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First Mover Advantage in Different Technological and Demand Regimes

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Abstract

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Although existing models offer plausible explanations for the dynamics of specific industries, the first mover advantage field still lacks a unifying framework that can make sense of the highly contingent empirical evidence (Lieberman and Montgomery, 1998, SMJ). Recently, Suarez and Lanzolla (2007, AMR) presented a theoretical framework where the mechanisms that generate and protect first-mover advantage are complemented by what happens at both the ?micro? (firm-level resources and capabilities) and the ?macro? level (market and technological environment). Nevertheless, a formal theory with sound theoretical foundations for the environmental variables and the possibility of interactions is still missing.
This work presents a model of industry evolution in the tradition of evolutionary economics that provides a formal representation of the rich framework explaining FMA. The environmental context is explicitly modeled by using the concepts of technological regimes (technology-specific patterns in the ways agents learn) and demand regimes (market-specific patterns regarding the interaction between agents) that are rooted in evolutionary theory and have been successfully applied to several empirical settings. Finally, the use of agent-based simulation methodology allows the observation of results emerging from the interaction between different environmental variables. The model includes three dimensions of demand regimes (horizontal fragmentation; vertical fragmentation; switching costs) and four dimensions of technological regimes (technological opportunities; appropriability conditions; cumulativeness of knowledge; locus of knowledge generation: internal to the firm versus external). A specific parameter in the model, ranging between 0 and 1, corresponds to each dimension of demand and technological regimes.
A three-steps process is used to generate results. First, data about firms are generated by running the model simulations with different sets of parameters. Second, a semi-parametric Cox Proportional Hazard Model is used to

regress survival time against model parameters, firms characteristics, industry conditions at entry and a dummy variable for early entry. Third, the latter coefficient is used as a measure of FMA and plotted against the corresponding values of model parameters.
Preliminary results focus on the role played by cumulativeness of knowledge in shaping FMA and its interaction with other dimensions of technological and demand regimes. One may reasonably expect a positive relationship between cumulativeness of knowledge and FMA: early entry should allow the possibility of starting knowledge accumulation before competitors. Still, if the control variables freely vary on their ranges, there is no evidence of a positive relationship between the cumulativeness of knowledge and FMA. The puzzle can be solved by observing the interaction between cumulativeness and locus of knowledge: when the relevant knowledge is internal to the firm, the relationship between cumulativeness and FMA becomes positive, because a firm can really exploit cumulativeness when internal development protects knowledge from imitation. Moreover, when the relevant knowledge is external to the firm, the relationship becomes slightly negative: early entry becomes less advantageous because firms develop their products without exploiting the knowledge externally available in the future.
Relevant interaction effects emerge also from the demand side: in presence of low switching costs FMA disappears for low values of cumulativeness, but as the latter increases the former increases as well. This signals that cumulativeness can be a partial substitute for switching costs, but there is low complementarity between the two mechanisms.
These results confirm the insights on which the model is built: the concepts of demand and technological regimes play an important role in shaping FMA, but it is important to consider not only their direct effects, but also their interaction to really explain the emergence of FMA; the use of formal modeling tools may help in generating clear and non-ambiguous propositions to be tested in empirical settings.

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ABSTRACT

This paper presents a model of industry evolution in which technological regimes and market regimes shape first mover advantage. By using simulation techniques, we focus on the role played by cumulativeness of technical change and we show that its impact on first mover advantage depends on the level of other relevant dimensions of technological regimes (innovative opportunities, appropriability conditions, locus of knowledge accumulation) and demand regimes (horizontal fragmentation, vertical fragmentation, switching costs).

Keywords: First Mover Advantage; Industry Evolution; Demand Regimes; Technological Regimes.

JEL: C63; L10; O30.

Introduction

First Mover Advantage (FMA) is one of most appealing and diffused concepts in strategy research; although a wide academic literature has flourished on this issue in the last twenty years, there is still no conclusive empirical evidence either in favor or against it. A natural, obvious candidate to put on trial for this unpleasant situation is the empirical literature: Lieberman and Montgomery (1988) recognized its lack of precision as a problem, and VanderWerf and Mahon (1997) showed that many issues that plagued the field (including the endogeneity of first-mover opportunities, the sample selection bias, and measurement problems) had a strong impact on the findings. On the other hand, many of these problems have been solved over time through the help of methodological advances and more suitable datasets (Bijwaard, Janssen, and Maasland, 2008; Eggers, Grajek, and Kretschmer, 2011). Moreover, some of the findings are at odds with theory-driven expectations: Makadok (1998) found evidence of FMA in a context where the ex-ante probability of observing it was very low and Lieberman (2007) showed that in the growing Internet industry the expectations about FMA, although high and widespread, were quite exaggerated.

Therefore, the theoretical literature shares at least in equal measure the responsibility of the current situation. Suarez and Lanzolla (2007) concisely and sternly point out the inability of FMA theory to explain the conflicting empirical evidence and to provide coherent guidelines for managers.

In this paper, we present a formal model of industry evolution that builds on the framework developed by Suarez and Lanzolla (2007) and derives implications regarding the effects of environmental influences – analyzed through the concepts of technological and demand regimes – on the emergence of first-mover advantages. The model is rooted in the evolutionary economics tradition (Nelson and Winter, 1982) and exploits the experience of the “history-friendly models” in reducing the gap between the richness and complexity of the empirical evidence and the abstractness of formal models. It draws its building blocks from “history-friendly” models describing the actual evolution of the computer (Malerba, Nelson, Orsenigo and Winter, 1999) and the pharmaceutical industry (Malerba and Orsenigo, 2002), and combines them in order to represent many different technology and market contexts and allow comparative exercises.

Towards a formal model of first mover advantage

The existence of FMA emerges as a common regularity in several theories of industrial dynamics (Mueller, 1997). Industry life cycle models (Klepper, 1996, 2002), aiming at explaining the dynamics over time of specific sectors, generate advantages for early entrants through a combination of increasing returns to process R&D, decreasing industry cost-price margins and transitory idiosyncratic cost shocks. A different model by Klepper and Thompson (2007), explaining patterns not conforming to the ILC, has similar conclusions as for early mover advantage, although here it depends on the positive relationship between the age of a firm and the average number of submarkets in which it operates, and the negative relationship between such a number and the probability of exit.

The game-theoretic industrial organization (IO) literature has focused on the specific mechanisms that drive the emergence of FMA, by means of more and more technically sophisticated models, but still limited to a static duopoly context. Moreover, the results have suffered from the well-known Pandora's box problem (Camerer, 1991): according to the assumptions on the cost structure, the distribution of information, and the level of commitment it is possible to generate first-mover advantage (Stackelberg, 1952), dissipation of any advantage due to a race to be first (Fudenberg and Tirole, 1985), second mover advantage (Dutta, Lach, and Rustichini, 1995; Hoppe and Lehmann-Grube, 2001) and even 1.5 mover advantage (Henkel, 2002).

The resource-based view of the firm has been a third stream of literature that has contributed to the current theoretical framework of FMA. Lieberman and Montgomery (1988) identified three isolating mechanisms that favor the emergence and protect the persistence of first mover advantage: technological leadership, preemption of scarce assets, and consumers switching costs. Still, resources and capabilities have been much more helpful in dealing with the issue of the determinants of entry timing (Klepper and Simons, 2000; Helfat and Lieberman, 2002; King and Tucci, 2002; Lee, 2008) rather than its effects on competitive advantage (Bayus and Agarwal, 2007).

Recently, Suarez and Lanzolla (2007) presented a theoretical framework where the isolating mechanisms and the resources and capabilities (the "micro" level) are complemented by the "macro" level: the market and technological environment. Recent empirical contributions (Franco, Sarkar, Agarwal, and Echambadi, 2009; Dobrev and Gotsopoulos, 2010; Echambadi, Bayus, and Agarwal, 2011; Grajek *et al*. 2011) have built upon this framework and have actually showed that it is a promising path for future research.

