REGULAR ARTICLE

Demand, innovation, and the dynamics of market structure: The role of experimental users and diverse preferences

Franco Malerba · Richard Nelson · Luigi Orsenigo · Sidney Winter

Abstract The history of a number of industries is marked by a succession of eras, associated with different dominant technologies. Within any era, industry concentration tends to grow. Particular eras are broken by the introduction of a new technology which, while initially inferior to the established one in the prominent uses, has the potential to become competitive. In many case new entrants survive and grow, and the large established firms do not make the transition. In other cases, the established firms are able to switch over effectively, and compete in the new era. This paper explores a model which generates this pattern and has focused on the characteristics of the demand. We argue that the ability of the new firms exploring the new technology to survive long enough to get that technology effectively launched depends on the existence of fringe markets which the old technology does not serve well, or experimental users, or both. Established firms initially have little incentive to adopt the new technology, which initially is inferior to the technology they have mastered. New firms generally cannot survive in head-to-head conflict with established firms on the market well served by the latter. The new firms need to find a market that keeps them alive long enough so that they can develop the new technology to a point where it is competitive on the main market. Niche markets, or experimental users, can provide that space.

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1 Introduction

The hypothesis, or theory, that a product technology and the associated industry structure tend to have a natural life cycle first originated among business school scholars (see in particular Abernathy and Utterrback 1978), but in recent years has been picked up by a number of economists (see for example Nelson 1994; Klepper 1996; and Malerba et al. 1999). Most versions of this theory posit that, when a technology is new, no version of it is completely satisfactory, many different firms try to produce and sell different variants, but none is able to achieve a large market. In the early stages of the life cycle, there is considerable entry to the market both of firms and of customers, and a lot of exit as well. However with time, the technology stabilizes and so does industry structure, which generally becomes quite concentrated.

The versions of the theory that were articulated first stressed supply side dynamics. After a certain amount of experimentation, a version of the product is found or developed that satisfactorily meets the needs of a large block of customers. Customers gravitate to that version, which becomes the dominant design, and firms must produce that version if they are to survive. With the product market now more homogeneous, and design more stabilized, firms are able to take advantage of cumulative learning, scale intensive production methods become profitable and are adopted, entry becomes more difficult, and industry structure tends to concentrate. In some versions of this supply side theory, successful firms consolidate and advance their advantage by plowing their profits back into R&D.

More recently, there have been versions of this theory that stress demand side dynamics. A dominant design emerges and industry stabilization occurs not so much because a particular satisfactory technological mode is found, but rather because there are network economies or bandwagon effects on the demand side. Thus customers gravitate to a particular design, and firms must also if they are to survive. In most of the models stressing demand side dynamics, with the development of a dominant design industry structure tends to concentrate, just as in the models stressing supply side dynamics.

These theories are not mutually exclusive. In a number of industry histories, it is apparent that both supply-side dynamics and demand-side dynamics led to increasing industry concentration.

Clearly not all technologies and industries display historical patterns that fit the life cycle story, and for many reasons. In the first place, many industries face a diverse set of customers and no single design ever emerges that satisfies all needs. Custom software is a good example. If one aggregates across different kinds of drugs, the pharmaceutical industry remains relatively unconcentrated because a variety of different types of drugs are needed to meet the diverse requirements of different humans with different ailments. (See e.g. Sutton 1991, 1998; Malerba and Orsenigo 2002). Cameras and sound amplifications systems, as reported by Windrum and Birchenhall (1998) are additional relevant cases. In some industries there would seem to be little in the way of economies of scale or cumulative learning advantages that would induce firms to grow large, and the productivity of large scale R&D is low. The housing and trucking industries have always been fragmented.

It also is apparent that a number of industries that display dynamics that fit the broad technology and industry cycle theory over certain bounded periods of time, do

not do so when a longer time horizon is considered. In particular, their technological histories are marked by a succession of different broad technologies, with one technology being dominant in one era, but then being succeeded by another technology that then is dominant for a while, and so on. Of particular interest, the firms that become dominant during one era often fail to hold their strong position after a new technology enters the picture. Rather, the new era belongs to new firms.

A considerable body of research and writing, a significant portion of it by economists, has developed and supported the argument that the effective transition to a new technology, and the changing of the locus of industrial leadership, are causally connected (Tushman and Anderson (1986), Henderson and Clark (1990), Christensen and Rosenbloom (1995)). The dominant firms of one technological era often have great difficulty seeing the advantages of the new technology, or learn to use it effectively, and the development of that new technology, therefore, becomes the business of new firms to the industry.

In this essay, we pick up on these themes, and argue the following supplementary hypothesis. The successful introduction of radically new technology in an industry, where a dominant design and a small collection of dominant firms had emerged using the older technology, may be dependent upon the presence of a group of experimental customers, or diverse preferences and needs among potential users, or both. If customers are not willing to experiment, and all potential customers have roughly the same tastes, the new firms that may be needed to introduce the new technology will not have enough of a market to stay around long enough to become viable. Despite the opportunities afforded by a potentially powerful new technology, the industry will stay stuck with the old.

This hypothesis was virtually forced on us by our analysis of the evolution of computer technology and industrial structure (see Malerba et al. 1999). The dramatic advances in computer performance that have occurred over the last 40 years have been largely driven by a succession of major advances in component technologies. In no case has the firm that had market and technological leadership under one regime of components been the leader in developing and marketing computers employing the next generation of components. In each case, new firms were key players in the transformation of the technologies and the industry. And in each case, the new firms got their start selling to experimental users, or to users whose needs were inadequately met by computers based on the older component technology. We will argue there that there are many other industry histories that look like the computer case.

In Section 2, we situate our argument within the context of the literature that has analyzed the role of heterogeneity in demand in preventing the establishment of a dominant design and/or lock-in into inferior, older technologies.

In Section 3, we develop a simulation model of technology and industry dynamics in which there is a succession of potentially dominant technologies. The model is based on our previous work on the evolution of the computer industry (Malerba et al. 1999). However, that model has been adapted in order to address the questions under examination. We shall highlight these modifications when discussing the model in detail. Moreover, it has to be emphasized here that this model is not "history-friendly" in the strict meaning that we attributed to our previous efforts (Malerba et al. 1999; Malerba and Orsenigo 2002). While those

earlier efforts were built with the explicit aim at qualitatively examining the main causal factors and processes that could explain the evolution of a particular industry (computers and pharmaceuticals), here we use and develop one of those models for investigating a more general phenomenon that—we argue—applies to a variety of industries. Thus, we claim that a history-friendly model is used here to develop and probe a theoretical and empirical argument of broad relevance for various historical cases.

In Section 4 we discuss and model how under any regime defined by a particular technology there are forces that drive a technology and industry structure life cycle. There are dynamic increasing returns on the supply side and, in our base set of runs, network externalities or bandwagon effects on the demand side. Then along comes a potentially superior new technology, and some new firms that give it a try. To be successful, they need to pick up some customers pretty quickly, in order to have the cash flow to develop their new technology to a point where its potential is realized.

Then in Section 5 we analyze various demand contexts. In our first set of runs, new firms try to introduce the new technology but they do not have a chance. Bandwagon effects are too high, and established leaders in the market do not have the incentive to adopt the new technology. In our second set of runs, we eliminate the bandwagon effect, which obviously has the consequence of making it difficult for new firms to find a market. However, in these runs customers are sophisticated, in the sense that they can accurately assess the quality of the products offered by different suppliers (there is no bandwagon effect) and preferences are homogeneous. We show that, in this case, too, if the new technology needs work before its potential is realized, and established firms are not interested in doing that work and hence the task falls to new entrants, sophisticated customers who see the potential in the new designs but prefer not to buy if products of the old design are still superior, act to wall off the new entrants from finding a profitable market, even if there are no strong bandwagon effects.

In runs three and four, we change the situation. In the third set of runs, there is a group of customers who have a policy of experimenting. The introduction of experimental users constitutes a major change as compared to our earlier model. They will buy some of the products based on the new technology, simply because they are new, and will not be deterred from that experimentation simply because the quality of the new products is not up to that which they had been buying. In the fourth set of runs, there is a group of customers with very different tastes than the customers who had been buying the old products, whose needs, however, can be met with the new technology. In both cases, the new firm, and the new technology, is able to get a foothold in the industry.

In Section 6 we show that even the old consumers over the long run may be significantly better off for this. Firms producing products using the new technology are profitable, and plow back their funds to further improving their technology. Established firms now are challenged by these new ones, and they change over their own practices. The result is that, down the road, products using the new technology come to dominate the market. Convergence of the two markets is also a new feature of this model as compared to the old one.

