare is maximized when the two firms adopt the new technology. Adoption of the new technology clearly implies better products for consumers and most of the times, it leads to a positive shift in the market coverage due to higher competition and lower prices.\(^7\)

Comparing Propositions 1 and 2, we obtain the following Remark.

**Remark 1** *In Region 1, the market leads to the optimal adoption level, while in Regions 2 and 3, there is an excessive of inertia.*

Thus, in the absence of snob effects, when brand image is weak, there is less adoption than expected. Thus, incentives to adopt a new technology could be useful to have.

---

\(^7\)When the brand image is weak and both firms adopt the new technology, vertical differentiation can be smaller than the case in which firm 0 will overtake firm 1. In this case, market coverage could be lower. Nevertheless welfare is maximized when both firms adopt the new technology since the additional value from having better products dominates the loss coming from a smaller coverage of the market.
In the next sub-sections we will consider three types of snob markets. Although our focus is on exclusive markets, for expositional reasons this case is presented at the end of the discussion of the other two. Indeed, we will first analyze high-tech markets, which are closest to the baseline case, and are characterized by a simpler equilibrium solution. Then, we will discuss vintage markets, which have a much more different and complex equilibrium solution. Finally, we present the exclusive markets which can be seen as the sum of the previous two cases.
4.2 High-tech markets

The first type of snob externalities occurs when consumers belongs to a high-tech snob market. As we have mentioned in Section 3, the technological component of SCEs emerges only when firm 1 has a better technology than firm 0.

Figure 1 shows the outcome of the model as a function of the strength of the brand

Notes: In panels (a) and (c), (x,y) refers to the technology adopted by firm 0 and 1, respectively. In Panel (d), (x,y) refers to the comparison of the technology adopted in the market solution and that of the first-best solution; ‘.’, ‘+’ or ‘−’ mean that in the market solution the firm adopts the same, a superior or an inferior technology with respect to the first-best solution.
image and the intensity of SCEs. With respect to the baseline case, we observe that the higher the snob externalities and the more likely to have that both firms will want to adopt the same technology (Panel a). Thus, snob externalities lessen competition and can be viewed as a special type of product differentiation.

The other results of the market solution coincide with that of the baseline model, including which firm will be patronized by high type consumers (Panel b). The first-best solution is indeed quite interesting, since in the presence of strong SCEs, it is optimal to have only one innovator (Panel c). Snobby consumers receive utility from having different varieties of the product, and this utility is lost if the two firms use the same technology. From a welfare point of view, in high-tech markets in addition to excessive inertia emerging in the baseline case, we can also observe excess momentum and reverse adoption (Panel d).

4.3 Vintage markets

The second type of SCEs occurs when consumers belong to a vintage market. Figure 2 describes this occurrence. Compared to the previous case there is a mix of different effects creating more complex situations. In particular, there is a new region characterized by medium-low to high brand image and sufficiently high SCEs in which firm 1 loses its technological leadership (Panel a). Firm 1 incentives to innovate are offset by larger SCEs it can receive when it stays on the old technology. When brand image is medium-low, firm 1 finishes to serve consumers with lower willingness to pay.

The first-best outcome presents two regions as in the high-tech case (Panel c). The first one, emerging when snob externalities are not too large, which exhibits the same outcome of the previous case: both firm should adopt the new technology. The second one, which differs from the high-tech case, since for strong SCEs, it is now optimal that only firm 0 should adopt. In both markets, asymmetric adoption generates value for consumers and it is worth having when SCEs are strong. Because markets are vintage, here it is necessary that firm 0 choose the new technology. The comparison of free market and first-best outcomes generate a large number of cases (Panel d). Generally, vintage markets are either efficient or characterized by excessive inertia. There may be reverse adoption only when SCEs are strong, brand image is weak.

4.4 Exclusive markets

The last type of SCEs occurs when consumers belong to exclusive markets, that is the sum of the previous two cases: SCEs emerge when the branded firm has either a better
Figure 3: Exclusive markets

Notes: In panels (a) and (c), (x,y) refers to the technology adopted by firm 0 and 1, respectively. In Panel (d), (x,y) refers to the comparison of the technology adopted in the market solution and that of the first-best solution; ‘.’, ‘+’ or ‘−’ mean that in the market solution the firm adopts the same, a superior or an inferior technology with respect to the first-best solution.

or a worse technology of the other firm.\footnote{Indeed, the indicator of technological SCEs when markets are exclusive is the sum of the other two, i.e. $t_E = t_H + t_V$.} In other words, exclusive consumers receive additional value from being a few having the product of firm 1, when it uses a different technology from firm 0.