Therefore, we extend the framework provided by Suarez and Lanzolla (2007) by presenting a formal model of industry evolution. Adner, Polos, Ryall, and Sorenson (2009) advocated for a greater diffusion of formal models in management, highlighting their benefits relative to merely verbal theories: formal models require precision and non-ambiguity in the definition of key concepts; they ensure the logical consistency of the arguments; and they also favor the generation of novel and unanticipated implications. The lack of a formal model might be traced to the difficulty of reconciling the complex framework that emerged in the FMA field with the modeling style that has been dominant since its beginning (game theoretic industrial organization). The evolutionary tradition of models of industrial dynamics (Nelson and Winter, 1982; Winter, Kaniovski, and Dosi, 2003) may prove useful as an alternative tool that allows a formal representation of the rich framework that should explain FMA: a recent stream of this literature (history-friendly models: Malerba et al., 1999) has gone as far as modeling the historical evolution of specific industries, with high richness of details, that allowed also to study counterfactual histories (Durand and Vaara, 2009). Moreover, the evolutionary theory can also contribute to a more general specification of the technology and demand environments, through the concepts of technological regimes – technology-specific patterns in the ways firms learn – and demand regimes – market-specific patterns regarding the characteristics of consumers. Technological regimes (Winter, 1984; Malerba and Orsenigo,

1997) are fundamental characteristics of the technological environment: they have been recognized as important determinants of firms innovative activities (Breschi, Malerba, and Orsenigo, 2000; Peneder, 2010), firms productivity growth (Castellacci and Zheng, 2010), technological entry (Malerba and Orsenigo, 1999), and new firm formation (Shane, 2000). Very recently, they have also been successfully applied to the issue of early mover advantage (Kim and Lee, 2011). On the other hand, demand regimes, although once confined in the role of selection rules, have been the subject of a growing attention in the past decade, with a specific focus on the role of demand in the growth process (Witt, 2001; Metacalfe, 2001), the importance of demand fragmentation in the evolution of industries (Kaniovski, 2005; Malerba and Klepper, 2010) and economies (Langlois, 2001), the interaction between consumers preferences and innovation (Consoli and Nelson, 2010), the role of users in the innovation process (Malerba, Nelson, Orsenigo, and Winter, 2007) and the interaction between different sectors (Malerba, Nelson, Orsenigo, and Winter, 2008). This stream of literature has also benefited from several contributions in the fields of management of innovation (von Hippel, 1988) and strategy (Christensen, 1997; Adner and Levinthal, 2001; Adner and Snow, 2010).

formal model of industry evolution in which technological regimes, market regimes and firms' heterogeneous capabilities shape first mover advantage.

Summarizing, we present a formal model of industry evolution in which the different dimensions of technological regimes and demand regimes determine the emergence of first mover advantage. Among these environmental conditions, we focus on the role of cumulativeness of technical change, and we show that the effects of this dimension on first mover advantage depends on the level of the other dimensions of both technological regimes and demand regimes. The model is analyzed with the help of simulation techniques: firms and consumers behaviors are specified by a number of equations, that are computed in each discrete time-step. The next section provides the main insights of the model; a fully detailed description can be found in the appendix.

The model

The Topography

The basic environment of the model is an industry with two main components: the market space and the technology space. The former is a characterization of consumers preferences for the products and their characteristics. Consumers preferences differ along three dimensions: preferences for variety (or horizontal fragmentation) refer to differences in "locations" and "ideal distances" from products (Hotelling, 1929); preferences for quality (or vertical fragmentation) refer to differences in the evaluation of the "minimum quality" that can satisfy consumers needs (Shaked and Sutton, 1982); preferences determined by consumers past behavior can be referred to as switching costs. Consumers are grouped in submarkets according to their preferences for variety. Within each submarket, consumers have heterogeneous minimum quality thresholds: the product is not taken into consideration for purchase until it meets this requirement. Once a consumer buys a product, he will take into account its past choice when facing again a purchasing decision.

The technology space is a characterization of potential products and their technological trajectories. Following the literature about technological regimes, four broad dimensions define the technology space: technological opportunities, appropriability of innovations, cumulativeness of technical change, properties of the relevant knowledge base (Breschi et al., 2000). Technological opportunities define the availability of innovative solutions to firms in search for them. Appropriability conditions express the possibility of protecting firms innovations from imitation. The cumulativeness of knowledge defines the degree to which today innovations depend on the level of knowledge that has been already reached. Finally, there are several properties of the knowledge base that may be relevant in this context: tacitness, complexity, specificity, applicability (Marsili, 2001). The property that better fits with the level of analysis adopted in the model is the *locus* of knowledge accumulation (whether it occurs within the firm or in the external environment).

The link between the market space and the technology space is established through firms activities. Firms search the technology space in order to find promising potential products from which they create products that generate utility for the consumers in the market space. A potential product is defined by a specific combination of characteristics and a technological trajectory that determines the evolution of its quality. A product is a firm-specific realization of the potential product, which is sold on the market space. Firms may differ either because they discover different potential products or because they do not have the same capabilities of exploring the technological trajectories.

<u>The market space and the behavior of consumers</u>

In the market space there are S submarkets, heterogeneous in size. The preferences of consumers in a submarket about the combinations of product characteristics are represented by a vector v_s of real values in the set [0,1] of dimension equal to the number of potential products (J). The highest value (1) means that the product perfectly satisfies the preferences for the combination of characteristics; the lowest value (0) means that the product has no utility for that group of consumers. A full description of the preferences of consumers would require a matrix R of dimension $S\times J$. In order to reduce the computational and memory burden of the model, we assume that for each product there is at least one submarket where it provides the maximum utility: we call it the main submarket of product j and we denote it by s_j. Products sharing the main submarket are considered as equivalent by consumers of other submarkets. By this simplifying assumption, the dimension of R reduces to $S\times S$, but R needs not to be symmetric: the fact that consumers in submarket s_j consider product k a good substitute for product j does not imply that consumers in submarket s_k consider product j a good substitute for product k. All the elements on the main diagonal of R are equal to one. The off-diagonal elements are independently extracted from a beta probability distribution: the mean of this distribution (μ_R) represents the extent to which consumers preferences are homogeneous. Starting from it, we can define the degree of horizontal fragmentation in the market space as $\mu_H = 1 - \mu_R$: when μ_H takes its maximum value (1) the fragmentation is so high that consumers consider purchasing only products belonging to their submarket; when μ_H takes its minimum value (0) consumers consider all the products as perfect substitutes for each other.

The preferences described by *R* interact with the quality of the products and determine their evaluation by consumers. Quality is a product-specific variable that may change over time: we denote as $q_{j,t}$ the quality that product *j* has in period *t*. Then, the quality of product *j* as perceived at time *t* by consumers in the submarket *s* is $q_{j,s,t} = q_{j,t} \cdot R_{s,s_j}$.

Within each submarket, the consumers refer to the perceived quality to evaluate whether the product satisfies their minimum quality requirements. The thresholds are distributed according to a beta cumulative function $F(\cdot)$, which is the same for all submarkets. One of the shape parameters represents the degree of vertical fragmentation (μ_V) in the market space: when this parameter takes its minimum value (0) all consumers have the same minimum quality requirements; when μ_V takes its maximum value (1) consumers minimum thresholds are uniformly distributed along the quality dimension.

Consumers consider also price in their purchasing decisions: the higher the price of a product, the lower the probability of buying it, keeping constant the perceived quality. Firms choose the price of their products with a profit-maximization rule, that takes into account both the price-elasticity of demand and the degree of competition in the previous period.

Finally, consumers that already bought the product in the past can be affected by switching costs, whose strength is expressed by the parameter ρ: when it takes its minimum value (0) consumers do not consider their past behavior in the purchasing choice; when ρ takes its maximum value (1) consumers keep buying the same product they bought in the past, irrespective of any change in quality or price that may occur over time.

The technology space and the behavior of firms

In the technology space there are *J* potential products. Each of them has its own main submarket (s_j) and its own technological trajectory. A technological trajectory is a potential product specific map from the dimension of knowledge (k) to the dimension of quality (q). This relationship is represented by a generalized logistic function, which imposes that quality is non-decreasing in knowledge and that the shape of relationship is like an S, as it is well established in the technology literature (Foster, 1986).

