Industrial Policies in complex, dynamic and interdependent contexts

Gianluca Capone and Luigi Orsenigo

Scuola Universitaria Superiore IUSS Pavia

November 2016

Paper prepared for the Workshop Industrial Policy for New Growth Areas and Entrepreneurial Ecosystems, Helsinki 28.-29. November 2016

First rough draft: please do not quote without authors' consent

Abstract

There is growing - although certainly not unanimous - agreement among economists that after around three decades industrial policies are no longer considered as a bad word, in theory and in some instances also in practice. This renaissance rests on and comes together with a deeper recognition of the dynamic and complex nature of the economic processes of industrial competition and growth, which are inherently characterised by strong uncertainty, heterogeneity of much less than fully rational interdependent agents, inertial behaviour coexisting with innovation and pervasive relevance of non-linear relationships and various forms of increasing returns. In such contexts, policy interventions are likely to have extremely heterogeneous and sometimes unpredictable and unintended effects. In this paper, we start to investigate these issues by examining via simulation exercises the efficacy of alternative simple (and often uncontroversial) policies in two different stylised contexts. The first one considers an environment characterised by extreme uncertainty, where new products and market niches have to be discovered and then developed by rather "ignorant" firms. Here, therefore, exploration is the name of the game. The second context refers instead to two vertically related industries, each characterised by strong increasing returns and cumulative technological progress. Results show that in these contexts many initiatives are likely to fail or to bear only very marginal impacts. But a few of them can obtain spectacular successes. Under some conditions, "small" actions may trigger self-sustaining growth; under different sets of conditions, massive interventions may be needed and critical thresholds must be reached. The timing of policy actions is also crucial in determining the outcomes over time.

1. Introduction

There is growing - although certainly not unanimous - agreement among economists that after around three decades industrial policies are no longer considered as a bad word, in theory and in some instances also in practice[1]. There are many convincing reasons for this comeback. Still, precisely because there is indeed a large variety of (not mutually exclusive but certainly diverse) arguments in favour of industrial policies, one observes a proliferation of different interpretations and suggestions about what these policies should try to achieve, how they should be designed and implemented, what kind of instruments and forms of governance are required, and so forth. In many cases, the need of “new” industrial policies is argued, emphasising that such interventions should not focus on specific industries, let alone firms, but more generally they should target broadly learning and discovery processes. In other interpretations, instead, a direct and decisive role of the government is called for, highlighting the role played in the past by “big” public programs supporting basic research all the way down to (at least partially) successful cases of explicit support to “strategic” industries and national champions.

In this paper, we shall not review this debate nor propose any specific interpretation or suggestion here. (See, among others, Hausmann and Rodrik, 2003; Rodrik, 2008; Cimoli et al. 2009; (Aghion et al., 2011; Dosi and Galambos, 2013; Mazzucato, 2013; Stiglitz and Lin, 201); Greenwald and Stiglitz, 2013; Pianta, 2014; Mazzucato et al., 2015). After all, the potential scope for industrial policies is so large and variegated in different places and periods of time that it is tempting to simply assert that almost everything may go according to the specific circumstances one faces. Yet, it is important at this stage to realise first that the renaissance of industrial policies rests on and comes together with a deeper recognition of the dynamic and complex nature of the economic processes of industrial competition and growth, which are inherently characterised by strong uncertainty, heterogeneity of much less than fully rational interdependent agents, inertial behaviour coexisting with innovation and pervasive relevance of non-linear relationships and various forms of increasing returns.

[1] In practice, and with different names, industrial policies have hardly disappeared from the scene, especially in East Asian and various Latin America countries but also in North America and Europe.

Indeed, analyses of the patterns of industrial change based on the availability of micro data at the firm level have indeed suggested remarkable and perhaps surprising regularities (see for example (Dosi *et al*., 2015)). Among them, for example:

- persistent heterogeneity in productivity and all other performance variables of firms at any level of disaggregation;
- persistent market turbulence, due to change in market shares and entry-exit phenomena;
- skewed firm size distributions;
- fat-tailed distribution of firm's growth rates, suggesting lumpy, infrequent episodes of very strong expansion;
- weak relationships between efficiency measures like productivity and profitability on the one hand and firm's growth at the other;
- persistent survival of dramatically inefficient firms.

At a first approximation, this evidence points at the widespread presence of highly asymmetric distributions of the variables of interest. More generally, these phenomena indicate that there is a rich structure in the evolution of industries, which bears the familiar signs of complex system dynamics and suggests the pervasive presence of increasing returns and "self-organization" in the growth process of firms, industries, networks and clusters.

Further theoretical and empirical analyses have begun to provide corroboration that these facts are generated by complex and diverse interactions between processes of innovation and learning on the one hand and of (market, political, institutional, etc..) selection on the other. The specific properties of these processes of learning and selection vary substantially across industries or other relevant definitions of the competitive arena. Concepts like technological and demand regimes, for example, have proved to be useful in distinguishing between alternative patterns of evolution (Malerba and Orsenigo, 1997; Capone et al., 2013). Similarly, the evidence gathered on the regularities (and deviations from them) in the life cycle patterns of industrial change and on the mechanisms generating them has shed light on important conceptual and policy relevant issues (Klepper, 2016): if anything, in showing that the factors which ignite the growth of firms, industries and clusters are often quite different from the factors that sustain their growth afterwards (Bresnahan et al., 2001; Orsenigo, 2006).