In our concluding section, we briefly discuss the implications of these findings.

2 Previous literature

In recent years, a number of models has focused attention on differences in consumers' preferences as an important factor influencing the industry life cycle and in some cases preventing the establishment of a dominant design. Thus, Saviotti (1996), Dalle (1997) and Windrum and Birchenhall (1998) model the industry life cycle ending up in the emergence of multiple, distinct market niches as a consequence of various forms of heterogeneity in consumers preferences. Our model, however, is not primarily interested in showing that different technologies and related products can survive, compete and co-exist over the course of an industry life cycle. Rather, our main interest is in examining the conditions at which a new potentially superior technology can fail to win market domination or even to survive and conversely how heterogeneity in demand can break the dominance of the older technology.

From this perspective, this paper naturally links with earlier contributions that, developing on the work by Christensen (1997), have examined how demand conditions can set on (or prevent) phenomena of technological disruption. In particular, Shy (1996), Dalle (1997), Adner and Levinthal (2001), Adner (2003) and Windrum and Birchenhall (2005) focus attention on how (alternative structures of) heterogeneity in consumers preferences influence the conditions at which a new technology can survive and eventually become displace the old one. Almost all of these models (particularly Shy (1996), Dalle (1997), and Windrum and Birchenhall (2005)) deal with cases where the continuing dominance of the older technology derives from the presence of network externalities.

However, our model differs from these previous contributions under a variety of aspects, even leaving aside important technical differences in the specific ways the models are built. First, our paper does not consider network externalities or bandwagon effects in demand as the only mechanism leading to a dominant design and to industry concentration. On the contrary, the same effect can arise in the presence of sophisticated consumers who are able to select always the best available design. Second, in our model the new technology is initially inferior to the old one but it has the potential to become better in terms of all the relevant product characteristics. The survival and growth of the new technology is made possible not only by the existence of groups of consumers having different preferences over product characteristics, but also by the existence of a niche of consumers who are simply willing to experiment the new inferior products. In this respect, the situation we examine is different from the models by Shy (1996) (where the new technology offers additional product characteristics) and by Windrum and Birchenhall (2005) (where substitution may occur only through the emergence of a new consumer class with new preference sets). Third, in our model, it is not only new firms that can bring the new technology to dominance. Also old firms can adopt the new technology and thereby maintain their market leadership, provided that the competition of new entrants can become strong enough to trigger adoption.

The model presented here shares also some similarities and differences with Adner (2003). There, the new technology is initially inferior to the old one in terms of the performance dimensions that are more important to "mainstream" consumers, but it offers more in terms of different ("secondary") characteristics. However, the

mechanism leading to either disruption, competition or co-existence of the new and old technologies are quite different. In particular, Adner's model assumes decreasing marginal utility to consumers from increases in products functionalities beyond their requirements, Thus, technological substitution occurs because incumbent firms "oversupply" the mainstream product characteristics, leaving increasing room to new products which offer more secondary characteristics and are therefore increasingly valued (at the margin) by consumers. Our model is similar to Adner's in that it assumes that the new technology allows more progress along a specific product characteristic that was not valued very much by "mainstream" consumers. However, our model does not rely on the assumption of decreasing marginal utility of mainstream characteristics. Rather, the new technology has the potential to become superior in terms of all the relevant product characteristics.

Thus, our model can be considered as a simpler baseline and possibly more general case of the models mentioned previously. The model identifies in fact the broad classes of variables which, on the demand side, can prevent the take-off of a new superior technology or break the dominance of the old one. The model can in principle be modified to consider more specific cases (e.g. emergence of new classes of consumers, technologies offering new characteristics, economies of scale in production) as well as other more specific mechanisms influencing technological transitions, like those discussed especially in Adner (2003) and Windrum and Birchenhall (2005).

3 The basic model and product life cycle dynamics

In this section we lay out the basic model. Given the nature of complex simulation models, it is impossible to present all the details of all the equations, without befuddling the reader and obscuring the basic logic of the model. We have tried, therefore, to lay out in transparent form what we regard as the gist. Interested readers may obtain a full copy of the simulation model by writing to the authors.

We start by considering the situation when a new product has just been invented. That product has the potential to get sales in a market, but it has to be developed and perfected before it can actually meet the potential market demand. Moreover, the current conception of the product and the technology it embodies has inherent limits.

To make the discussion concrete, let the product be the first generation of electronic computers. The potential purchasers of computers value two attributes. One is the "performance" of the computer. The other is its price, or "cheapness." The desirability of any computer design can be summarized in terms of how it rates in those two dimensions of Lancaster attribute space. By a useful product we mean one that meets threshold requirements of potential purchasers—more on this shortly.

The innate characteristics of product designs of this first generation limit what products can achieve in these two dimensions, even when those designs are perfected. For analytic convenience, we treat these technological constraints as defining a rectangular box. Thus in Fig. 1 the outer boundaries of the box mark the set of technological characteristics that potentially can be achieved by products of this first generation.
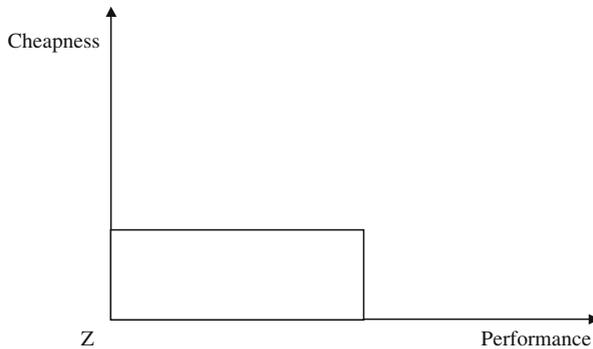
Fig. 1 Technological frontier of the first generation products

These outer limits of what is feasible under the current technology are "potentials." The potential is not achievable, however, without significant investment of resources in research and development, and requires learning from experience. The first efforts of a new firm trying to design a product will only be able to achieve a design characterized by point Z (for zero experience). We will specify the dynamics of design improvement built into the model in Section 3.2.

3.1 The market

Later in this essay we will consider a market that consists of different subgroups of potential customers who value the two product attributes—cheapness and performance—differently[1]. For the present we consider only one homogeneous group of potential customers. Before members of this group can be induced to buy any products at all, a product offered to them must meet certain threshold requirements. Once these threshold requirements are met, the value that customers place on a product is an increasing function of its cheapness and performance. In Fig. 3 we depict the preferences of the customers that can be induced to buy some of these first generation products, if they are good enough.

The "indifference curves" of Fig. 2 depict designs of equal value or "merit" in the eyes of customers. Product designs whose characteristics fall outside the box, that is that do not meet threshold requirements, have a merit of zero. For the time being, let us just note that we assume that higher product merit translates into more products bought by customers.

3.2 Supply dynamics

In our model, firms gradually and cumulatively develop competence in using the new technology as a result of the R&D investments they make. Our model of firm learning is meant to capture significant elements of the "dynamic competence" theory of the firm that has been developed by Nelson and Winter (1982), Winter

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[1] These subgroups can be interpreted as collections of consumers having similar preferences or even as individual consumers
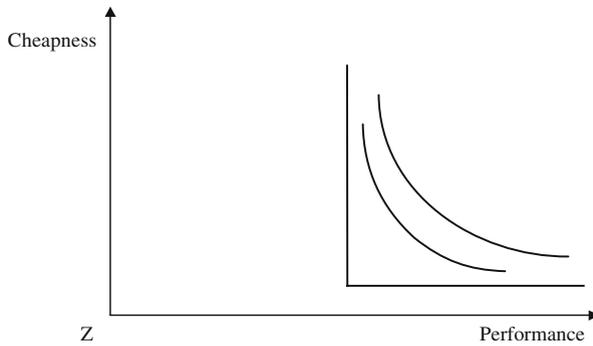
Fig. 2 The indifference curves

(1987), Dosi and Marengo (1993), and Teece et al. (1992, 1994). Our model also incorporates the fact that in this industry, and in a number of others, a considerable period may go by after a firm starts trying to operate in a new technology before it is able to sell any product, if it ever achieves that. At the start it must have external financing.