Firms innovation activities are twofold: they can either search the technology space to find new products or explore the knowledge dimension of existing products in order to improve their quality. In both cases, firms choices are based on routines and are a function of observable variables, which include profits, sales or quality, but do not include knowledge. For the sake of simplicity, we assume that a firm uses all its profits to finance innovation activities. The allocation of financial resources to innovation activities follows a multi-step procedure. First, we assume that all the operations regarding a product in a firm are conducted by a specific team: firms producing multiple products allocate the resources among multiple teams. A team has more resources if its product earns a higher share of firm's profits or if its innovation activities are successful, both in relative and in absolute terms. Then, each team chooses whether to use its financial resources to improve its existing product or to search for new products: this choice depends on the past achievements of the team in the two activities.

When a team searches for new products, the amount of invested financial resources determines the probability of finding a promising product, given the level of innovative opportunities in the technology space, which is the fraction ξ of potential products that have a quality higher than 0. When the parameter ξ takes a low value, teams have a limited amount of innovative opportunities; when it takes its maximum value (1) it becomes much easier for them to discover new potential products. A team may also run into products already discovered by other firms; in this case, it can use the product only if it is not protected by a patent. Let L and T be the granted length of a patent and the time-horizon of the industry, respectively; then, the ratio $\chi = \sqrt{L/T}$ represents the degree of appropriability of innovations. When χ takes its minimum value (0) there is no patent protection; when it takes its maximum value (1) patents, once granted, last until the end of the simulation.

When a team chooses to improve its existing product, the amount of invested financial resources ($b_{j,t}$) determines the probability of getting a positive increase in quality, given the firm's capabilities (θ_f), the existing level of product-specific knowledge ($k_{j,t-1}$) and the existing level of external knowledge ($k_{e,t-1}$). The importance of past knowledge in generating new knowledge, that is the cumulativeness of knowledge, is expressed by the parameter γ: when it takes its minimum value (0), the increase of knowledge depends only on the financial resources and the capabilities of a firms; when γ takes it maximum value (1), the starting point for the generation of new knowledge is the existing level of knowledge. The relative strength of internal, product-specific knowledge *vis-à-vis* external, publicly available knowledge is represented by the parameter δ: when it takes its minimum value (0), internal, product-specific knowledge plays no role in the generation of new knowledge; when δ takes its maximum value (1), only internal knowledge matters and there is no role for external knowledge.

<u>Model Dynamics</u>

A simulation run represents the evolution of an industry over time and it goes on until the last period (T) is reached. At the beginning of each period, a new potential firm searches the technological space: if it finds a promising potential product which is not under patent protection, the firm enters and starts producing and selling the product in the market space; otherwise, in that period no entry occurs. Since no more than one firm can enter the market in each period, it is possible to define a univocal order of entry.

Then all the existing firms perform their activities in the following order: first, they allocate among their teams the existing financial resources; then, each team chooses and executes its specific innovative activity. Once new products have been discovered and existing products have been improved, firms set the prices and try to sell their products in the market space: market shares and profits are determined according to the utility that products provide to consumers.

Finally, exit of products and firms occurs. A product that does not reach a minimum market share (E) in at least one submarket is withdrawn from the market space. A firm that does not have any product to sell in the market space fails and exits from the industry.

Analysis

Before specifying the strategy we used to obtain and analyze results, we need to clarify our terminology. A simulation model of industrial dynamics describes the rules that govern the evolution of an industry over time; the actual realization of the model is a run and it is a function of a set of initial conditions, which include both the values of the parameters and the initial values of variables. The parameters are the elements of the model whose value does not change within a single run; the variables are the elements of the model whose value is updated according to the rules of the model. We distinguish three groups of parameters. Individual parameters refer to the invariant properties of specific objects (firms, products, submarkets) that guarantee within-category heterogeneity (for instance: capabilities of firms; relatedness of submarkets): they are randomly extracted from the range of all meaningful values. General parameters are the elements that do not change across different runs: their value is determined through a process of calibration that ensures some basic requirements (for example: the viability of the industry). Several methods have been proposed for calibration (Windrum, Fagiolo, and Moneta, 2007; Werker and Brenner, 2004): here we refer to the history-friendly literature and use as reference points the models about the computer industry (Malerba *et al*., 1999) and the pharmaceutical industry (Malerba and Orsenigo, 2002). Focal parameters are the elements we choose in a systematic way in order to answer the research questions of this paper: they include the four dimensions of technological regimes, and the three dimensions of demand regimes.

We focus our analysis on a specific dimension of technological regimes: the cumulativeness of technical change. First, we study the existence of a generic relationship between this dimension and first-mover advantage, which should hold irrespectively of the value taken by the focal parameters[1]. Then, we study how this relationship changes if we increase or decrease the value of the other dimensions. For each of these cases, we systematically change the value of cumulativeness from 0 to 1 at intervals of 0.01; moreover, in order to reduce the impact of random elements on results, we perform 100 runs for each combination.

The next step requires the choice of a indicator for first-mover advantage. The empirical literature has employed several measures both for the “first-mover” and for the “advantage”, according to the characteristics of the setting; moreover, Vanderwerf and Mahon (1997) show that this choice can have an impact on the findings. Since our purpose is inherently comparative and involves quite different settings, we choose the measures that are less affected by these differences. Our measure of advantage is in terms of survival odds: since the time dimension of the model is intrinsically discrete, we use a logit specification, which also allows us to include time-varying covariates (Jenkins, 2005). In order to capture order-of-entry effects, we include as explanatory variables a dummy for first movers (firms that enter the industry earlier than any other firm) and a dummy for followers (firms that enter as second, third or fourth in the industry). The baseline is given by all other firms that enter the industry: we will refer to them as late entrants. Given the characteristics of the simulation model, we can exclude most of the causes of duration dependence: we only include a dummy for the first period of life of each firm, as in that interval there is an higher hazard rate for all firms. We also include other controls in the regression: the capabilities of the firm, the level of concentration (as expressed by the Herfindahl index), density, and squared density. In each regression we include all firms that entered the industry in the 100 runs for a given combination. Finally, in order to capture the relationship between switching costs and order-of-entry we provide a graphical representations of the relationships between cumulativeness and first mover advantage that we obtain in each case.

[1] The analysis of the generic relationship would require that all other focal parameters randomly take any value in their range; since such a procedure is highly time-consuming, we present all preliminary results in this work by fixing focal parameters at their mean value. Some tests show that there is no relevant difference in the results, with the notable exception of vertical fragmentation.

Results

First of all, we study the existence and the relevance of a relationship between cumulativeness and order-of-entry advantages, i.e. whether there is any difference in survival rates due to order-of-entry and whether this difference changes as a function of cumulativeness. Figure 1 shows that the cumulativeness of technical change has a quite important impact on first mover advantage: the odds of survival increase from 3 to 8 times higher for first movers than for late entrants as cumulativeness increases from its minimum to its maximum. Followers also enjoy an advantage over late entrants, but their gap with first movers increases with cumulativeness.

More interesting results emerge if we consider the impact of the other environmental variables. In Figure 2 we consider the level of innovative opportunities: when this level is very high, the advantage of early movers over late entrants is much lower, because the former group cannot preempt the technology space; the impact of cumulativeness is also reduced, because there is an high probability that even a late entrant finds a better product to compete with technologically advanced incumbents. The results are quite the opposite when opportunities are very rare: here it is possible to draw a clear hierarchy of entry timing advantages. The most interesting result is observed when cumulativeness is very high and the survival odds of early movers quickly decrease. In a situation where opportunities are very rare, barriers to entry are very high: high cumulativeness, complemented with partial accumulation of knowledge outside the firm, allows late entrants to hit the market with better products and to have higher probability to build a stable bridgehead in the market to challenge the incumbents.

The analysis of the level of appropriability shows that not all the dimensions of technological regimes have an impact on the relationship between cumulativeness and first mover advantage (Figure 3). More surprisingly, the appropriability has also a limited effect on first mover advantage by itself: this finding can be explained by considering that the importance of the appropriability depends on the availability of alternative resources, and it is very high only when these resources are quite limited.

The last dimension of technological regimes is the locus of knowledge. Here the most interesting effect is displayed in the case of followers (Figure 4). If we compare the results with the baseline (red, crossed line), we observe that differences emerge only with levels of cumulativeness quite high. Moreover, even when the knowledge is accumulated mostly externally, the increase in cumulativeness generates an advantage for followers.