Against this background, we take in this paper a humbler approach, i.e. we start to investigate how even very simple and perhaps quite traditional forms of public intervention in support of firms and industrial growth more generally can work in complex dynamic environments, what kind of challenges they face and what intended and above all unintended consequences they can produce.

The evidence of such complex dynamics poses in facts significant questions in terms of policy-making. To begin with, it is clear that any consideration of the desirability, feasibility, organization and implementation of policies must take into consideration an explicit and complex dynamic perspective.

In interdependent and correlated (and often non Gaussian) economic environments, policy interventions are likely to be intrinsically different from more conventional approaches and to have extremely heterogeneous and sometimes unpredictable and unintended effects. In this kind of worlds, many initiatives are likely to fail or to bear only very marginal impacts. But a few of them can obtain spectacular successes. Under some conditions, “small” actions may trigger self-sustaining growth; under different sets of conditions, massive interventions may be needed and critical thresholds must be reached. The timing of policy actions may become crucial in determining the outcomes over time.

The study of policy-making in complex environments is still in its infancy. In previous works, Malerba *et al*. (2001 and 2008), have begun to analyse the effects of alternative policy interventions (antitrust, promotion of the entry of new firms, public procurement, open standards, information diffusion and support to basic research) using history-friendly models of the evolution of the computer and semiconductor industry (Malerba et al. 2016). Those exercises showed in particular that different policies have quite different effects (or no effect at all) on some key policy targets as a function of the timing of policy interventions and of the specific nature of the dynamic processes driving industry evolution, particularly as it concerns the existence and strength of increasing returns on the supply and demand side; and of the nature of the dynamic feedbacks governing the coupled dynamics of vertically and horizontally related industries.

In this paper we expand this style of analysis. We do not discuss the desirability of industrial policies. Rather, we examine via simulation exercises the efficacy of alternative simple (and often uncontroversial) policies in two different stylised contexts, derived and adapted from earlier history-friendly models of – respectively – the pharmaceutical industry on the one hand and computers and semiconductors on the other (Malerba *et al*., 2016). The first one (Section 2) considers an environment characterised by extreme uncertainty, where new products and market niches have to be discovered and then developed by rather “ignorant” firms. Here, therefore, exploration is the name of the game. The second context (Section 3) refers instead to two vertically related industries, each characterised by strong increasing returns and cumulative technological progress. Section 4 concludes the paper by summarizing and discussing the main results.

3. Exploration of unknown opportunities

2.1 A sketch of the model

The first set of exercises focuses on an extreme scenario where firms “simply” explore an unknown space of opportunities. One can think of a stylized “industry” composed of a number of potential products, market niches or submarkets characterized by different economic potential that must be discovered and opened by firms. Firms do not know the characteristics of this environment - e.g. the distribution of the values of products or submarkets – and therefore exploration is essentially random. Moreover, to make the case even more extreme, this scenario assumes that very little of learning is possible: success with one product in a particular submarket does not provide further benefits in the search and development of new products, except by the larger resources – profits - that can be further invested. Thus, there is very little cumulativeness in innovative and product development activities.

Extreme and oversimplified as it might look, this simple setting might actually capture some very real situations. Indeed, the model used to carry on the following exercises is based on the history-friendly representation of the pharmaceutical industry developed by Malerba and Orsenigo (2002), Garavaglia et al. (2012), and Malerba et al. (2016). The model depicts in fact an industry characterized by market fragmentation, an innovative process in presence of low cumulativeness, and a competitive context where imitation plays an important role: therefore, it is suited for the analysis not only of pharmaceuticals, but also of other industries such as lasers or (partly) semiconductors. Even more generally, this scenario might apply to many cases where firms operate under deep uncertainty and even ignorance of the properties of the environment, be it an industry, a region, a country; very much in the spirit of Rodrik (2004).

We do not present here the full model, but only recall qualitatively its main features. A number of firms compete to discover, develop and market new products to satisfy a large variety of consumers’ needs. They face a space of opportunities that, at the beginning, is largely unexplored. R&D activity is split in two stages: research, i.e. the attempt to discover promising product designs; and development, when these potential products are transformed into actual market products. In the first stage, firms randomly explore the space of products: only a very limited number of product designs has the potential to become an actual product, while the others have “zero quality”. There is little scientific knowledge guiding search, and success is a random event. When a firm finds a design that might become a marketable product, the firm patents it. The patent provides protection from imitation for a certain amount of time and over a range of similar designs.