   Thus at the beginning of our episode, we assume that there are a number of firms, each endowed by "venture capitalists" with an initial budget to spend on R&D, who hope to exploit the new technological opportunities. All firms start with the same initial design capabilities, depicted by Z in Fig. 1. Firms start off with different, randomly selected initial budgets, B, which are used to finance an R&D program, the length of which is fixed and equal for all firms. During this initial time, in each
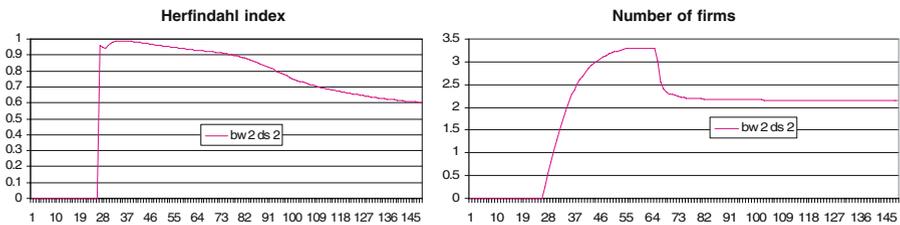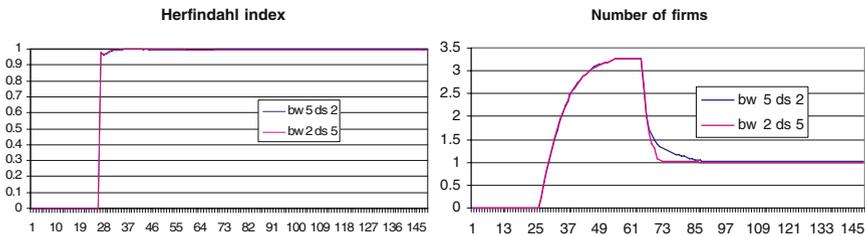
Fig. 3 Product life cycle and standard set (bw = bandwagon; ds = design sensitivity)

period firms spend a constant fraction of their budget on R&D. If the funds are exhausted before a marketable design is achieved, firms exit.

Design outcomes are influenced by firm-specific strategies represented by choices of search direction in the capabilities space. In our model these strategies are reflected in randomly selected trajectories of technological improvement along the two technological dimensions, price and performance. It is assumed that trajectories are firm-specific and time-invariant. Thus, after the initial period, the firms in the industry will be doing different things, and will be achieving product designs of different characteristics.

As firms spend down their initial loan doing R&D, from period to period the quality of the design that a company is able to achieve in each relevant dimension—performance and cheapness—improves according to the following equation:

$$\text{change } X_i = a_0 (R_i)^{a1} (L_i - X_i)^{a2} \tag{1}$$

The first variable, R, is the firm's R&D expenditure aimed at achieving design improvements of a particular sort, where $i=1$ denotes performance and $i=2$ denotes cheapness. This expenditure is a constant fraction of its period-by-period R&D expenditures in total.

The second variable in the equation, $L_i - X_i$, is distance of the achieved design to the frontier. As what is achieved comes closer and closer to the limits of what is achievable, a given R&D expenditure will achieve less and less further progress.

As indicated, if a firm runs through its initial loan before it achieves a marketable product, it simply fails. However, if a firm manages to push its design into the region where customers are buying, it is a new ball game. Now funds from revenues can be invested in R&D.

Profits, π are calculated in each period t as:

$$\pi_t = M * p - M * k, \tag{2}$$

where M is the number of products sold, p is the product price and k is production cost of a single c product. Production costs, k, are determined by the technical progress function. Price is obtained by adding a mark-up, μ, to costs:

$$p = k * (1 + \mu) \tag{3}$$

The mark-up, μ, is initially set equal for all firms, but that subsequently it can vary over time as a function of the market share that has been achieved. In particular, we assume that as firms gain monopoly power, they (partly) exploit it by charging a higher mark-up. Specifically

$$\mu_t = 0.9 * \mu_{t-1} + 0.1 * (m_i / (\eta - m_i)) \tag{4}$$

where η is the elasticity of demand (equal to 2 in the first market and to 4 in the new market in the parametrization used here) and m is the firm's market share.

The gross margin over production costs is used to cover several things. Firms spend a constant fraction σ (15% for all firms in this version of the model) of their profits in each period to pay back their debt D_t to investors—that is to say, the initial budget capitalized at the current interest rate, r, until the debt has been fully paid

back. What is left of the initial loan in each period is reinvested in R&D. R&D expenditure, R_t, is determined as a constant fraction, φ, of what is left of gross profits, π_t, after the repayment of the initial budget

$$R_{t,} = \phi * \pi_t(1 - \sigma) \tag{5}$$

In this version of the model this fraction is the same for all firms and constant over time.

The excess gross profits after debt repayment and R&D expenditures is invested in an account, B_t, that yields the interest rate, r, in each period and is treated in this model as "reserves." These reserves will enter the model in an important way when we shall examine the case of a new technology becoming available as an alternative component technology.

Firms exit the market when their budget becomes negative (because current profits are insufficient to pay back the due fraction of the outstanding debt) and/or when their rate of profit becomes negative and it has been falling faster than a given rate (a parameter of the model) over the past four periods. (See Appendix 1 for details)

3.3 Demand dynamics

The customers in our model are visualized as shopping around at any time, and homing in on a particular product as a candidate for purchase. They are drawn to a particular product by their assessment of its "merit," which is a Cobb Douglas function of its two valued attributes, performance and cheapness, each attribute measured from its threshold value:

$$M = b_0(X_1 - X_1\, min)^{b1} (X_2 - X_2\, min)^{b2} \tag{6}$$

However, customers do not have perfect ex-ante information about the merits of the available products, while they have access to some direct indicators (for example engineering reports) they also use various indirect indicators that they think are related to merit to focus their attention. In particular, the larger is the share of the market that a product already holds, the greater the likelihood that a customer will consider that product. Thus a bandwagon effect is built into this model. The particular rationale invoked here is that use by others provides an indication that the product has relatively high merit, but there may be other reasons as well why a potential customer might be attracted to bands that are selling well.

Putting these two variables together, the probability that any customer will consider a particular product for purchase in a particular period is:

$$P_i = c_0(M_i)^{cl}(m_i + d_1)^{c2} \tag{7}$$

c_0 is specified so that the sum of the probabilities adds to one. As noted, M denotes the "merit" of a product. "m" is the market share, in terms of the fraction of total sales revenues accounted for by that product. We note that the market share variable can be interpreted either in terms of a bandwagon effect, or a (probabilistic) lock-in of customers who previously had bought machines of a particular brand. The

"d_1" assures that products that have just broken into the market, and have no prior sales, can attract some sale.

Above we proposed that the logic of our model implies that the greater the merit of a product, the more of that product should be sold to customers who are looking at it. We now adopt the simple assumption that a potential customer who is considering a particular product of merit M, will buy M units of that product. If the notion of a single customer buying many products is bothersome to the reader, think of the customer as a large organization, or a collection of smaller ones or individuals. Thus if there are N customer or customer groups on the market, the expected amount of sales of a product of merit M will be

$$\text{Expected number of sales} = N \cdot P \cdot M \tag{8}$$

Note the following. First, if there is only one product that meets threshold requirements, each customer or customer group will buy it with probability 1, and will buy "M" units of it. Second, if there is more than one product that passes the threshold, then if "c1" is very high, and "c2" is very low, virtually all the customers will buy the product with the highest merit score. On the other hand, if "c1" is relatively low, or "c2" is high, a higher merit product design may be "out sold" by a rival product that has the higher existing market share.

3.4 A product life cycle

Our first simulation replicates the essential features of an industry life cycle. The reported results for the relevant variables on which we have concentrated our attention are the means of extensive Monte Carlo exercises (1,000 runs for each exercise). Sensitivity and robustness analysis are reported in Appendix 3. For each of the following simulations, Appendix 3 reports mean, standard deviation and confidence intervals for the main variables under investigation.

Product life cycle features emerge clearly under average values of the bandwagon effect (bw) and design sensitivity (ds), each set equal to 2 (see Appendix 2) for the description of parameters values). In fact after an initial entry of new firms, the industry gets concentrated as the industry matures and few firms survive (see Fig. 3—*Product life cycle*). In this case, six initial firms were potential entrants, 3–3.5 of them entered the industry and between 2 and 2.5 survived in the long run and dominated the market.