Figure 3 describes exclusive markets. As expected this case has some similarities with
the two previous ones. The market solution and customer affiliation are indeed very similar to the vintage case (Panels a and b), while first-best solution is close to the high-tech case for medium to high strength of brand image and it is close to vintage case for low values of brand image (Panel c). In the market equilibrium, when firm 0 is going to adopt, the branded firm will prefer to use the old technology because it leads to a higher level of differentiation.

In the first-best outcome, when SCEs are sufficiently high, it is optimal having technological differentiation. Since now there are two different ways to add values from asymmetric adoption, it is necessary to explain the reasons why for low values of brand strength, the adopter is firm 0 (as in the vintage case), while the opposite occurs for medium to large values (as in the high-tech case).

The two outcomes derive by the relative size of two opposite effects. First, firm 0 adoption yields a larger average quality of the product. Second, firm 1 adoption yields to a larger market share for firm 1, and therefore larger SCEs. When the brand image is weak, also SCEs are low and the first effect dominates the second one. From a welfare point of view, it is therefore better to choose the adoption scheme in which the average quality is larger. When brand image is strong, indeed, it is paramount to maximize SCEs and the opposite result emerges.

Comparing welfare and market solutions, we find that a quite variegate set of results may emerge. When SCEs are weak, we can have either the optimal adoption (if brand image is strong) or excessive inertia (if brand image is weak). Indeed, when SCEs are strong we mainly observe reverse adoption or excessive inertia, where the latter case is more likely to occur when brand image is weak.

5 Conclusions

In this paper we have analyzed the impact of SCEs on technological adoption in vertically differentiated markets, and we have offered some anecdotal evidence of such markets. Our model has provided a rich set of solutions including the decision of the branded firm, which initially holds the best technology, not to adopt. From a welfare point of view we have identified cases in which there is excessive inertia, excessive momentum and reverse adoption, while in the absence of SCEs our results are consistent to the literature, i.e. in some cases there is excessive inertia.

\footnote{Simple computations imply that overall SCEs are maximized when firm 0 covers half of the market. There are no cases where firm 1 has more than half of the market. Moreover, when firm 1 covers the richest segment its market share is larger than when it covers the other one.}
These findings are particularly relevant for innovation policy. A first lesson is that when SCEs are small, in vertically differentiated markets it is useful to provide incentive for (developing and) adopting new technologies. In markets characterized by higher SCEs the optimal policy is affected by the type and intensity of SCEs as well as by the strength of the brand image. In some cases we observe reverse adoption, which raise a quite sophisticated point in terms of how to design right incentives to enhance market efficiency.
References


6 Appendix

Proof of Proposition 1. By assumptions (a) and (b) when $\sigma = 0$ the payoffs are:

<table>
<thead>
<tr>
<th>0 (1)</th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>0</td>
<td>(\frac{2}{16})</td>
<td>(\frac{(3-\beta)(2-\beta)}{(11-4\beta)^2})</td>
</tr>
<tr>
<td></td>
<td>(\frac{7}{117})</td>
<td>(\frac{4(3-\beta)^2(2-\beta)}{(11-4\beta)^2})</td>
</tr>
<tr>
<td>2</td>
<td>(\frac{(3-2\beta)(1-2\beta)}{(3-2\beta)(1-2\beta)})</td>
<td>(\frac{\beta(3-2\beta)(4-\beta)}{(5-4\beta)^2})</td>
</tr>
<tr>
<td></td>
<td>(\frac{2}{2(5-4\beta)^2})</td>
<td>(\frac{4\beta(3-\beta)^2}{(9-2\beta)^2})</td>
</tr>
</tbody>
</table>

(a) when $\beta < \frac{1}{2}$

<table>
<thead>
<tr>
<th>0 (1)</th>
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<th>2</th>
</tr>
</thead>
<tbody>
<tr>
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<td>(\frac{4(3-\beta)^2(2-\beta)}{(11-4\beta)^2})</td>
</tr>
<tr>
<td>2</td>
<td>(\frac{2(3-\beta)(2\beta-1)}{(5+2\beta)^2})</td>
<td>(\frac{\beta(3-2\beta)(4-\beta)}{(9-2\beta)^2})</td>
</tr>
<tr>
<td></td>
<td>(\frac{2}{(9-2\beta)^2})</td>
<td>(\frac{4\beta(3-\beta)^2}{(9-2\beta)^2})</td>
</tr>
</tbody>
</table>

(b) when $\beta \geq \frac{1}{2}$

If firm 0 maintains its old technology, by $\beta \in [0, 1]$, we observe that:

\[
\frac{16}{7^2} \leq \frac{4(3 - \beta)^2(2 - \beta)}{(11 - 4\beta)^2}.
\]

Then firm 1 adopts the new technology.