Once a promising design has been found, a firm engages in its development, which requires time and resources. The firm does not know how difficult, time consuming and costly the process will be, or what the actual quality of the new product will be. Development projects sometimes fail, because the quality of the product does not meet minimum requirements for sale in the marketplace. While the product is under development, a firm puts aside marketing resources: after development is completed, the firm uses these resources to launch the product in the marketplace. Sales are influenced by the quality of the product, but also by the marketing efforts and by the price that is charged. Pricing is based on a mark-up rule that takes into account the competitive pressure in the submarket.

Firms are represented as strategically heterogeneous, displaying differing propensities towards innovation on the one hand and imitation and marketing on the other. The first successful product offered to satisfy a particular need faces no competition, and the firm may experience a burst of growth. But after some time, other firms may discover and develop competitive products. Moreover, after patent expiration, imitation may occur. As a consequence of the competition from competing or imitative products, the market share and revenue of the original innovator will be eroded away by competitors and imitators.

A key concept in the model is that of a submarket. The term is meant to represent a group of customers that are related in the sense that they share similar or related needs, that can be satisfied by similar or related products. In the model, submarkets are anonymous as well as abstract: they do not have names that correspond to real world analogues.

The discovery of a product in a particular submarket does not increase the probability that a firm can discover another product in the same submarket or in a different one, given the firm's innovative effort. However, as it discovers and develops new products, a firm will progressively diversify into new submarkets. Thus, diversification into new submarkets is treated as a random process: firms are always searching everywhere in the space of products. A firm's growth will then depend on the number of products discovered and commercialized, the size and the growth of the submarkets they are present in, the number of competitors and the relative quality and price of the products.

If it has the resources, a firm can choose to invest simultaneously in several parallel projects for developing different product designs it has discovered. If some project needs to be postponed because of lack of resources, the choice of which project to develop depends on the economic value of the submarket and the residual length of patent protection.

Initially, firms are endowed with external seed resources to conduct their early research and development activities. Once the discovered products are commercialized, profits coming from the sales of products are reinvested in R&D and marketing. As time passes in the simulated history, there is a broad tendency to diminishing returns to R&D that is attributable to the fact that the space of untapped opportunities is getting depleted by the ongoing discovery process – but the complex details of this evolution are determined endogenously.

2.2 Policy exercises

2.2.1 Performance measures

In the context of this model, a good metric of social welfare is represented by the number of new submarkets discovered through the innovation process. In fact, until at a least a product within a submarket is not discovered, all consumers within the submarket cannot satisfy their needs. A second metric is represented by firms' profits (the producer surplus): high profits are also positive from a welfare point of view because in the model we assume that a fraction of it is invested in R&D activities. However, high profits are also an indicator of concentration, which can be harmful for social welfare. Therefore, for each exercise we conduct, we also consider the dynamics of concentration as measured by the Herfindahl index.

2.2.2 Benchmark: difficult innovation

The relevance of industrial (innovation) policy actions depends much on how difficult is for economic agents to operate within the context set by the market forces and the technological environment. If the environment is munificent in terms of innovation opportunities, policy might well become irrelevant. Therefore, as a benchmark for our analysis we use a context in which innovation is quite difficult because of both costs and uncertainty.

Figure 1 shows the results of the benchmark case: in Panel A, after an initial period of search, submarkets start to be discovered by firms. Their number increases quite quickly at the beginning, but then the growth rate slows down. The rapid growth at the beginning is due to the entry of many new innovative firms in a relatively short period. Later, the discovery process becomes slower also because innovative firms face the competition by imitators, that reduces their profits. This can also be appreciated by looking at Panel B: the average firm profit increases steadily at the beginning, and then declines once the entry of imitators reduces margins. Towards the end, profits start increasing again, as an effect of a selection process across firms. Finally, the Herfindahl Index (depicted in Panel C) starts growing steadily quite soon and reaches a relatively high level.

2.2.3 Watering-Can Policy

In this context, the simplest incentive policy that can be designed is just to give money[2] to all firms, according to the watering-can principle. All firms receive an incentive in the form of an amount of money, that must be spent in innovation activities. In the early phase, this money is calibrated to double the level of private investment of the firms. Later, once firms start gaining profits, the incentive is financed by a 20% tax on profits, but this amount is again doubled by the government. This way, in the second phase there is also a shift of resources from imitative to innovative firms.

Results are showed in Figure 2 and are quite striking. The number of discovered submarkets (Panel A) shows a steeper growth in the early phase, and by the end of the simulation it reaches a value 60% higher than in the benchmark case. This is also possible because in the early phase, firms get much higher profits, that allow them to finance further innovation activities and to discover more

[2] The term "money" is used here in a very generic fashion. One could think of other kinds of resources (skills, technical information and knowledge, infrastructures, etc.) which might increase firms' innovative capabilities.

submarkets (Panel B). However, the increase in profits is only temporary: by the end of the simulation, the level of profits is lower than in the benchmark case. This is due to the fact that over all the simulation, the concentration is always much lower than in the benchmark case (Panel C). So, the results of this policy is that we get more innovation, but we also end up in a quite competitive environment.