Then we have simulated the model by using a parametrization that we call the "standard set," in which either the bandwagon effect or design sensitivity are high. The details of the parameter setting are provided in Appendix 2. Also these simulations generate an industry history which replicates the essential features of the product life cycle model, but with a greater level of concentration. Results are shown in Fig. 3. As in the previous simulation, the industry gets concentrated rather quickly. Here however a dominant firm emerges and maintains its leadership for a long period of time. This result emerges as the consequence of a "success-breeds-success" process. In turn, this feature is the result of the interplay of three factors. First, technical progress is cumulative. Today's design efforts build on what was
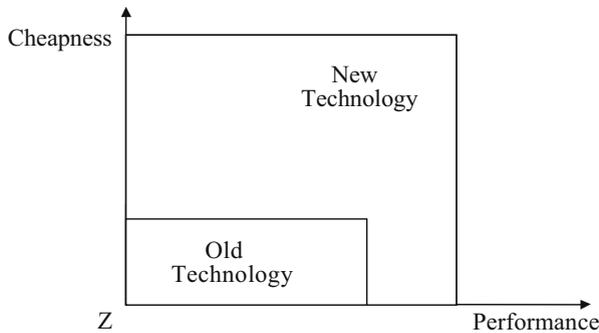
Fig. 4 New technology defining new boundaries to the technological characteristics of products

achieved yesterday and firms tend to get better and better at the particular things they are doing. Second, an early leader will gain a large market share and hence profits that allow for higher R&D expenditures as compared to the rivals. As a result, the 'merit' of the early leader's computers will tend to be enhanced relative to those of its competitors. Third, the bandwagon effect in the demand function (the parameter c_2 in the demand function (7) set equal to 5) further magnifies the initial advantage: a larger market share at time t will attract other customers at time $t+1$. The same holds in the case of high design sensitivity by consumers (the parameter c_1 in the demand function (7) set equal to 5), who flock always to the current best design.

This process is only partially countervailed by the onset of diminishing returns to R&D towards the end of the runs. As the best products get close to the boundaries, their rate of technological advance slows down and laggards begin to catch up. However, the bandwagon effect in the demand function shelters the dominant firm position from the increased technological competitiveness of rival products and concentration remains high.

4 The emergence of a new product design

Let us now introduce a new feature into the basic model. Assume that at a certain time t^* a new technology emerges, which opens a "second generation" of product designs. The new technology is potentially superior to the old one in the sense that it allows, in principle, the design of products that are better than "first generation" ones regarding both characteristics, performance, and cheapness. In other words, as shown in Fig. 4, the new technology defines new boundaries to the technological characteristics that potentially can be achieved.

As with the old technology, however, the new product designs have to be developed and perfected.

4.1 Competition between technologies and adoption with "locked-in" effects

The introduction of the new technology is associated to the entry of new firms. A number of new firms start out at point "Z" in Fig. 4, with funding provided by venture

capitalists, just as earlier new firms had started out at that point using the old technology. Some of these firms will fail before they get into a market. Others may succeed.

However, the existence of established firms in the market creates a significant barrier to entry. First of all, if a "new generation" firm achieves a design that meets threshold requirements in the market, that product is in competition with existing products that already have achieved higher than threshold quality levels. Second, the established firms have acquired positive market share which, in itself, attracts and holds the attention of customers, and makes it hard for new products to be seen. It is clearly difficult in this context for a new firm to survive, even if it succeeds in cracking into the market at small scale. If new firms can't survive, and if extant firms cannot or do not switch over to making product designs using the new technology, the potential afforded by the new technology will never be realized.

In the model, extant firms who have been using the old technology have the capability to switch over to the new, but it is costly to do so, and unless pressed by new firms the motivation may be weak. We noted in the introduction to this paper that established firms often are sluggish and unsuccessful in adopting new technologies.

We make the probability that an established firm will try to adopt the new technology a function of two variables. One is the extent to which new firms, or other old firms that have adopted, have developed the new technology to a point where the merit of the product based on it is close to the merit of products using the old technology. The second variable is the extent to which established firms are pressing close on the borders of the feasible using the old technology. The precise specification is laid out in the Appendix 1.

5 The role of experimental users and users with different preferences.

In this Section, we explore the role of demand in affecting technological change and industrial dynamics. First, we show that using what we called the "standard set," the new firms are unable to get a viable foothold in the old market and nothing induces the dominant old firms to switch over to the new technology. We show also that this result is not simply an artifact of a strong bandwagon effect, but that the new technology fails to take off in this model even if there is no bandwagon effect, at least if consumers are sophisticated, i.e. they tend to choose (almost) always the best available product at any given period.

Second, we show that the existence of experimental users, i.e. customers who attribute an intrinsic merit to a product simply because it embodies the new technology, can break the lock-in and allow the new technology to take-off. Third, we show that the same result can be obtained if there are customers with diverse preferences about the characteristics of the products.

Fourth, and finally, we show that in the long run the existence of experimental users and/or diverse preferences benefits all types of consumers.

5.1 Blockaded entry

We start by simulating the model under the standard set. In this case (Fig. 5), the new technology does not take off. This result stems first of all, from the

cumulativeness of technical advance coupled with strong bandwagon effects on the demand side built into these runs. As a result, incumbents have such a large market share and demand is so locked-in to existing technologies that a new technology cannot possibly take off. New firms spending down their initial loans can achieve product designs that meet threshold requirements, but do not survive for long in the market where they are competing with established firms offering polished first generation products. Thus the new technology does not develop enough to make it competitive and, as a consequence, incumbents do not feel any pressure to adopt the new technology.

However, this result is not simply an artifact of a strong bandwagon. To show this, in Simulation II of Fig. 5, we eliminate the bandwagon effect, and we consider a situation in which consumers are highly sophisticated. Thus we put the exponent of the market share equal to zero and we increase the exponent of the design sensitivity parameter (c1 in the demand equation) to 5. In this case customers can assess very well the quality of the products offered by different suppliers and choose at any time the best available product. Customer tastes however are homogeneous. As Fig. 5 shows, also in this case the new technology is not able to take off. All the sophisticated customers prefer to buy the products with the most advanced design. The new technology has a very high potential but starts from a lower level than the existing one and it is not chosen by sophisticated customers. Thus, new entrants do not survive and the new technology does not have the opportunity to develop. The established leaders are not threatened by the new firms and don't realize that the new technology might be better in the future. Thus, the established leaders do not adopt the new technology.
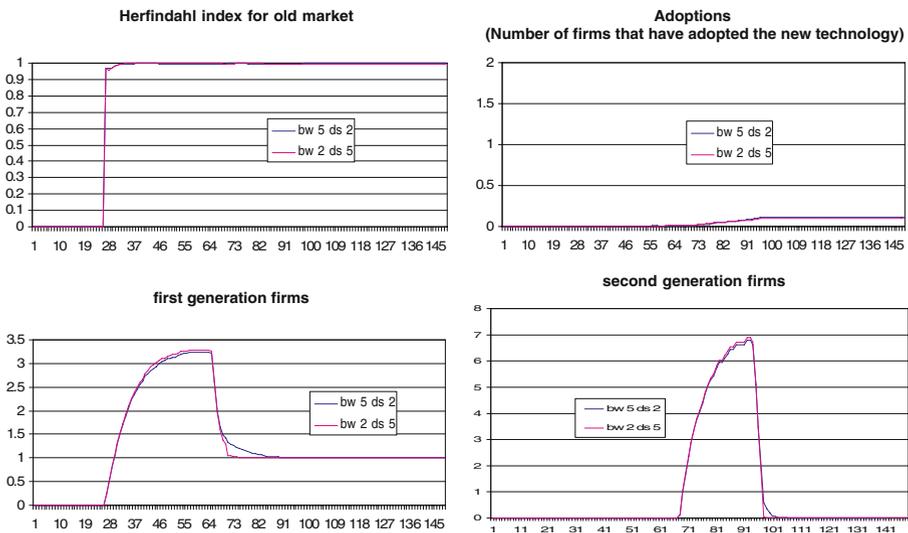

Fig. 5 No adoption of new technology

5.2 Experimental users

Under what conditions could the new technology develop? One possibility is perfect foresight on the part of consumers, and a willingness to incur costs today for the benefit of getting better products tomorrow. In this case, purchase decisions will take into account that the new technology is potentially better and this might enable the new products to crack into the market and get a significant market share. However, this presumes greater ability at technology forecasting than is reasonable, and in any case customers have little incentive to subsidize the new technology with their purchases of inferior products, since the benefits of the new technology taking off are, to a considerable extent a "public good."