The cumulativeness interacts not only with the other dimensions of technological regimes but also with the dimensions of demand regimes. When horizontal fragmentation is very high, first mover advantages disappear (Figure 5): the existence of several market niches makes irrelevant entry timing in the general market, because what matters is entry in the niche; moreover, even very late entrants can still survive by finding a niche that is not crowded. When the market is completely homogenous, there is the opposite result: both first movers and followers enjoy an advantage over later entrants, but quite surprisingly followers perform better than first movers. This results is due to a "trial-by-fire" effect: in a homogenous market, followers must be really good in order to survive because as soon as they enter they suffer from strong competition; on the other hand, first movers can often survive for some periods only because of the lack of any competitor, but as a better firm appears they are swept away.

The effects of vertical fragmentation are slightly different, because of their interaction with switching costs. When the market is vertically homogenous, quality improvements do not matter at all; in this situation, even a small level of switching costs may determine a strong success of the first mover.

Finally, switching costs provide the best example of interaction with the cumulativeness of technical change. When switching costs are high, cumulativeness is a source of further advantage for early movers, but its impact is limited. On the other hand, the importance of cumulativeness becomes much stronger when there are no switching costs, and it also creates a big difference between first movers and followers. For the former category, cumulativeness is perfectly able to substitute switching costs.

Conclusions

The exercise conducted in this study aimed at clarifying the role played by the environmental context in determining first mover advantages. Integrating insights from previous empirical and theoretical literature with the formal and conceptual elements developed by evolutionary theories of industrial dynamics, we have provided some examples of the effects and the interactions that we should expect in different environments with respect to entry timing advantages.

Although we focused on a specific dimension of technological regimes, we showed that its impact on first mover advantages depend on the level of other environmental dimensions pertaining to both technological regimes and market regimes.

Some limitations may be highlighted in this study. First, we focus the analysis on extreme cases in order to get results that might be more easily interpreted; still, it is possible to exploit theoretical and empirical literature to identify viable combinations of technological and demand regimes, that may correspond to the conditions of specific sectors. Second, although firms heterogeneity is included in the model as a control variable, the potential interactions between micro-level and macro-level variables are not explicitly considered: it would be interesting to conduct an analysis on the specific capabilities that allow a firm to capture stronger entry-timing advantages in the different technological and demand environments.

Finally, the model is characterized by exogenous entry. While exogeneity is useful in that it helps to isolate causal mechanisms, it may prove tricky at providing clear implications. For example, with respect to one of the dimensions of technological regimes – the appropriability of innovations – recent evidence shows the importance of firms reaction to environment challenges in their choices about the type and the timing of entry (Ethiraj and Zhu, 2008), and patenting behavior (Ceccagnoli, 2009). Therefore, a necessary step for the future lays in providing endogenous mechanisms to model entry behavior in an evolutionary framework.

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TABLES

TABLE 1

FOCAL PARAMETERS

Parameter	Meaning	Range	Domain	FMA Theory
μH	Variey or horizontal fragementation	$0 \leq \mu H \leq 1$	Market Regimes	Macro-level
μV	Quality or vertical fragmentation	$0 \leq \mu V \leq 1$		Macro-level
ρ	Buyers' switching costs	$0 \leq \rho \leq 1$		FMA mechanism: switching costs
ξ	Level of technological opportunities	$0 \leq \alpha \leq 1$	Technological Regimes	FMA mechanism: preemption of scarce assets
χ	Degree of appropriability of innovations	$0 \leq \beta \leq 1$		
γ	Degree of cumulativeness of technical change	$0 \leq \gamma \leq 1$		FMA mechanism: technological leadership
δ	Relevance of internal knowledge base	$0 \leq \delta \leq 1$		

FIGURES

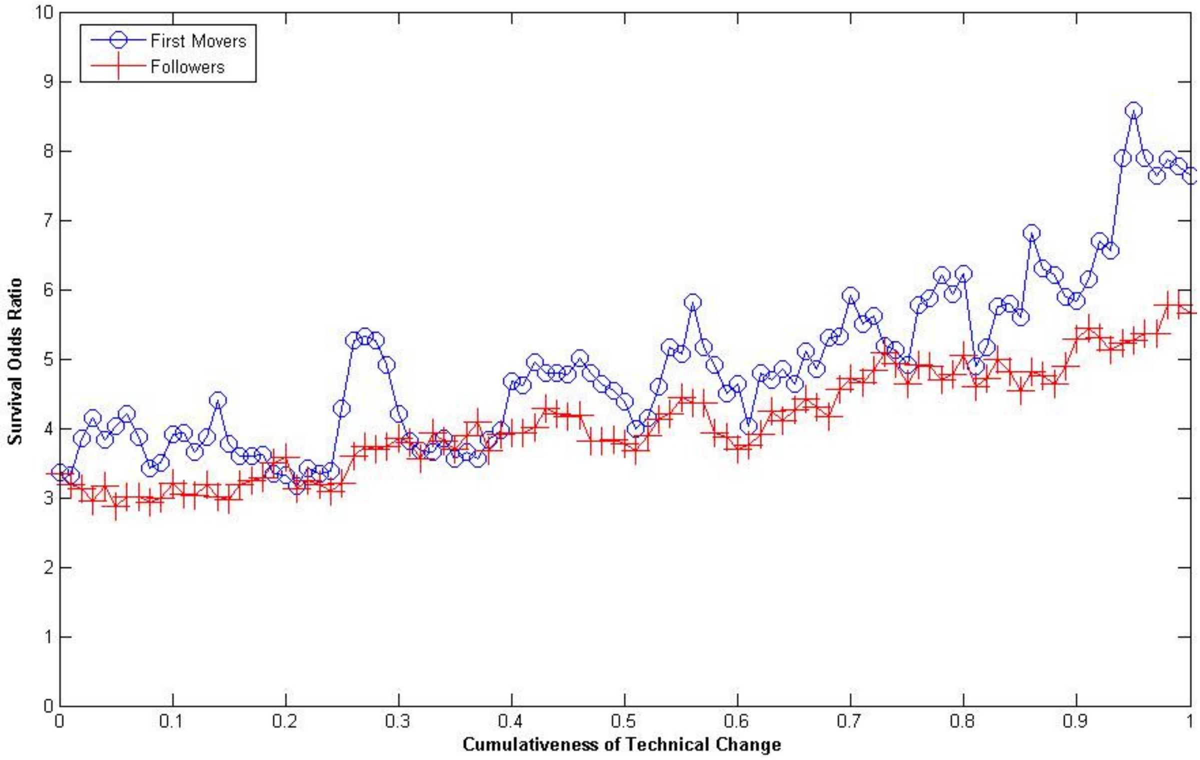

Figure 1
Survival-to-failure odds ratio for the first movers and the followers in a general case.