A natural follow-up question we can ask, is whether the timing of the incentives matters. Therefore, we run two more simulations in which this incentive scheme applies either only in the early phase (early life cycle, or ELC) or only in the late phase (late life cycle, or LLC). Results are showed in Figure 3: it is quite evident that this type of incentives is particularly effective in the early phase because they allow more firms to discover more submarkets at the beginning and to use the resulting profits to finance further innovation activities, without harming, but actually sustaining competition. When incentives are given too late, i.e. when the growing and exploratory phase of the industry life cycle is already exhausted, we do not observe significant differences with respect to the benchmark case with no incentives.

2.2.4 Merit-Based Incentives

Rather than simply distribute money to all firms, the policymaker might choose to select only some of the firms as recipients of the incentives. We model this policy alternative by changing the probability distribution of innovation activities letting the chances to innovate depend on past innovative performance as measured by the number of discovered innovative products. Therefore, best performing firms in terms of innovation outcomes (discovered and commercialized product designs) will get a higher probability to discover new products, in a similar way to what would happen if they would receive a monetary subsidy[3].

Results of this exercise are presented in Figure 4, and are compared to the Benchmark and Watering-Can cases. The new policy generates only a limited increase in the number of discovered submarkets (around 10%), and the additional discoveries occur quite late in the life cycle of the industry. This pattern is also associated to a relevant increase in both firms profits and concentration. Overall, the Merit-Based policy performs worse than the simple Watering-Can policy:

[3] An indirect form of subsidy calibration (through a change in the probabilities rather than through the actual allocation of resources) is preferable in this scenario, since the policy applies only to selected firms.

the main reason is that a Merit-Based policy cannot be properly applied when the industry is young, because it is more difficult to recognise which are the best firms in this period. However, as it was clear from the Timing experiment, the early phase is also the one in which incentives are more important.

2.2.5 Ex-Ante Selection

An even more sophisticated policy might consider the possibility to identify and select the most promising areas for research and to concentrate in those areas the extra-resources provided by the policymaker. We model this exercise by shifting the distribution of search efforts from a Uniform density function to a Pareto-like density function, where the submarkets with the highest probability to be explored are those with the highest number of customers. As a consequence of this change, the probability of selection of a product design satisfying the needs of a particular submarket is not equal for all product designs. So, this policy indirectly operates like a subsidy given to firms for conducting specific research activities. This way, we partially relax the extreme uncertainty assumption and we consider that a high number of customers can be more easily recognised and therefore become the indirect target of a policy, or might even act directly to lobby the policymaker.

Results are shown in Figure 5. This policy produces higher profits than the benchmark in the growing stage of the life cycle (Panel B), but they are not used to explore more submarkets as in the Watering-Can case. In fact, Panel A shows that the number of discovered submarkets is 15% lower than the benchmark case, and is less than half the number of discovered submarkets in the Watering-Can exercise. Moreover, there is also no benefit in terms of concentration, which remains stable around the same levels of the benchmark case (Panel C).

The reason behind these results is that the incentive scheme induces firms to concentrate only on a limited set of submarkets. Many areas are subject to a limited innovative effort, whereas the most popular submarkets are subject to strong selection forces that reduce the number of surviving firms and therefore increase concentration.

Given this explanation, it is interesting to explore a follow-up exercise changing the timing of the incentive scheme, analogously to what we did in the Watering-Can case. Again, we run two more simulations in which the Ex-Ante Selection (EAS) incentive scheme applies either only in the early phase (EAS_ELC) or only in the late phase (EAS_LLC). The basic expectation is that an application of the scheme only in the early phase might improve the outcomes: early selection might help firms to focus on the right areas, and then later on they can use profits to explore more submarkets. The late life cycle scheme, instead, would be less effective in that it does not affect much the behaviour of the firms in the growing stage of the industry life cycle.

Results are shown in Figure 6. Limiting the incentive to the early life cycle has a positive effect as compared to the full time scheme, since the number of discovered submarkets increases in the later stages of the simulation. However, this is not enough to match the outcomes of the benchmark case. Firms do not get enough profits from the most populated submarkets, due to the strong competition that occurs in these selected submarkets. As expected the late life cycle policy has a limited effect on the number of discovered submarkets, but it also has a positive effect on concentration: the Herfindahl index increases to levels higher than the Benchmark case due to the indirect protection that is ensured to monopolists or oligopolists in the less explored submarkets.

Finally, an important variant of the Ex-Ante Selection policy would require that the policymaker has not perfect information about the submarkets characteristics, and therefore it might actually select the wrong ones – maybe because groups taking advantage by the development of some submarkets are better able to exercise pressure or gain visibility, or simply because we are back in the extreme uncertainty scenario, with the policy maker being wrongly unaware of it. Results presented in Figure 7 show that the outcomes become worse in this situation: since the amount of profits available to firms decreases, the number of discovered submarkets is lower than in the perfect information case. Concentration, however, remains stable at lower levels, because lower profits reduce the possibility for the best firms to discover new products and drive out of the market laggard firms.