On the other hand, the histories of technological advance often have been influenced by the presence of a group of experimental users. In the following simulations, it is assumed that a set of experimental users exists who will buy products based on the new technology, simply because they are new, and will not be deterred from that experimentation simply because the quality of the new products is not up to that which they had been buying. We have represented this situation in Fig. 6, where a group of customers likes experimenting and buy products with the new technology. In this case we have examined two scenarios, one with a high bandwagon (bw=5, Fig. 6a) and the other with high design sensitivity (ds=5, Fig. 6b). In the runs we have a case in which experimental customers constitute only 10% of the total demand, another in which they reach 20%, and a third one in which they are 30%. In all cases the new technology takes off, first through the survival of the new entrants and later, induced by the success of the new firms, through the adoption of the new technology by established firms. When experimental users represent only a small fraction of the market, the new entrants are allowed to survive for a while. They will develop the new technology enough to trigger the industry leader to adopt it. After adoption, the dominant firm reinforces its advantage and shake-out occurs, with the new firms exiting the market. In the case of a larger share of experimental users (20%), the new firms with the new technology do not only survive briefly, but are also able to establish and hold a non-trivial position in the market.

Finally, a large share of experimental users (30%) allows a change in market leadership between the established and the new firms in two cases out of five (high bandwagon setting) and in one third of the cases (high design sensitivity setting). In these cases, the new firms grow rapidly and dominate the market.

Thus, these results suggest that for the diffusion of the new technology to take place it is not strictly necessary that the new firms survive in the long run. It is enough that they survive for some time in order to improve the new technology sufficiently to make it visible and thus to force adoption by the incumbents (who are also starting to experience diminishing returns in their technical advance, because they are approaching the technological frontier related to the old technology).

5.3 Diverse Preferences

A second route through which new technology which is potentially superior to the old, but which requires considerable work before its potential is realized, gets brought to the market is through incubation in a separate market. Thus in Fig. 7 we introduce a
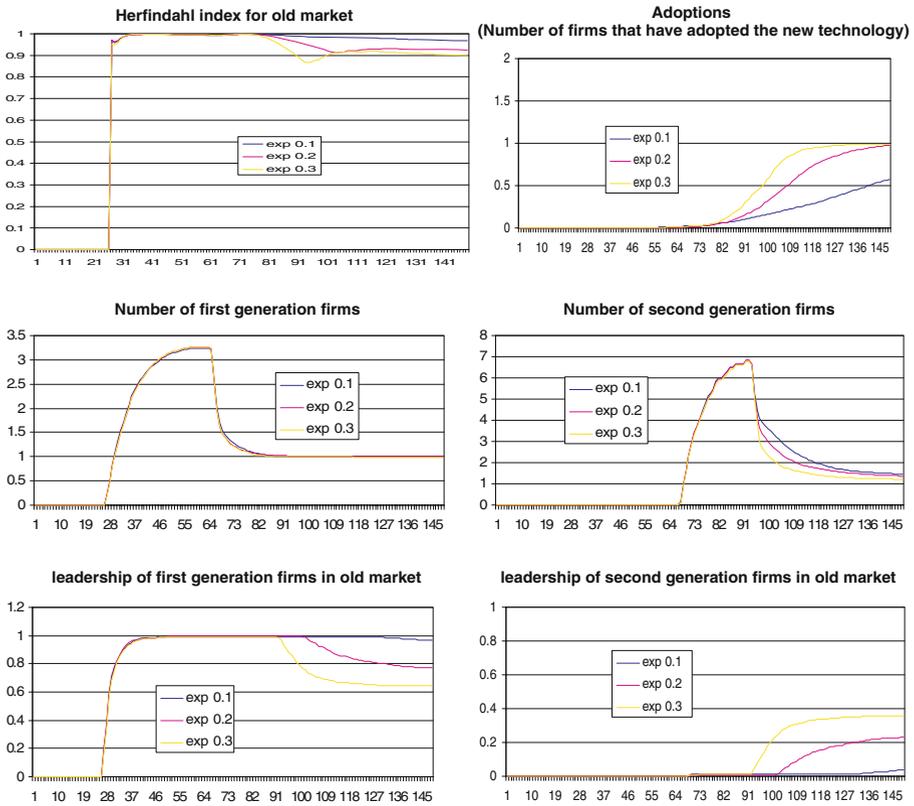
Fig. 6 a Experimental users with a high bandwagon, **b** Experimental users with high design sensitivity

second group of potential customers, a group that greatly values cheapness. First generation products could not achieve the threshold demands of this second group, and they were left out in the cold. On the other hand, with second generation technology, products that meet this group's threshold demands can be provided.

Indeed, the fact that there are no first generation products, or companies producing them, that meet the demands of user group 2 means that that market is open to the new firms using second generation technology. The products they introduce to that market do not face competition from refined first generation products.

In runs of the model in which there is such a second market, unserved by first generation products, but approachable by firms using second generation technology, second generation firms do crack into that market. In the first market second generation firms continue to be losers. However, the new technology and the second generation firms that are nurtured in the second market have as effect the adoption of the new technology in the first market. This is shown in Fig. 8.

5.4 From incubation to new dominant technology

Experimental users, and a separate market, both provide spaces for firms using a new technology to develop, without confronting the old dominant firms at least at
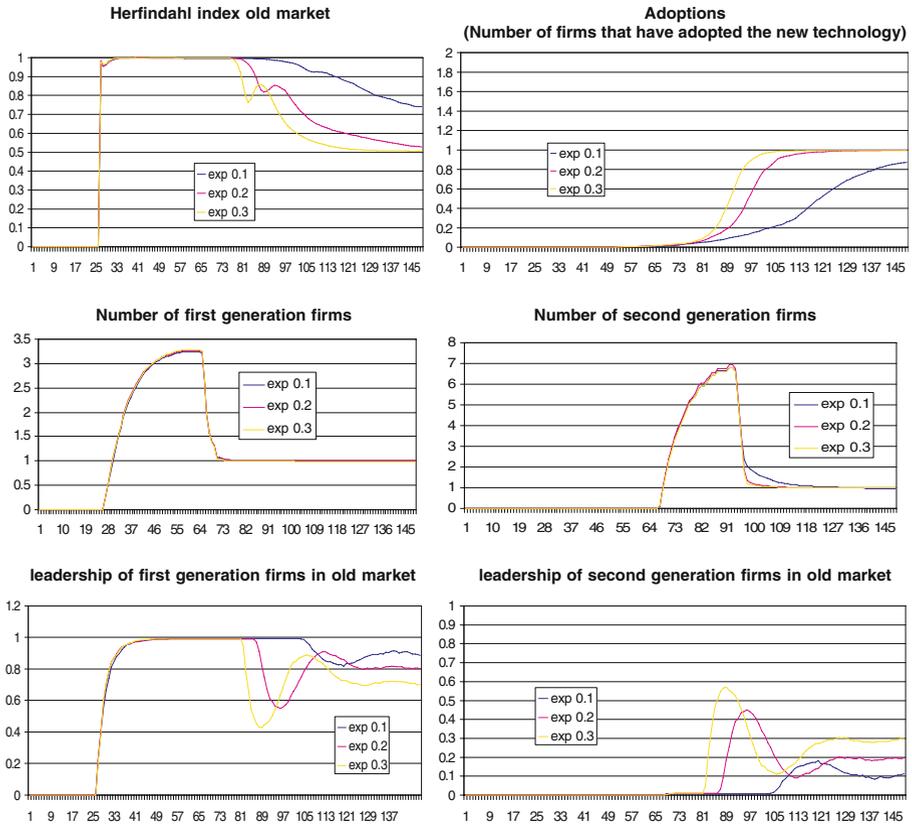
Fig. 6 (continued)

the start. As we have just seen, for a new technology that requires considerable work before it can compete with polished products of an older technology, dominant firms employing that older technology are not motivated to adopt unless under considerable pressure: hence the new technology can get developed only through the efforts of new firms. This incubator space may be necessary if the promise of the new is ever to emerge.

But if the second generation firms in the new market receive sufficient funds, with time their products will become competitive. The way we have modeled the new market, the products that are sold there are not capable early in the game of attracting customers from the main market. But, if these products continue to improve along their trajectories, with time some of them may come to meet and exceed threshold requirements of the main market.