If firm 1 maintains its old technology, when $\beta < \frac{1}{2}$, we observe that:

\[
\frac{2}{7^2} \leq \frac{(3 - 2\beta)^2(1 - 2\beta)}{(5 - 4\beta)^2},
\]

when $\beta \in \left[0, \hat{\beta}\right]$, where $\hat{\beta} \simeq 0.45$. When $\beta \geq \frac{1}{2}$, we observe that:

\[
\frac{2}{\hat{\beta}^2} \leq \frac{2(3 - 2\beta)(2\beta - 1)}{(5 + 2\beta)^2},
\]

when $\beta \in \left[\hat{\beta}, 1\right]$, where $\hat{\beta} = 43/50$. Combining both results, firm 0 adopts the new technology when $\beta \in \left[\hat{\beta}, \hat{\beta}\right]$; otherwise it uses the old technology.

If firm 0 adopts the new technology, when $\beta < \frac{1}{2}$, we observe that:

\[
\frac{(3 - 2\beta)(1 - 2\beta)}{2(5 - 4\beta)^2} \leq \frac{4\beta(3 - \beta)^2}{(9 - 2\beta)^2},
\]

when $\beta \in \left[\hat{\beta}, 0.5\right]$, where $\hat{\beta} \simeq 0.12$. When $\beta \geq \frac{1}{2}$, we observe that:

\[
\frac{16(2\beta - 1)}{(5 + 2\beta)^2} \leq \frac{4\beta(3 - \beta)^2}{(9 - 2\beta)^2}.
\]
Combining both results, firm 1 adopts the new technology when $\beta \in [\hat{\beta}, 1]$; otherwise it uses the old technology.

If firm 1 adopts the new technology, we observe that:

$$\frac{(2 - \beta)(3 - \beta)}{(11 - 4\beta)^2} \leq \frac{\beta(3 - 2\beta)(3 - \beta)}{(9 - 2\beta)^2}.$$ 

when $\beta \in [0, \hat{\beta}]$, where $\hat{\beta} = (25 - \sqrt{193})/16 \approx 0.69$. Therefore, firm 0 adopt the new technology when $\beta \in [\hat{\beta}, 1]$; otherwise it uses the old technology.

Finally, high type consumers always patronize firm 1 when $\theta_1 > \theta_0$. When firm 1 adopts the new technology then, by $\beta > 0$, we observe that $\theta_1 > \theta_0$. However, when only firm 0 is the adopter and $\beta \in [0, \hat{\beta}]$, then high type consumers patronize firm 0: $\theta_1 = 2 < 3 - 2\beta = \theta_0$.

**Proof** of Proposition 2. Putting prices in demand function, we rewrite the following demands without snob effect as:

$$D_0 = \begin{cases} \frac{\theta_1}{4\theta_1 + \theta_0} & \text{if } \theta_1 > \theta_0 \\ \frac{2\theta_0 + \theta_1}{4\theta_1 + \theta_0} & \text{if } \theta_1 \leq \theta_0 \end{cases},$$

$$D_1 = \begin{cases} \frac{2\theta_1 + \theta_0}{4\theta_1 + \theta_0} & \text{if } \theta_1 > \theta_0 \\ \frac{2\theta_0 + \theta_1}{4\theta_0 - \theta_1} & \text{if } \theta_1 < \theta_0 \end{cases}.$$

Assuming welfare as $W = \theta_0 D_0 + \theta_1 D_1$, it becomes:

$$W = \begin{cases} \frac{2\theta_1^2 + 2\theta_0 \theta_1}{4\theta_1 + \theta_0} & \text{if } \theta_1 > \theta_0 \\ \frac{2\theta_0^2 + 2\theta_0 \theta_1}{4\theta_0 - \theta_1} & \text{if } \theta_1 \leq \theta_0 \end{cases}.$$

When $\theta_1 > \theta_0$ we have that $\frac{dW}{d\theta_1} > 0$. Then observing that:

$$\frac{dW}{d\theta_1} = \frac{2(4\theta_1^2 - 2 - \theta_0^2)}{(\theta_0 - 4\theta_1)^2} > 0,$$

when $\frac{\theta_1}{\theta_0} > \frac{1 + \sqrt{5}}{4}$ and then it always holds. Symmetrically, we observe that when $\theta_1 \leq \theta_0$ we have $\frac{dW}{d\theta_0}, \frac{dW}{d\theta_1} > 0$. Therefore, we can conclude that the first-best is when both firms adopts the new (and highest) technology.