2.2.6 Few Submarkets

The analysis conducted so far refers to an industry characterized by a high number (200) of independent submarkets. An interesting question to ask is whether results would differ by changing this aspect of the environmental context. In this exercise, we reduce the number of submarkets to 1/10 of the original value (20), keeping constant the total number of potential products to be discovered and the global size of the industry. In this modified context, we compare the results of the Benchmark case with the Watering-Can policy and the Ex-Ante Selection policy, as defined in the previous sections. Since the number of submarkets is much lower, we also consider a different metric to evaluate results: the number of discovered (innovative) products.

Results are presented in Figure 8. Although in the Ex-Ante Selection the dynamics of discovery is slower, in all three cases all submarkets are discovered in the early phase of the industry (Panel A). In terms of products discovered, the best performance is guaranteed by the Ex-Ante Selection (Panel B): in this case the higher profits earned by firms (Panel C) determine higher investment opportunities that can be translated in the discovery of new products, since there are no neglected submarkets. Analogously to what found in the previous cases, the Ex-Ante Selection policy determines a higher level of concentration (Panel D).

2.2.7 Supporting entry of new firms

A last exercise examines a policy supporting the entry of new firms in the industry. The question is very simple: does a larger number of entrepreneurial efforts lead to higher and faster rates of discovery of submarkets and products?

Here, it is important to highlight a distinction between potential entrants and actual entrants. Standard theories of entry typically posit the existence of a pool or queue of potential entrants, the origin of which is unspecified and the size of which is assumed to be infinite or again is unspecified (see however Klepper and Sleeper (2005) work on spinoff for a significant step forward in this direction and Capone et al. (2016) for an exploration of sectoral differences in the spinoff process). Potential entrants then decide to enter evaluating the prospects for profitability. However, the size of this queue might be crucial for determining the actual amount of entry. If the queue is small, entry will be limited irrespective of any other condition. When the pool is very large, “excessive entry” might take place, as soon as heterogeneity among firms, imperfect information, or uncertainty are considered. Thus, our exercise considers actions meant to increase the pool of potential entrants. These firms start to explore the space of submarkets and products but only some of them will be successful in their search. Moreover, only a fraction of these entrants will be able to survive in the longer run.

Figure 9 shows that indeed the number of active firms grows as the population of potential entrants becomes larger but at a decreasing rate. Figure 9 also suggests that a strong selection process is under way: at the beginning a high number of firms enters the industry, but soon a shake-out takes place. This shake-out is unsurprisingly very strong when the number of potential entrants is very high. As time goes by, the number of surviving firms converges to a steady state.

Thus, the dynamics of the industry is indeed influenced by initial conditions concerning the number of potential entrants. Yet, selective pressures allow for the survival of only a limited number of firms. A "revolving door" effect is at work: many firms try to enter, but they are pushed out of the market very quickly. Results of the simulations (not reported here) confirm also that early entrants enjoy a significant advantage in terms of survival vis-à-vis later entrants,

3. ENTRY POLICY IN VERTICALLY RELATED INDUSTRIES WITH TECHNOLOGICAL DISCONTINUITIES

3.1 Overview

In this Section, we examine a radically different context and highlight two important features of policies in dynamic, interdependent industries characterised by strong increasing returns. In such a setting, first, industrial policies may not be effective in modifying the course of the industry history, given the strong path-dependent nature of the processes of learning and competition. Second, the timing of the intervention is crucial in order for policies to bear effects. In particular, when technological progress is highly cumulative, but marked by significant discontinuities like the discrete appearance of new superior technologies, policies can be effective mainly (or only) in specific windows of opportunities: that is to say, when those discontinuities occur. Third, policies aimed at one industry can have important effects on other (vertically) related sectors.

To fix ideas, think at the following scenario. Industrial policy is targeted towards favouring entry of new firms in an industry characterized – as we just stated – by strong increasing returns. Entry may be considered an objective of industrial policies for different reasons. First, a larger number of active firms might increase exploration and the rate of innovation. Second, entry can countervail emerging monopolistic positions in the market and again have positive effects on technological progress and industrial growth, if and when monopoly is thought to stifle innovation. We ask: how effective might be and under what conditions can this kind of intervention reach its objectives? Moreover, does this intervention produce desirable or undesirable unintended effects on a vertically related sector?

3.2 Model's sketch

This model is based on the history-friendly model developed by Malerba *et al*. (2008, 2016) to analyse the co-evolution of the computer and semiconductor industry. This setting can be extended to many contexts in which two sectors are related by vertical relations, and both industries are characterized by both cumulative technological progress, sharp technological discontinuities - i.e. the appearance of new superior technologies in the upstream industry – and other sources of increasing returns like bandwagon effects on the demand side (e.g. brand loyalty, imitative behaviour relating to brand preferences, etc..).

In the model, a product produced by a particular company has two attributes that are relevant to its potential purchasers: performance and cheapness. Customers buy a product only if both performance and cheapness meet a minimum threshold level. *Ceteris paribus*, the market share that a product gains is a function of the merit of its design in terms of these two attributes, relative to that of other products on the market, as well as of bandwagon effects. Both performance and cheapness are determined also by the quality of the components that are used in the product. Therefore, there are two sources of firms' heterogeneity in the model: the path-dependent process of learning and technological change, through which the attributes of the product are improved, and the quality of the supplier of the component technology (if this is not developed internally).