In either case, when this happens, the established firms had better pay attention, or risk losing out to the new comers. And in our model, they will, as Fig. 8 shows: the two markets converge and the second generation firms come to dominate also the first market.
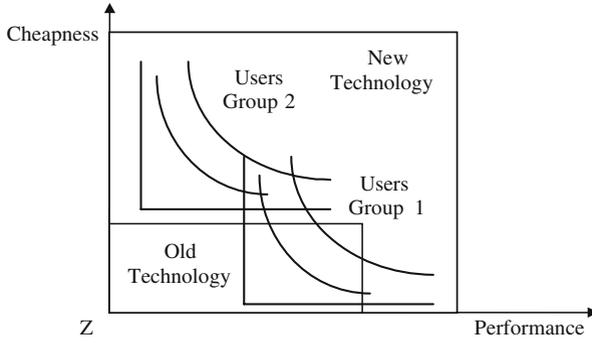
Fig. 7 Entrance of new group of customers (2) that greatly values cheapness
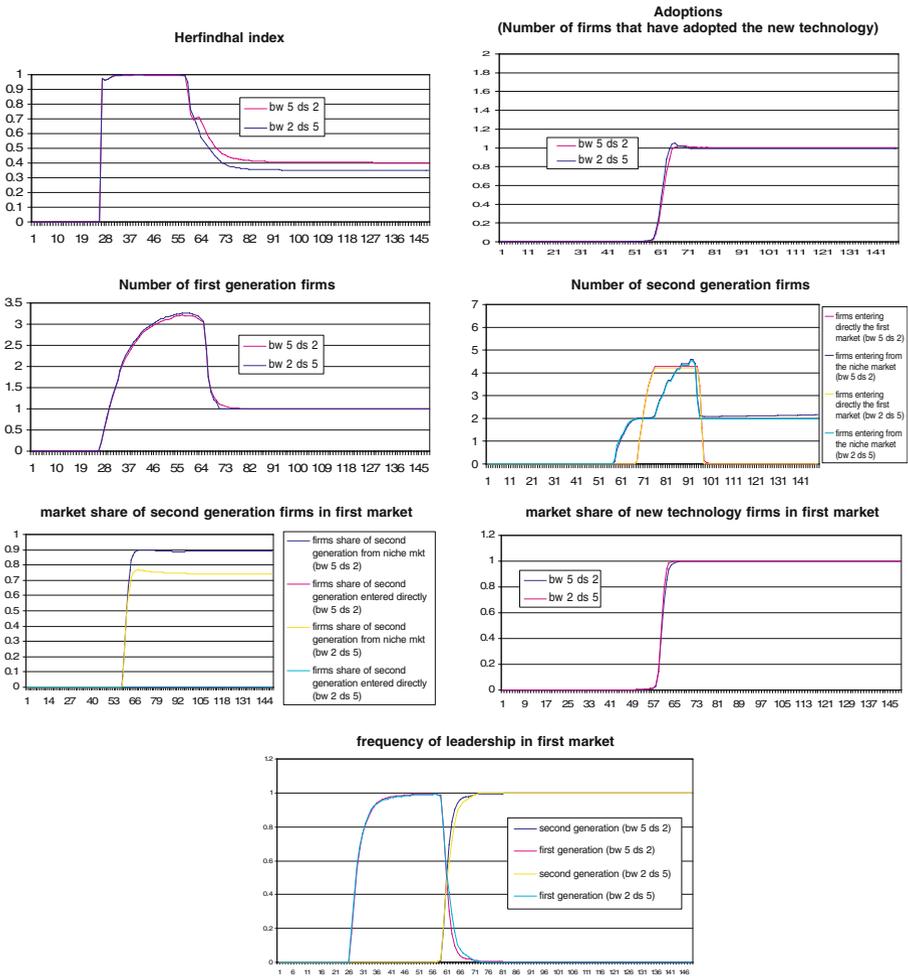

Fig. 8 Old market in the presence of niche market and convergence

6 Conclusions

The history of a number of industries is marked by a succession of eras, with different eras associated with different dominant technologies. Within any era, industry concentration tends to grow, because of dynamic economies of scale on both the supply side and the demand side. Particular eras are broken by the introduction of a new technology which, while initially inferior to the established one in the prominent uses, has the potential to become competitive. In many cases new entrants rather than the established firms are the vehicles through which the new technology is introduced. Very often the large established firms do not make the transition, and if the new technology takes hold sooner or later they are replaced by new firms. In other cases the established firms of the old era are able to switch over effectively, and compete in the new era. In either case, the process of concentration begins again, until it is broken (again) by the advent of a new technology.

This paper has explored a model which generates this pattern. The focus of our analysis has been on the characteristics of the demand for the products of the industry. We have argued that the ability of the new firms exploring the new technology to survive long enough to get that technology effectively launched depends on the existence of fringe markets which the old technology does not serve well, or experimental users, or both. Established firms initially have little incentive to adopt the new technology, which initially is inferior to the technology they have mastered. New firms generally cannot survive in head-to-head conflict with established firms on the market well served by the latter. The new firms need to find a market that keeps them alive long enough so that they can develop the new technology to a point where it is competitive on the main market. Niche markets, or experimental users, can provide that space.

The stimulus for this analysis has come from our research on the computer industry, and we believe the model fits very well there. But there are many other industries where this analysis also seems to apply.

Thus, when transistors were first introduced as a potential substitute for vacuum tubes, in most uses they were inferior. However, in the Unites States the Department of Defense recognized the potential advantages of transistors in several of the weapons systems it was contemplating. The American Department of Defense thus provided a special market for transistors, and companies selling almost exclusively to that specialized market were able to survive and advance transistor technology to a point where it could compete effectively with vacuum tubes in a wide range of civilian uses. By the mid-1970s, transistors had virtually eliminated vacuum tubes from those markets.

The American Department of Defense also provided a (large) niche market that induced the development of aircraft jet engines. Without that specialized market, it is likely that jet engine technology would have developed much more slowly. As it happened, supported initially by defense demand, jet engine technology rapidly advanced and relatively quickly replaced piston engines on the civilian aircraft market (Malerba 1985, Langlois and Steinmueller 1999).

A recent study on the development in Europe and the United States of intraocular lenses as a technology for effectively solving the cataract problem documents the considerable period of time when those lenses, and the surgery

needed to implant them, were considered by many ophthalmologists to be inferior to other means of treating cataracts, and for many patients, that probably was the case. The persistence of a group of ophthalmologists who had faith in intraocular lenses, and their ability to convince a number of patients that this was the best treatment for them, provided a market and a testing ground for the development of intraocular lenses to the point where they became very effective, and the surgery safe and more or less routine (Metcalfe and Andrew 2005).

As is well known, the early work which started progress toward the Internet was funded by the American Department of Defense because of its own special needs. Those needs called for something like a packet switched network, as an alternative to a circuit switched network. As that technology developed, a new group of experimental users joined the market, principally academic researchers, who used ARPANET to connect research laboratories. As a result of further development, the Internet became a technology capable of attracting a large market of users (McKnight and Bailey 1998).

The Internet case is not so much one of a new technology replacing an older one in a given market, but rather one in which an initial niche market, and a group of experimental users, enabled a new technology to survive and advance to the point where it could tap a major new market. There are many examples of important new technologies that developed this way. Thus, around the world the market for automobiles was initially almost exclusively a market made up of sportsmen, and experimenters. The same is true for the market for early aircraft (Prencipe 2000).

Scholars of technological change have not ignored demand in its effects on innovation and on market structure (Von Hippel 1988). Indeed they long have seen the size and structure of demand as important factors influencing the magnitude and orientation of inventive effort. And scholars concerned with the factors influencing industry structure also have paid attention to the structure of demand, the sensitivity of customers to advertising, and the strength bandwagon and network effects, in determining whether or not the industry gets concentrated (see in particular Sutton 1991 and 1998).

The focus on the demand side in this paper has been different than in either of these research traditions, but is in some cases strongly complementary. The argument has been that the presence of markets not well served by incumbent firms, and of experimental users, often has been an important factor permitting new technologies to effectively enter a field, and that when new technologies enter these submarkets through new firms, this can have a profound, long-run effect on industry structure. We think that this has been an important phenomenon in the history of a number of industries, and deserves more attention from economists than it thus far has been given.

Appendix 1

The model

Firm capabilities: directions in attribute space

The basic firm-specific characteristics in the model are the fractions θ_1, θ_2 of R&D expenditures that are devoted to improving the two product attributes. These are determined for each firm at the start of each run by a draw on the uniform distribution. With total R&D expenditure at t equal to R, the R&D devoted to the improvement of attribute i is $R_{it} = \theta_i R_t$.

Here, $i=2$ denotes performance and $i=1$ denotes cheapness.