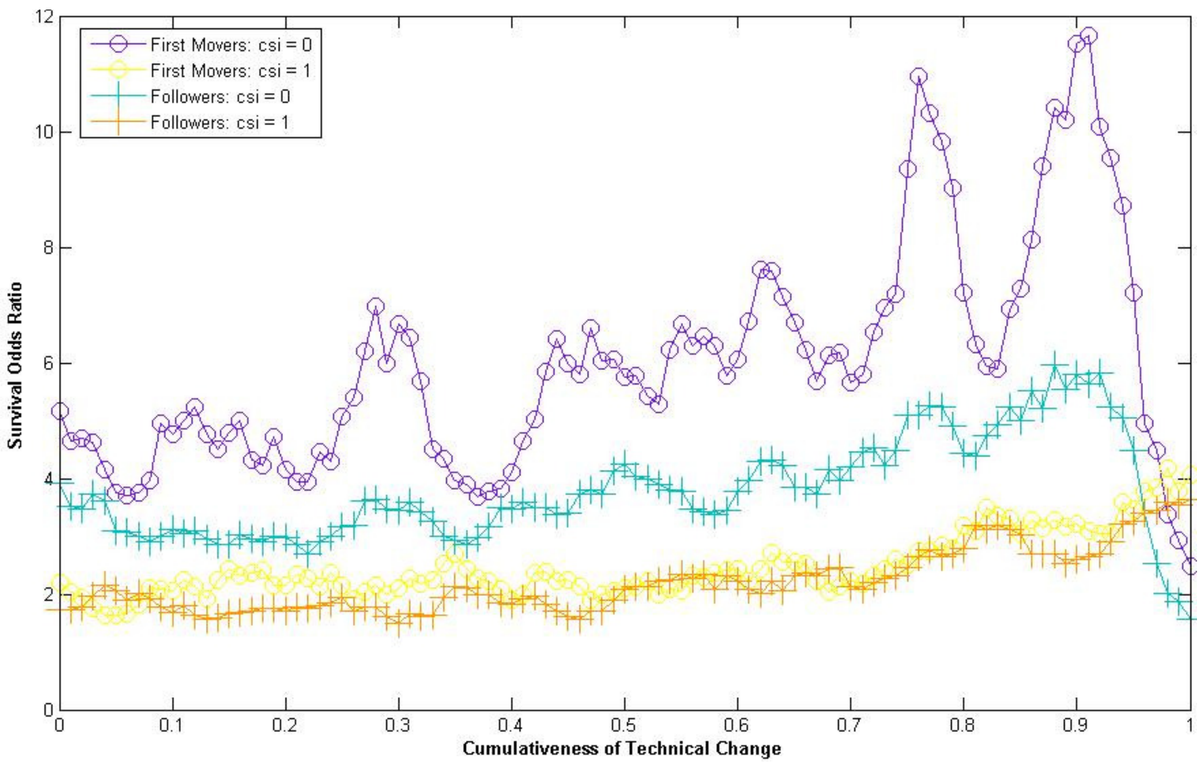

Figure 2
Survival-to-failure odds ratio for the first mover and the followers
with different levels of innovation opportunities (csi).

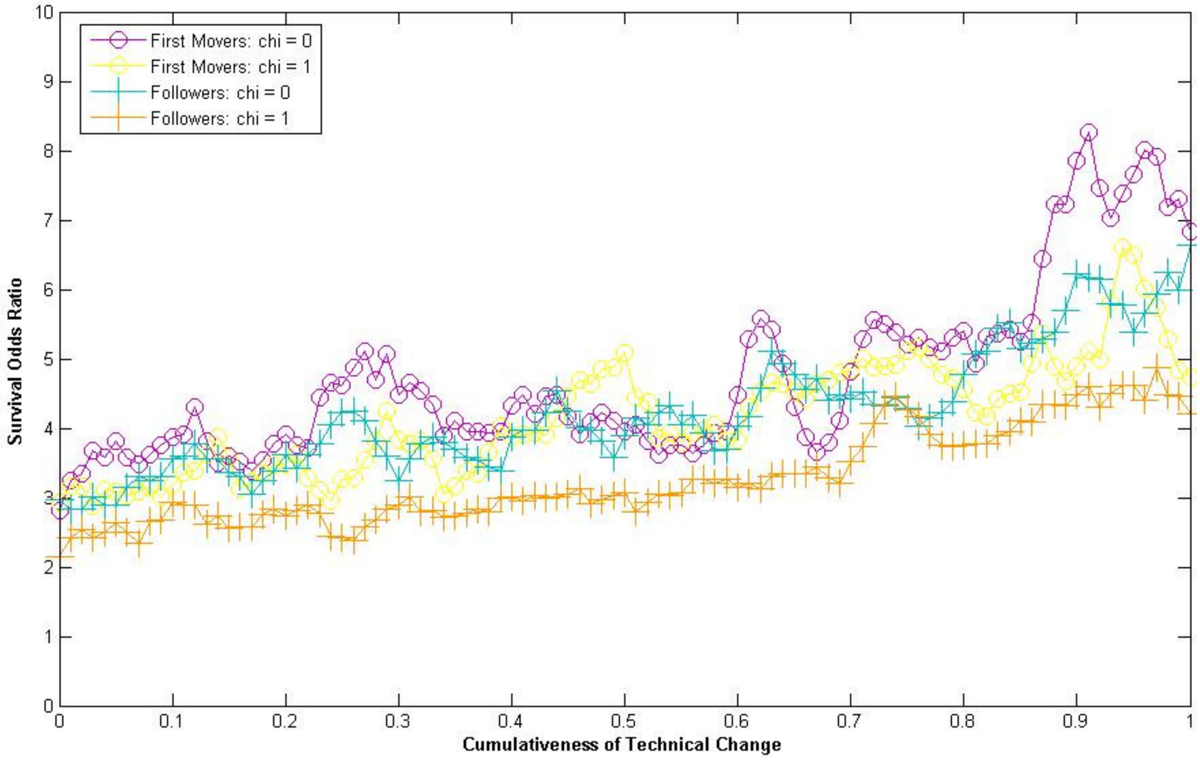

Figure 3
Survival-to-failure odds ratio for the first mover and the followers
with different levels of appropriability (chi).

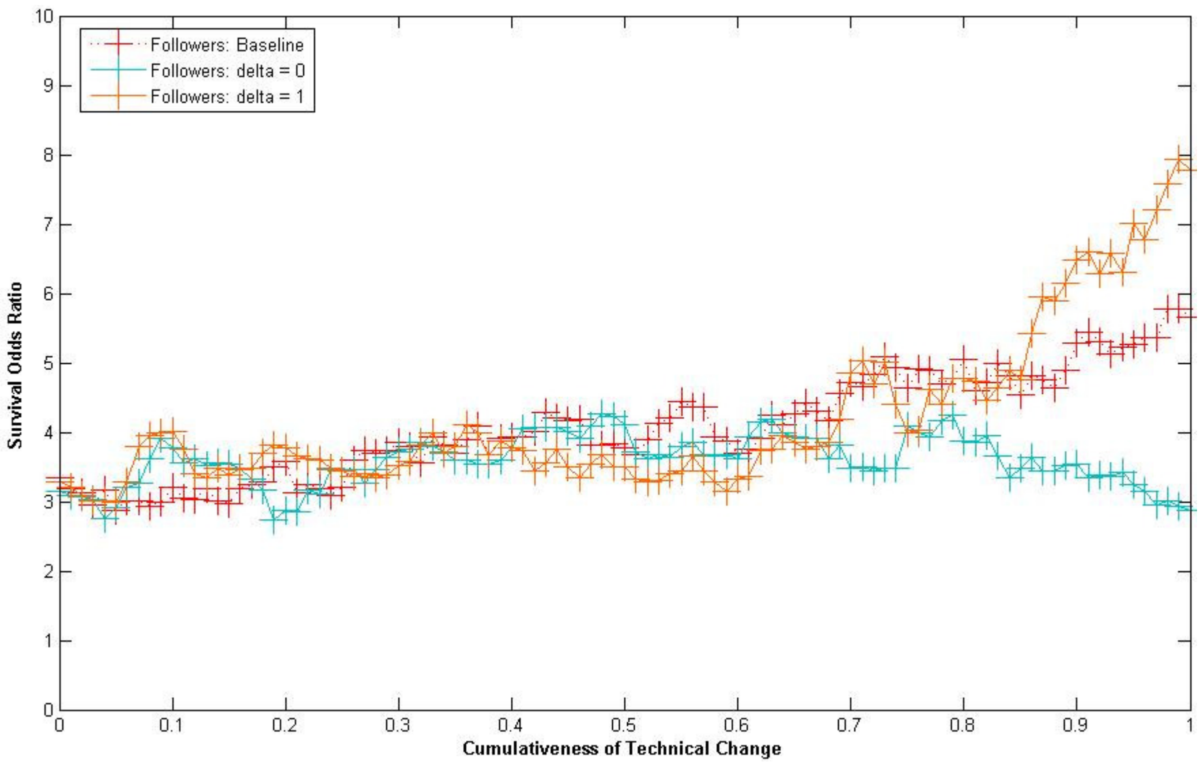

Figure 4
Survival-to-failure odds ratio for the followers
with internal (delta = 1) and external knowledge (delta = 0).