Firms that sell more products are more profitable than their competitors, and therefore can grow more quickly by reinvesting their profit in R&D activities. Moreover, technological progress is strongly cumulative: firms improve their products on the basis of what they have achieved previously. Since on average higher R&D spending enables a firm to make larger improvements in the product it sells, these assumptions determine a high probability that a dominant firm would emerge through the dynamics of competition. Diminishing returns to R&D partially slow down and limit this tendency. Yet, increasing returns on the demand side are an additional powerful mechanisms generating concentration and possibly lock- in in an inferior technology (if current leaders are not capable and quick enough to jump on and master the new technology) (See, for example, Malerba *et al*., 2007).

The component industry is characterized by the exogenous arrival of different technologies over time: at the beginning, there is a dominant technology, but over time this is replaced by superior technologies that arrive in a predetermined period and have different disruptive potentials. The new technology is always introduced on the market by a new cohort of supplier firms. Within each technological era, there is continuing and cumulative improvement in the basic component being produced and sold, but with the advent of the new technology the rate of progress speeds up. Specifically, we consider two technological discontinuities. The first one occurs at time 40; the second one – characterised as much more disruptive than the previous one - at time 120.

At the beginning, downstream firms are not vertically integrated and they choose a supplier among existing component firms; once the contract expires, they can either switch to a new supplier or choose to vertically integrate and produce the required components by themselves. The higher the quality of a component product, the higher the probability it will be selected by a downstream firm that is searching for a supplier. The choice of vertical integration or specialization is not symmetric: when a firm is integrated, it can compare the internally developed product with the best one available on the market. As this is not possible for a non-integrated firm, its choice depends on two observables: its size and the size of the biggest independent components producer.

3.3 Policy exercises: entry in the downstream market

A striking characteristic of the model described in the previous section is that, especially in presence of strong bandwagon effects, a concentrated structure (and more often a monopoly) emerges quite quickly and remains stable over time, even in the presence of sharp technological discontinuities. A natural policy exercise to conduct in this context is given by measures that stimulate entry by new firms that can contrast the power of the leading incumbent firm and speed up further innovation and industrial growth.

More in detail, we change both the number of entrants in the industry (N varies from 1 to 80) and their time of entry (from T=1 to T=150). All new firms are assumed to be specialized producers of downstream products, and are required to choose their supplier as incumbent firms do; the technological level of entrants is in line with the public knowledge in the industry[4]. For any value attributed to the time of entry (T), we let the number of entrants (N) change; and for each

[4] Therefore, we rule out some alternative possibilities: entry of big firms from related markets, that could have chosen vertical integration as entry strategy; or also the possibility of spin-offs from the best firms, that should have a technological level higher than the average. Actually, these cases have been separately investigated, and they did not generate any other insight on top of what we present here.

combination of these two parameters we run 100 simulations. We focus our analysis on the outcomes of the entry process at period T+100 (where T is the date of entry), in order to allow a sufficient length of time for the effects of entry to be displayed.

First, we study the effects of the policy in the downstream market. In Figure 9, the number of surviving firms at T+100 is showed as a function of the number of entrants (N) and the time of entry (T). The first element to notice is that a massive entry (N > 40) is required to have a long-term effect on the number of surviving firms: in contexts characterised by strong increasing returns, entrants face a very hostile environment and the policy is ineffective unless it is successful enough to generate a very large number of entrepreneurial efforts. Second, the consequences of higher numbers of entrants become significant only in specific time windows, i.e. those that are associated with the origin of the industry (0 < T < 25) or the last technological discontinuity (T > 120), and to a lesser extent with the second (and weaker) technological discontinuity (40 < T < 60). These results are also confirmed by the representation of the Herfindahl index in the downstream market (Figure 10). Thus, the timing of intervention is key to the success of industrial policy: action can be effective in specific and limited windows of time and opportunity, mainly when technological discontinuities perturb the otherwise established trajectories of advance.

Third, an important characteristic of the context that we model here is the relation between the two industries. Thus, we ask whether there is any effect of the entry process in the downstream market on the structure of the upstream sector. The Herfindahl index in the upstream market is showed in Figure 11: the entry process in the related sector has major consequences for the sector. Generally, more entry in the downstream market means that there is a larger market for the upstream firms. As a consequence, *ceteris paribus* the level of concentration tends to be lower in presence of many downstream entrants[5]. Yet, this effect appears only when entry occurs in the early or late discontinuity period there is such an effect: again, there are windows of opportunity for entry to exert effects.