Firm capabilities: movement along trajectories

Capability trajectories for all firms begin at the attribute point $Z=(Z_1, Z_2)$. For each attribute, the design improvement produced in a single period is an increasing function of R-D devoted to that attribute and the remaining distance, $L_i - X_i$, to the maximum value, L_i, of that attribute. Specifically,

$$\text{change}_i = a_0 (R_i)^{a1} (L_i - X_i)^{a2} \tag{9}$$

Firms' finance, R-D and pricing decisions

New firms starting at point Z have a loan that gets them started. Absent other sources of funds, firms spend a constant fraction of their loan on R-D in each period, so long as there are remaining funds, or revenues from sales, begin to come in. If the funds are exhausted before a marketable design is achieved, firms exit.

If and when a marketable design is achieved before the initial loan is all spent, gross profits become positive. Gross profits are defined as revenues from sales minus the costs of production.

$$\pi = Mp - Mk, \tag{10}$$

M is the number of units sold, p is their price, and k is unit production cost. A fraction, ϕ, of this profit is returned to investors each period until the loan is paid off. R&D expenditures are financed out of the remainder.

Production costs, k_t, are the inverse of the cheapness attribute of the firm's current capability. Price is obtained by adding a mark-up, μ, to costs:

$$p = k(1 + \mu) \tag{11}$$

The mark-up, μ, is initially set equal for all firms, but subsequently it varies over time as a function of the market share that has been achieved. Specifically:

$$\mu_t = 0.9\mu_{t-1} + 0.1[m_i/(\eta - m_i)] \tag{12}$$

where η is a notional elasticity of demand (equal to 2 in the first market and to 4 in the new market) and m_i is the firm's market share. Thus the mark-up is constant when it is equal to the value appropriate to a firm with market share m in an asymmetric Cournot equilibrium.

R&D expenditures, R, are determined as follows:

$$R_t, = \phi * \pi(1 - \sigma) \tag{13}$$

The excess gross profits after debt repayment and R-D expenditures, is invested in an account, Bt, that yields the interest rate, r, in each period.

Demand

The overall market consists of a large number of "submarkets," the number being a parameter of the model. A submarket buys from at most one supplier in each period. If a purchase is made, the number of units purchased equals the merit of design, M, of the product offered by that supplier. For a product with cheapness $X_1=1/p$ and performance X_2, the merit of design is given by:

$$M = b_0(X_1 - X_{1min})^{b1}(X_2 - X_{2min})^{b2} \tag{14}$$

where b_0 is a scale parameter, and X_{1min} and X_{2min} are the threshold levels for cheapness and performance. If there is more than one computer that meets threshold demand requirements, that has M greater than zero, the probability that customers in a submarket will buy from a particular supplier is positively related to the merit of that supplier's design, and to the suppliers overall market share. Specifically:

$$P_i = c_0(M_i)^{c1}(m_i + d_1)^{c2} \tag{15}$$

where c_0 is specified so that the sum of the probabilities adds to one. M denotes the "merit" of a product. "m" is the market share in terms of the fraction of total sales revenues accounted for by that product. The constant "d_1" assures that new firms entering the market have a positive probability of making a sale.

In the initial runs, there is a class of customers, who have the same preferences. In the runs that explore what happens after new basic technology becomes available, two additional classes of customers are added to the model. First, there is a group of experimental users. Experimental users are represented by a fraction of the submarkets, determined by a model parameter. Second, there are potential new users, who have very different preferences than the users that had been served previously. In particular, they value cheapness greatly, and place less value on performance.

Long run convergence

If and when the computers using the new component technology achieve threshold levels of merit for the old customers, those computers enter the set being scanned by those submarkets. If those new computers achieve levels of merit exceeding those of the old computers, they can take over the old market as well as the new.

Adoption of new component technologies

Adoption of the new technology takes place in two steps. First, a firm must perceive the new technology. Perception is a stochastic process that depends on the current technological position of the potential adopter in relation to the technological frontier in the old technology and on the progress realized by the new technology:

$$Pr_{perc} = \left[\left(zi_j^u + z_h^v \right) / 2 \right]^{\lambda} \tag{16}$$

where Pr_{perc} is the probability of perceiving the new technology, zi_j is fraction of the old technological frontier covered by firm i and z_h is the fraction of the new technology frontier covered by the best-practice new generation's firms. The parameter λ measures the general difficulty of perceiving the new technology.

Once firms have perceived the possibility of adoption, they have to invest in order to acquire the new technology. Adoption costs (C_{ad}) entail a fixed cost, F_{ad}, equal for all firms, and the payment of a fraction q of firms' accumulated budget, linked to factors like the training of engineers and the like. Thus,

$$C_{ad} = F_{ad} + qB_t \tag{17}$$

Firms whose budget does not cover the fixed costs or whose profit rate is negative cannot adopt the new technology.

Exit

Firms exit the market when their budget becomes negative (because current profits are insufficient to pay back the due fraction of the outstanding debt) and/or when their rate of profit becomes negative and it has been falling faster than a given rate (a parameter of the model) over the past four periods.

Specifically, the rate of profit is defined as:

$$\overline{\pi}_{i,t} = \frac{B_{i,t} - Debt_{i,t}}{B_0 \cdot (1+r)^{(t - t_{b,i})}}$$

where $\overline{\pi}_{i,t}$ is the profit rate of firm i at time t, $B_{i,t}$ is the budget of firm i at time t, $Debt_{i,t}$ is the debt of firm i at time t, B_0 is the initial budget, $r = 0.025$ is the one period interest rate and t_b is the birth time of firm i.

Let us then define a weighted change of the rate of profit as

$$\widehat{\pi}_{i,t} = \widehat{\pi}_{i,t-1} \cdot (1 - w) + \left(\overline{\pi}_{i,t} - \overline{\pi}_{i,t-1} \right) \cdot w \tag{18}$$

where $w = 0.25$ is a parameter
Firms then exit the market when

$$\left. \begin{cases} \overline{\pi}_{i,t} < 0 \\ \widehat{\pi}_{i,t} < VRP \end{cases} \right\} \text{and}$$

VRP$= -0.03$ is parameter

Firms exit also when their budget or their R&D expenditures becomes too small. In particular:

$$B_{it} < 0 \text{ or } R > R_{\min}, \text{ where } R_{\min} \text{ is a parameter} \qquad (19)$$

Appendix 2

We provide here a complete list of the notation used in the model:

Indices:

- i index for firms,
- t index for time periods,

General model parameters

- $T=150$ time horizon
- $T_{MP}=30$ time of introduction of new microprocessor technology
- $T_{fTR}=0$ birth period of first generation firms with transistor technology
- $T_{fMP}=35$ birth period of second generation firms with microprocessor technology

Exogenous industry characteristics

- $F_{TR}=6$ number of first generation firms with transistor technology
- $F_{MP}=20$ number of second generation firms with microprocessor technology
- $r=0.025$ one period interest rate
- $b_0=0.02$ gives a scale for the utility function
- $b1_{MF}=0.3$, $b1_{PC}=1.15$ exponent of cheapness in the utility function
- $b2_{MF}=1.1$, $b2_{PC}=0.35$ exponent of performance in the utility function
- $c1_{MF}=2$, $c1_{PC}=2$ exponent of utility in the probability of selling function
- $c2_{MF}=2$, $c2_{PC}=0.1$ exponent of share in the probability of selling function
- $\eta_{PC}=4$, $\eta_{MF}=2$ elasticity of demand
- $Lc_{TR}=2{,}000$, $LcMP=9{,}000$ limit of cheapness for technology
- $Lp_{TR}=8{,}000$, $Lp_{MP}=9{,}000$ limit of performance for technology
- $Tc_{MF}=400$, $Tc_{PC}=2{,}000$ minimum value of cheapness for entering the market
- $Tp_{MF}=4{,}000$, $Tp_{PC}=500$ minimum value of performance for entering the market
- $subm_{MF}=100$ number of submarkets that create the mainframe market
- $subm_{PC}=100$ number of submarkets that create the PC market

Endogenous industry characteristic

- $\text{Leader}_{PC\ t}$ leader in PC market at time t
- $\text{Leader}_{MF\ t}$ leader in MF market at time t

Exogenous firm characteristics

- $\mu_0=0.1$ initial mark-up of firms
- $\phi=0.1$ fraction of profits invested in R&D
- $B=9$ initial budget given to first generation firms
- $Br_\%=0.45$ initial budget reduction factor for second generation firms
- $\sigma=0.15$ fraction of profit used for debt pay back