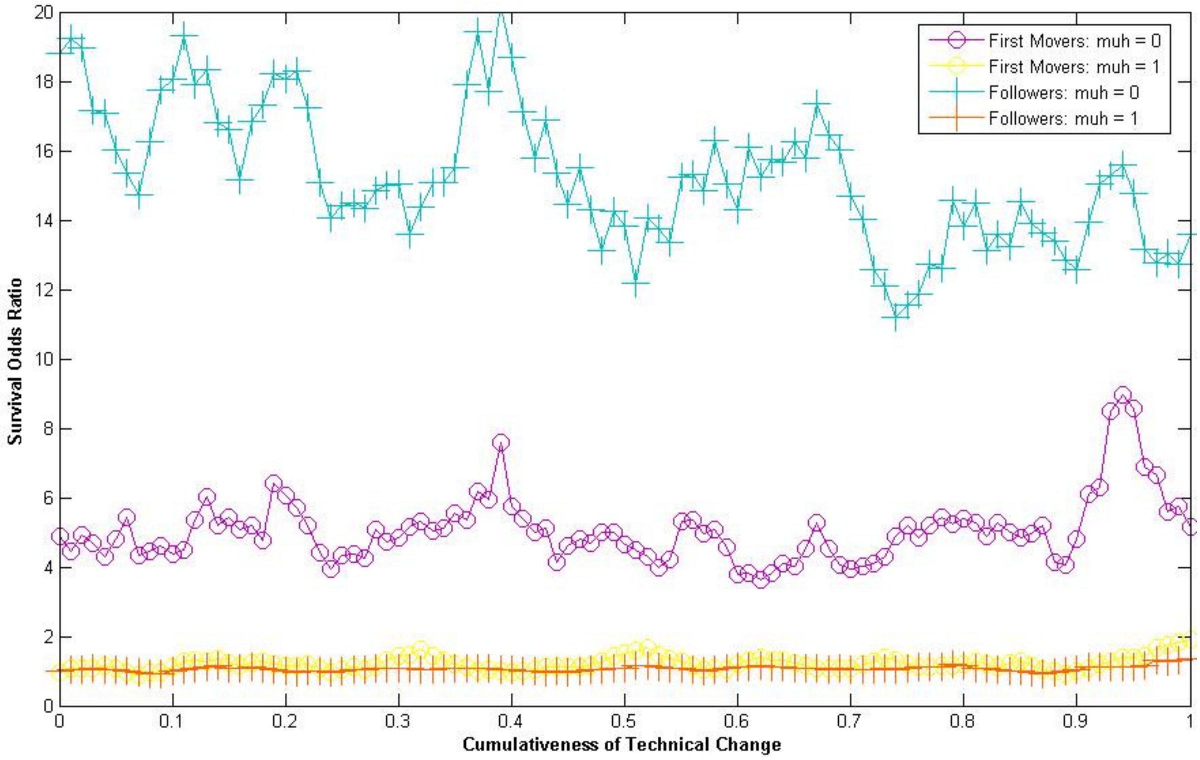

Figure 5
Survival-to-failure odds ratio for the first mover and the followers
with different levels of horizontal fragmentation (muh).

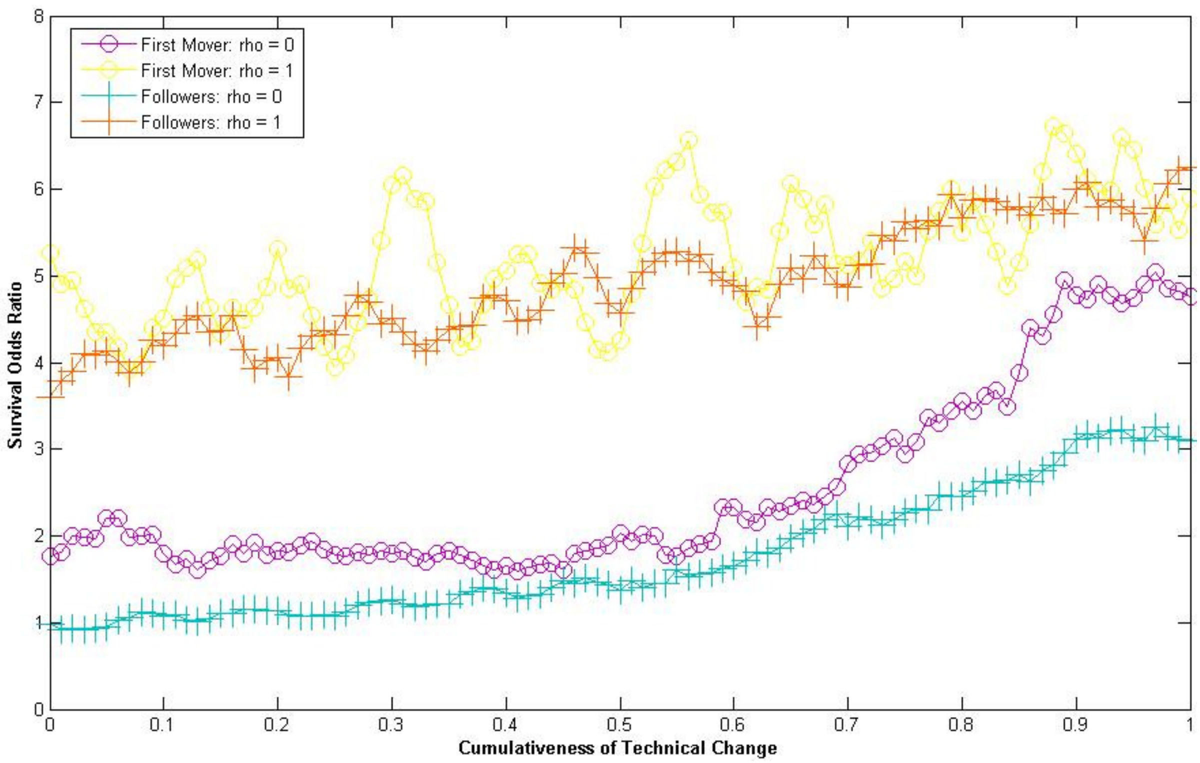

Figure 6
Survival-to-failure odds ratio for the first mover and the followers
with different levels of switching costs (rho).

APPENDIX

Market Activities

Consumers purchasing decisions depend on their preferences, the characteristics of products (including quality and price) and their past purchasing behavior (as summarized in the past market share of the product). Let the consumers in a submarket be uniformly distributed along the real unit segment: we define the propensity for the product j ($j \in \{1, \dots, J\}$) to be sold to a consumer i ($i \in [0,1]$) in the submarket s ($s \in \{1, \dots, S\}$) at time t ($t \in \{1, \dots, T\}$) as:

$$U(i)_{j,s,t} = \begin{cases} 0 & , \quad q_{j,s,t} < F(i) \\ \dfrac{q_{j,t} \cdot R_{s,s_j}}{p_{j,t}} & , \quad q_{j,s,t} \geq F(i) \ \wedge \ \nexists h\colon U(i)_{h,s,t-1} > 0 \\ (1-\rho) \cdot \left(\dfrac{q_{j,t} \cdot R_{s,s_j}}{p_{j,t}}\right) + \rho \cdot \left(m_{j,s,t-1}\right), & \quad q_{j,s,t} \geq F(i) \ \wedge \ \exists h\colon U(i)_{h,s,t-1} > 0 \end{cases} \quad (1)$$

where $q_{j,t}$ is the quality of product j at time t, R_{s,s_j} is the preference of consumers belonging to submarket s for the product j, $q_{j,s,t}$ is the quality of product j as perceived at time t by consumers in the submarket s ($q_{j,s,t} = q_{j,t} \cdot R_{s,s_j}$), $p_{j,t}$ is the price of product j at time t, $m_{j,s,t-1}$ is the market share of product j in the submarket s at time $t-1$, h refers to any product that was produced by firms at time $t-1$, ρ is the degree of switching costs and F(.) is a function that assigns a minimum quality threshold to each consumer. Condition (1) says that consumers never consider a product for purchase if it does not meet their minimum quality requirements; they consider objective (quality and price) and subjective (preferences for variety) elements in their decision, if they never bought anything in the past; they also consider past purchasing behavior, if they were already active in the past. In the following sections we provide details on all the elements included in the equation.