We can look at the relation between the two markets also from a different angle. Since entry in downstream market occurs at different time periods, entrants can find different conditions

[5] Of course, this need not be always the case. If strong increasing returns characterise the upstream industry too, then large demand translates into stronger monopoly power. For a discussion, see Malerba et al., (2008).

characterizing the upstream market. These conditions can have important consequences on the chances of survival of downstream firms. Figure 12 presents the number of surviving downstream firms entering in the first discontinuity era, as a function of the number of upstream firms active at the time of entry: there is a clear positive relationship between the two numbers, showing that more firms survive in the downstream market when there are more upstream firms: in the early phase of the industry – when a leading firm in the downstream market still has to emerge – there are also more upstream firms. The pattern is quite different when looking at the second discontinuity (Figure 13). Here a first peak in the number of surviving downstream firms is reached when there is a monopoly in the upstream market. In this case, the upstream monopolist acts as a collector of resources from downstream entrants, allowing them to gain from big investments in the component technology and to compete on a parity base with the leading incumbent in the downstream market. We observe also an increase in the survival of downstream firms when the number of upstream firms is very high: when entry occurs a competitive situation is already prevalent in the downstream market. As a consequence, more upstream firms can survive. Yet, this scenario is not frequent, as it can be seen from the low number of occurrences (that is the number of simulation runs in which we observe that specific number of upstream firms at entry).

In sum, the effect of a policy aimed at one industry depends crucially on the conditions defining the structure and dynamics of a related sector. Even more important, such an intervention may bear significant consequences in the related sector. In the specific case discussed here, these effects are desirable: more entry downstream promotes competition upstream and policy kills two birds with one stone. It is not too hard to think of cases where unintended consequences are instead negative (see Malerba *et al*. (2008) for examples).

4. Conclusion

This paper has examined the effects of alternative industrial policies in two different scenarios. First, we have studied the effects of financial subsidies to firms who explore randomly an unknown space of market opportunities and where there is very little cumulativeness in innovative and product development activities.

Results show that the most effective policy is also the simplest: just to give money to all firms, i.e. the watering-can principle. Other, more sophisticated forms of intervention do not match this policy design. The reason behind these results is clear: in such an uncertain environment, there is very little room for learning and exploration is the best (only?) way to discover new markets and products. Moreover, simulations clearly show that the timing of intervention is essential. Policies exert their effects only in the earlier stages of the discovery process – when exploration occurs – and become rather ineffective afterwards.

Second, we analysed a rather different setting where industrial policy supports entry of new firms in a downstream industry that is characterized by strong increasing returns, but it is also subject to major technological discontinuities. The main results in this scenario confirm that policy may be ineffective when strong forms of increasing returns generate path-dependency. Moreover, outcomes depend once again crucially on the timing of the intervention, i.e. mainly in the very early stages of industry evolution and when new superior upstream technologies become available and perturb the otherwise inertial path of innovation and industrial growth. Finally, policy results are largely dependent on the nature and structure of the interdependencies and linkages between the downstream and upstream sectors. In particular, policies targeting the downstream industry may have important unintended (positive or negative) effects upstream.

These exercises just begin to scratch the surface of the problem of designing, evaluating and implementing policies in complex, dynamic and interdependent contexts. If anything, they show how challenging and rewarding this task is. But these are the features of the world we live in. Beyond highly simplified and stylised scenarios, the results of this paper indicate that the details of the contexts matter much in determining the scope and the effects of alternative interventions. Systematic further work along these lines should, in our view, become a top priority for the discussions on industrial policies.

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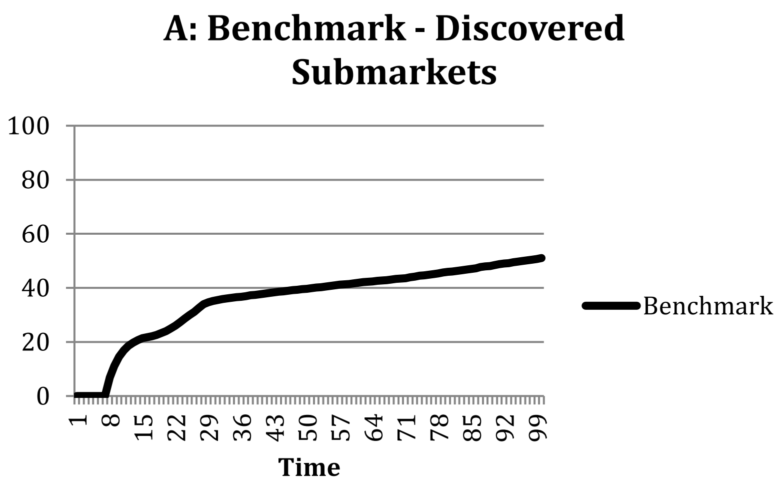
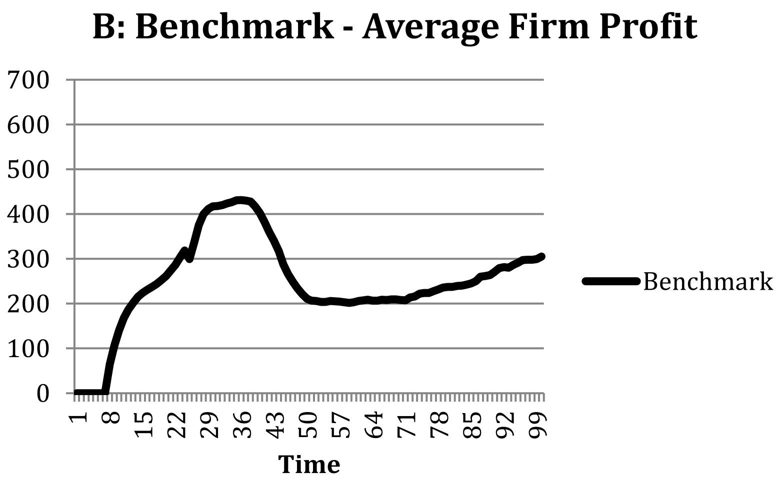
FIGURES