- $a1 = 1$ exponent of distance from corner in design change function
- $a2 = 0.65$ exponent of R&D expenditure in design change function
- $u = 1$ exponent of the distance from corner in the function that defines probability of adoption
- $v = 1$ exponent of distance of the best-practice new generation's firm in the function that defines probability of adoption
- $\lambda = 15$ exponent that measures the general difficulty of perceiving the new technology
- $q = 0.6$ cost of adoption in terms of budget fraction
- $F_{ad} = 2.5$ fixed cost of adoption

Endogenous firm characteristics:

- $M_{i,t}$ merit of design of a computer produced by firm i at time t
- $X_{c\ i,t}$ value of cheapness of computer i at time t
- $X_{p\ i,t}$ value of performance of computer i at time t
- $m_{i,t}$ market share of firm i at time t
- $p_{i,t}$ price of a mainframe/PC produced by firm i at time t
- $\mu_{i,t}$ mark-up of firm i at time t
- $\pi_{i,t}$ profits of firm i at time t
- $R_{i,t}$ R&D spending of firm i at time t

Appendix 3: Sensitivity and robustness analysis

Following Dawid (2004) and Dawid and Reimann (2005), we carried out sensitivity and robustness analysis on the model by generating 100 different profiles of the basic model parameters, except those that are at the centre of our analysis, i.e. the bandwagon (c_1 in Eq. 7) and design sensitivity (c_2 in Eq. 7). The profiles were generated randomly, where each parameter was drawn from a uniform distribution bounded by a conceptually plausible range. Each particular setting for our control parameters was run over all 100 profiles and the results obtained were averaged over these runs. As an additional robustness check we repeated the procedure with

Table 1 Parameters drawn from a uniform distribution bounded by a conceptually plausible range

	Parameter	Lower bound	Upper bound
1	μ_0 (mark-up)	0.09	0.11
2	ϕ (fraction of profits invested in R&D)	0.09	0.11
3	B (budget)	8.1	9.9
4	σ (% of profit used to repay initial loan)	0.135	0.165
5	Q (budget fraction for adoption)	0.54	0.66
6	F_{ad} (fixed cost of adoption)	2.25	2.75
7	$Br_\%$ (budget reduction second gen.)	0.405	0.495
8	$b1_{MF}$ (parameter of utility function)	0.27	0.33
9	$b2_{MF}$ (parameter of utility function)	0.99	1.21
10	U (parameter of probability of adoption function)	0.9	1.1
11	V (parameter of probability of adoption function)	0.9	1.1
12	λ (parameter of probability of adoption function)	13.5	16.5

Table 2 Simulation summary statistics: $t=150$

Figure 3 bw=2 ds=2 (no MP no second generation)				
	H	A	L1	S
Mean	0.59522	0	0.988	0
Std	0.28112	0	0.10894	0
Max	1	0	1	0
Min	0	0	0	0
Upper tail confidence interval (99%)	0.61816	0	0.99689	0
Lower tail confidence interval (99%)	0.57229	0	0.97911	0
Figure 3 bw=5 ds=2 (no MP no second generation)				
	H	A	L1	S
Mean	0.99287	0	0.994	0
Std	0.077869	0	0.077266	0
Max	1	0	1	0
Min	0	0	0	0
Upper tail confidence interval (99%)	0.99922	0	1.0003	0
Lower tail confidence interval (99%)	0.98652	0	0.9877	0
Figure 3 bw=2 ds=5 (no MP no second generation)				
	H	A	L1	S
Mean	0.987	0	0.993	0
Std	0.099201	0	0.083414	0
Max	1	0	1	0
Min	0	0	0	0
Upper tail confidence interval (99%)	0.99509	0	0.99981	0
Lower tail confidence interval (99%)	0.97891	0	0.98619	0
Figure 5 bw=5 ds=2 (MP and second generation)				
	H	A	L1	S
Mean	0.99825	0.113	0.992	0.12
Std	0.014896	0.3199	0.089129	0.32512
Max	1	2	1	1
Min	0.84305	0	0	0
Upper tail confidence interval (99%)	0.99947	0.1391	0.99927	0.14653
Lower tail confidence interval (99%)	0.99704	0.086901	0.98473	0.093474
Figure 5 bw=2 ds=5 (MP and second generation)				
	H	A	L1	S
Mean	0.99489	0.104	0.99	0.112
Std	0.049827	0.3119	0.099549	0.31552
Max	1	2	1	1
Min	0.5	0	0	0
Upper tail confidence interval (99%)	0.99895	0.12945	0.99812	0.13774
Lower tail confidence interval (99%)%	0.99082	0.078553	0.98188	0.086257
Figure 6a bw=5 ds=2 exp 0.1				
	H	A	L1	S
Mean	0.96686	0.576	0.965	0.59915
Std	0.05364	0.50644	0.18387	0.47792
Max	1	2	1	1
Min	0.5016	0	0	0.0015458
Upper tail confidence interval (99%)	0.97123	0.61732	0.98	0.63814
Low CI 99%	0.96248	0.53468	0.95	0.56016
Figure 6a bw=5 ds=2 exp 0.2				
	H	A	L1	S
Mean	0.9245	0.974	0.771	0.97203
Std	0.044786	0.22666	0.4204	0.15609
Max	1	2	1	1
Min	0.52245	0	0	0.011953
Upper tail confidence interval (99%)	0.92815	0.99249	0.8053	0.98477
Lower tail confidence interval (99%)	0.92084	0.95551	0.7367	0.9593

Figure 6a bw=5 ds=2 exp 0.3

	H	A	L1	S
Mean	0.89916	0.992	0.644	0.99999
Std	0.030678	0.1263	0.47905	0.00025227
Max	1	2	1	1
Min	0.80136	0	0	0.99202
Upper tail confidence interval (99%)	0.90166	1.0023	0.68308	1
Lower tail confidence interval (99%)	0.89665	0.9817	0.60492	0.99997

Figure 6b bw=2 ds=5 exp 0.1

	H	A	L1	S
Mean	0.74107	0.872	0.887	0.90982
Std	0.23481	0.35741	0.31675	0.27595
Max	1	2	1	1
Min	0.49332	0	0	0
Upper tail confidence interval (99%)	0.76022	0.90116	0.91284	0.93233
Lower tail confidence interval (99%)	0.72191	0.84284	0.86116	0.88731

Figure 6b bw=2 ds=5 exp 0.2

	H	A	L1	S
Mean	0.52765	0.996	0.804	0.999
Std	0.10087	0.12649	0.39717	0.031623
Max	1	2	1	1
Min	0.33334	0	0	0
Upper tail confidence interval (99%)	0.53588	1.0063	0.8364	1.0016
Lower tail confidence interval (99%)	0.51942	0.98568	0.7716	0.99642

Figure 6b bw=2 ds=5 exp 0.3

	H	A	L1	S
Mean	0.50675	0.994	0.701	0.99906
Std	0.05873	0.12641	0.45805	0.029721
Max	1	2	1	1
Min	0.33343	0	0	0.060155
Upper tail confidence interval (99%)	0.51154	1.0043	0.73837	1.0015
Lower tail confidence interval (99%)	0.50196	0.98369	0.66363	0.99664

Figure 8 bw=5 ds=2 (niche market, convergence)

	H	A	L1	S
Mean	0.39824	1.002	0	1
Std	0.064839	0.12654	0	7.034e-017
Max	0.99994	2	0	1
Min	0.19005	0	0	1
Upper tail confidence interval (99%)	0.40353	1.0123	0	1
Lower tail confidence interval (99%)	0.39295	0.99168	0	1

Figure 8 bw=2 ds=5 (niche market, convergence)

	H	A	L1	S
Mean	0.35077	0.992	0	1
Std	0.07265	0.11811	0	6.6275e-017
Max	1	2	0	1
Min	0.20318	0	0	1
Upper tail confidence interval (99%)	0.3567	1.0016	0	1
Lower tail confidence interval (99%)	0.34485	0.98236	0	1

H=Herfindahl index
A=Adoptions
L1=Leadership of first generation firms
S=Share of new technology firms in first market

another 100 random profiles in the same manner and tested several of our qualitative insights obtained with the initial set of profiles. In all these cases our findings were confirmed by such a check. Summarizing, all the results were found to be very robust under the settings we discussed above, namely 100 distinctly different runs,

with profiles based on parameter ranges that were determined by plausibility checks beforehand. (Table 1).

Table 2 reports the essential statistics for the main variables of interest in each of the simulation runs presented in the paper.

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