Consumers Preferences and Horizontal and Vertical Fragmentation

The preferences of consumers for variety are summarized in the matrix R of dimension $S \times S$. The value at the intersection of the row s_{row} and the column s_{col} expresses the extent to which a product that has s_{col} as its main submarket is a good match for consumers belonging to submarket s_{row}. The maximum value (1) represents perfect matching; the minimum value (0) means that consumers of s_{row} will never buy a product in s_{col}. By assumption, all the elements on the main diagonal of R are equal to one: a product is always a perfect matching for consumers of submarket s if s is its main submarket. The off-diagonal elements are independently extracted from a beta probability distribution: the mean of this distribution (μ_R) represents the extent to which consumers preferences are homogeneous; then the degree of horizontal fragmentation in the market space is $\mu_H = 1 - \mu_R$. The beta probability distribution has two shape parameters, usually denoted as α and β. An intermediate level of fragmentation is obtained by setting both the shape parameters to the value 1, which yields a uniform distribution between 0 and 1. In order to get higher values of fragmentation, we decrease the value of β keeping constant $\alpha = 1$; symmetrically, to get lower values of fragmentation we decrease the value of α keeping constant $\beta = 1$. Since the beta distribution is defined only with strictly positive shape parameters, we separately define the matrix R in the extreme cases of maximum and minimum fragmentation: in the former case, R is the identity matrix of dimension S; in the latter case, R is a matrix of ones of dimension S.

All consumers prefer a higher quality product, keeping constant the price and the preferences for variety. Still, consumers have different minimum quality requirements: if (perceived) quality is lower than their threshold, they do not take the product into consideration for purchasing whatever the price. By no loss of generality, we can assume that consumers are distributed along the unit segment so that their thresholds are in non-decreasing order; moreover, we also assume that quality is bounded between 0 and 1. Then, the function $F(\cdot)$ that assigns to each consumer i its minimum quality requirement $F(i)$ can be represented through a cumulative distribution function: we use the beta cumulative distribution function. The highest level of vertical fragmentation (1) is obtained when both the shape parameters are equal to 1 and $F(\cdot)$ is analogous to the standard uniform distribution. In order to get lower values of vertical fragmentation, we increase the value of β keeping constant $\alpha = 1$; the value of vertical fragmentation is the reciprocal of β. The lowest level of vertical fragmentation (0) implies that all consumers will consider a product with a strictly positive quality.

Market shares

The computation of market shares is non-trivial because horizontal and vertical fragmentation affect the boundaries of the space that should be considered as the "relevant market". Consider a generic submarket s and assume there are J_s products with a strictly positive perceived quality in this submarket, arranged in ascending order by quality, so that $q_{1,s} \leq q_{j,s} \leq q_{J_s,s}$. Moreover, let $F^{-1}(\cdot)$ be the inverse of $F(\cdot)$. Since a product j with quality $q_{j,s}$ has a strictly positive propensity to be sold only to the fraction of consumers whose quality threshold is no higher than $q_{j,s}$, that is $F^{-1}(q_{j,s})$, we can also define J_s groups of consumers such that $\mathfrak{G}_1 = F^{-1}(q_{1,s})$ and $\mathfrak{G}_g = F^{-1}(q_{j=g,s}) - F^{-1}(q_{j=g-1,s})$. The market share of product j in group g is:

$$m_{j,g} = \begin{cases} \dfrac{U_{j,g}}{\sum_{j=g}^{G} U_{j,g}}, & if\ j \geq g \\ 0 \quad , & if\ j < g \end{cases} \qquad (2)$$

The market share of product j in the whole submarket is simply the sum of its shares in the groups weighted by group size (possibly rescaled if some consumers are not satisfied by any competing product), that is:

$$m_{j,s} = \sum_{g=1}^{J_s} m_{j,g} \cdot \frac{\mathfrak{G}_g}{F^{-1}(q_{J_s,s})} \qquad (3)$$

Finally, if there is at least one product with a market share lower than the exit threshold (E), we exclude from the market the product with the lowest market share and repeat the procedure with $J_s - 1$ groups; the process is iterated until all the remaining products have a market share higher than the threshold.

Price

Firms set the price of each product according to a mark-up rule, as follows:

$$p_{j,t} = C \cdot \left(1 + w_{j,t}\right) \qquad (4)$$

where C is the marginal cost, that we assume equal across all products and constant over time. At time t, a firm chooses the mark-up $w_{j,t}$ for product j in order to maximize profits, given the price elasticity of demand η and the global competitive pressure at time t-1 as expressed by market share:

$$w_{j,t} = \frac{m^*_{j,t-1}}{\eta - m^*_{j,t-1}} \qquad (5)$$

It is important to highlight that $m^*_{j,t}$ is product-specific variable, while $m_{j,s,t}$ differs across submarkets. Moreover, $m^*_{j,t}$ takes into account only consumers whose quality threshold is lower than the quality of the product, as consumers with an higher threshold would not be affected by changes in price; and it ignores other products of the same firm. In order to compute it, we start by defining the number of consumers in the group g of a submarket s that buy product j as:

$$\mathfrak{C}_{j,g,s} = m_{j,g} \cdot \mathfrak{G}_g \cdot \mathfrak{C}_s \qquad (6)$$

where $\mathfrak{C}_s$ is the number of consumers in submarket s. Then, the number of consumers in submarket s that buy product j is simply:

$$\mathfrak{C}_{j,s} = \sum_{g=1}^{J_s} \mathfrak{C}_{j,g,s} \qquad (7)$$

The number of potential consumers of product j in submarket s ($\widehat{\mathfrak{C}}_{j,s}$) is given by all customers whose quality threshold is lower than the perceived quality of the product; to this number, we have to subtract the consumers in the submarket that chose another product of the same firm, even if they were satisfied also by the focal one:

$$\widehat{\mathfrak{C}}_{j,s} = F^{-1}\left(q_{j,s}\right) \cdot \mathfrak{C}_s - \sum_{j=1}^{J_f} \mathfrak{C}_{j,s} \qquad (8)$$

where J_f is the number of products of firm f.

Then, the number of consumers that buy product j and the number of potential consumers to use as a benchmark are:

$$\mathfrak{C}_j = \sum_{s=1}^{S} \mathfrak{C}_{j,s} \qquad (9)$$

and

$$\widehat{\mathfrak{C}}_j = \sum_{s=1}^{S} \widehat{\mathfrak{C}}_{j,s} \qquad (10)$$

respectively.

Finally, the market share a firm uses to set the markup in the next period is given by:

$$m_j^* = \frac{\mathfrak{C}_j}{\widehat{\mathfrak{C}}_j} \qquad (11)$$

All earned profits are used to finance innovation expenditures in the following period.

Innovation Activities

All firms finance their innovation activities by investing all the profits earned in the previous period. The profits of firm *f* at time *t* are the sum of the profits obtained from all its products:

$$\Pi_{f,t} = \sum_{j=1}^{J_f} \Pi_{\mathrm{j,t}} = \sum_{j=1}^{J_f} \left(p_{j,t} - C\right) \cdot \mathfrak{C}_j \qquad (12)$$

Innovation activities require several procedures. First of all, available financial resources must be allocated between different teams. Let $q'_{j,t}$ be the increase in the quality of product *j* that has occurred from the previous period, that is:

$$q'_{j,t} = q_{j,t} - q_{j,t-1} \qquad (13)$$

then the budget of team *j* for its innovative activities in period *t* ($b_{j,t}$) is determined according to the following rule:

$$b_{j,t} = \left[\lambda_{f,t} \cdot \frac{q'_{j,t-1}}{\sum_{j=1}^{J_f} q'_{j,t-1}} + \left(1 - \lambda_{f,t}\right) \cdot \frac{\Pi_{j,t-1}}{\sum_{j=1}^{J_f} \Pi_{\mathrm{j,t-1}}}\right] \cdot \Pi_{f,t-1} \qquad (14)$$

which means that the share of resources that can be used by group *j* depends on both the percentage of profits actually earned by the product and the team innovative performance in the last period *vis-à-vis* the other teams of the firm. Moreover, the weight that is assigned to earned profits and innovation performance varies over time, according to the overall innovative performance obtained by the firm:

$$\lambda_{f,t} = \frac{1}{2}\left(1 - \frac{1}{1 + \sum_{j=1}^{J_f} q'_{j,t-1}}\right) \qquad (15)$$

A team *j* is completely autonomous in its decision about the use of the financial resources it obtains: it can use them either to improve the quality of its product or to search for new products. A team *j* will use its resources at time *t* to improve its product with probability $z_{j,t}$:

$$z_{j,t} = \frac{1}{2}\left(z_{j,t-1}\right) + \frac{1}{2}\left(\hat{z}_{j,t}\right) \qquad (16)$$

The new element $\hat{z}_{j,t}$ depends on the type of activity the team chose in the previous period and on whether it was successful or not: if the team chose to improve its product in the previous period, then:

$$\hat{z}_{j,t} = \begin{cases} 1, & q'_{j,t-1} > 0 \; or \; t_j = 1 \\ 0, & otherwise \end{cases} \qquad (17)$$

If the team chose to look for new products, then:

$$\hat{z}_{j,t} = \begin{cases} 0, & found\ new\ product \\ 1, & otherwise \end{cases} \qquad (18)$$

<u>Search for new products</u>

If the team chooses to search for new products, the probability of success will be a non-linear function of the level of innovative opportunities (ξ) and the appropriability of innovations (χ). The team will try to extract a promising potential product from the technology space until it is successful or it exhausts its financial resources for the current period. The number of tries that are available for a team j with financial resources $b_{j,t}$ is equal to $floor\left(\frac{b_{j,t}}{C_1}\right)$, where C_1 is the unit cost of search for new products.

We assume that the financial resources of a new firm that wants to enter the industry guarantee that is has at least (and no more than) one try.

Improvement of existing products

If the firm chooses to improve its existing product, it tries to explore its technological trajectory, which expresses the relationship between knowledge and quality. A simple formalization of this relationship is provided by the generalized logistic function:

$$q_j(k_j) = \frac{1}{\left[1 + X_j e^{-Y_j \cdot k_j}\right]^{\frac{1}{Z_j}}} \qquad (19)$$

The numerator sets to 1 the maximum quality that can be reached by any product. Three parameters, which differ across potential products, determine the exact shape of the technological trajectory. The parameter X_j determines the level of quality when there is no knowledge, that is $q_j(0)$: the only constraint we impose to its value guarantees that quality has a strictly positive value even for $k = 0$. The parameter Z_j determines the symmetry of the function and in particular the distance of the maximum growth rate from the asymptotes. If Z_j is higher than 1, the maximum growth rate occurs towards the upper asymptote, vice versa if it is lower than 1. Z_j takes any value in the range of real numbers (to the extent this is possible in a simulation model) with the same probability. The parameter Y_j represents the average growth rate of quality with respect to knowledge. Its value is partially constrained by the previous parameters; we also restrict the range of possible values so that the growth of quality is neither too fast nor too slow.

A team undertaking innovative activities aimed at improving an existing product explores its knowledge dimension. The probability of generating a new piece of knowledge ($n_{j,t}$) depends on the amount of resources that is invested in this activity; if a new piece of knowledge is generated, then its importance is a positive function of the technological capabilities of the firm (θ_f); this is formally expressed by the following condition:

$$n_{j,t} = \begin{cases} 0, & if\ U(0,1) < \dfrac{1}{1+\sqrt{b_{j,t}/C_2}} \\ \mathrm{Exp}\left(\dfrac{1}{\theta_f}\right), & \text{otherwise} \end{cases}; \qquad (20)$$

where C_2 is the unit cost of improvements of existing products.

The extent to which the new piece of knowledge can be added to the existing knowledge depends on the degree of cumulativeness (γ); moreover, the parameter δ determines the mix of internal and external knowledge in the composition of the relevant existing knowledge. The new knowledge ($k_{n,t}$) is given by the combination of the new piece of knowledge and the relevant existing knowledge, and can be expressed formally as:

$$k_{n,t} = \gamma \cdot \left[\delta \cdot k_{j,t-1} + (1-\delta) \cdot k_{e,t-1}\right] + n_{j,t} \qquad (23)$$

The external knowledge ($k_{e,t}$) is a function of the increase in knowledge generated by all the teams working on the improvements of existing products in the current period:

$$k_{e,t} = k_{e,t-1} + \frac{\sum_{f=1}^{\mathfrak{F}} \sum_{j=1}^{J_f} q'_{j,t}}{\sum_{f=1}^{\mathfrak{F}} \sum_{j=1}^{J_f} j} \qquad (24)$$

where $\mathfrak{F}$ is the number of firms currently operating in the industry.

Finally, the firm uses the new knowledge only if it allows to increase the quality of the product, that is if the new knowledge is higher than the previous internal knowledge:

$$k_{j,t} = \max\left(k_{j,t-1}, k_{n,t}\right) \qquad (25)$$

Table A1
Index of Symbols

Symbol	Meaning	Type	Level (Indicator)	Value / Range
b	Financial resources for innovation	Variable	Team (j)	$\mathbb{R}_+$
C	Marginal cost of production	Parameter	General	1
C_1	Unit cost of search for new products	Parameter	General	50
C_2	Unit cost of improvement of existing products	Parameter	General	10
E	Market share threshold for exit	Parameter	General	0.05
$F(\cdot)$	Minimum quality requirements	Function	Consumers (i)	[0,1]
g	Indicator	Indicator	Group of consumers	$\{1,\ldots,J_s\}$
h	Indicator	Indicator	Products, Teams	$\mathbb{N}_{++}$
i	Indicator	Indicator	Consumers	[0,1]
J	Number of potential products	Parameter	General	1000
J_f	Number of products of a firm	Variable	Firm	$\mathbb{N}_+$
J_s	Number of products in a submarket	Variable	Submarket	$\mathbb{N}_+$
j	Indicator	Indicator	Products, Teams	$\mathbb{N}_{++}$
k	Knowledge	Variable	Product (j), Industry (e)	$\mathbb{R}_+$
m	Market share	Variable	Product / Submarket (j/s), Firm /Submarket (f/s)	[0,1]
m^*	Market share for markup	Variable	Product (j)	[0,1]
n	New piece of knowledge	Variable	Product (j)	$\mathbb{R}_+$
p	Price of a product	Variable	Product (j)	$\mathbb{R}_{++}$
q	Quality of a product	Variable	Product (j)	[0,1]
q'	Increase in quality	Variable	Product (j)	[0,1]
R	Relatedness matrix	Parameter	Submarkets	[0,1]
S	Number of submarkets	Parameter	General	50
s	Indicator	Indicator	Submarkets	{1,…,S}
s_j	Main submarket of a product	Parameter	Product	{1,…,S}
T	Time-horizon of the industry	Parameter	General	100
t	Indicator	Indicator	Time	{1,…,T}
$U(\cdot)$	Propensity to purchase	Function	Consumers (i)	[0,1]
w	Markup	Variable	Product (j)	$\mathbb{R}_+$
X	Intercept of technological trajectory	Parameter	Product (j)	$\mathbb{R}$
Y	Growth of technological trajectory	Parameter	Product (j)	$\mathbb{R}_{++}$
Z	Symmetry of technological trajectory	Parameter	Product (j)	$\mathbb{R}$
z	Probability of improving existing product	Variable	Team (j)	[0,1]
$\hat{z}$	Updating element of z	Variable	Team (j)	{0,1}
$\mathfrak{C}$	Consumers	Variable	Product / Submarket (j/s), Product (j)	$\mathbb{R}_+$
$\hat{\mathfrak{C}}$	Potential consumers	Variable	Product / Submarket (j/s), Product (j)	$\mathbb{R}_+$
$\mathfrak{F}$	Number of firms in the industry	Variable	Industry	$\mathbb{N}_+$
$\mathfrak{G}$	Group of consumers	Variable	Submarket (g)	$\mathbb{N}_+$
α	Shape parameter of beta distribution	-	-	$\mathbb{R}_+$
β	Shape parameter of beta distribution	-	-	$\mathbb{R}_+$
γ	Cumulativeness of knowledge	Parameter	Focal	[0,1]
δ	Weight of internal knowledge	Parameter	Focal	[0,1]
η	Price elasticity of demand	Parameter	General	1.5
θ	Firms improvement capabilities	Parameter	Firm (f)	$\mathbb{R}_+$
λ	Weight of innovation in resources allocation	Variable	Firm (f)	[0,1]
μ_H	Horizontal fragmentation	Parameter	Focal	[0,1]
μ_V	Vertical fragmentation	Parameter	Focal	[0,1]
ξ	Level of opportunities	Parameter	Focal	(0,1]
Π	Profits	Variable	Product (j), Firm (f)	$\mathbb{R}_+$
ρ	Switching costs	Parameter	Focal	[0,1]
χ	Appropriability of innovations	Parameter	Focal	[0,1]