Figure 1: Benchmark case





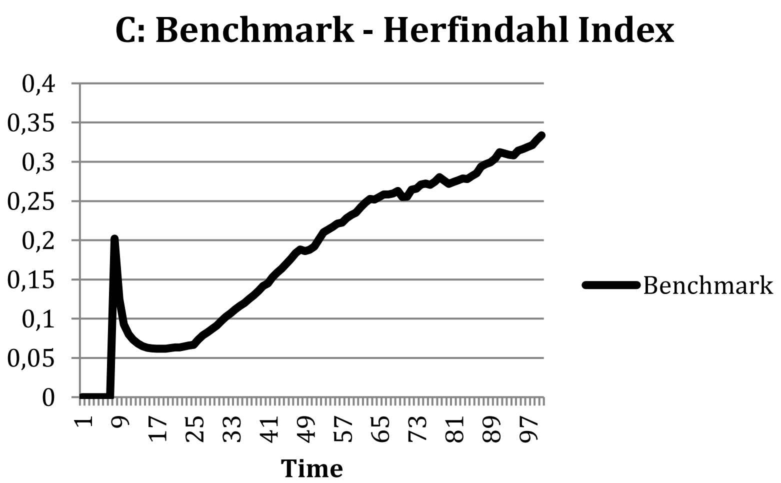
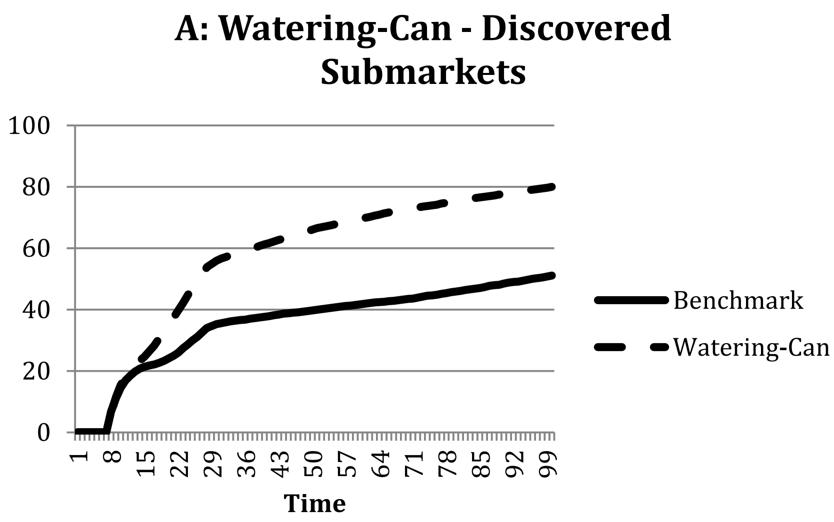
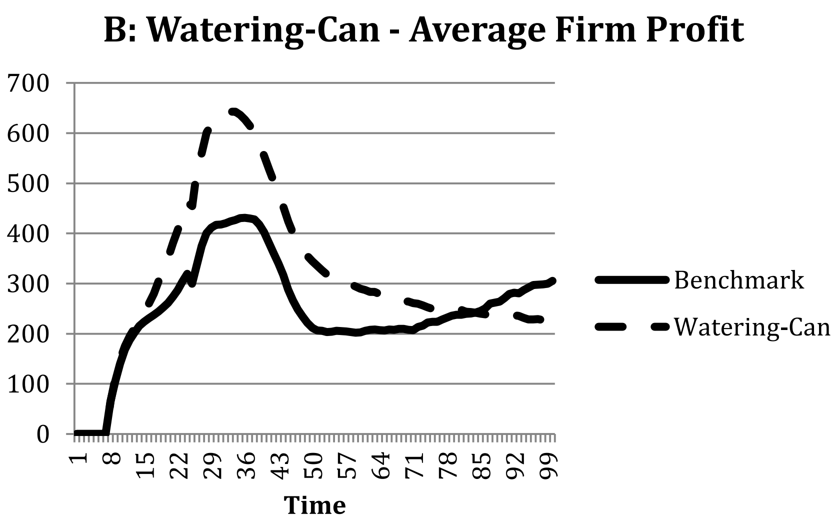


Figure 2: Watering-Can Policy





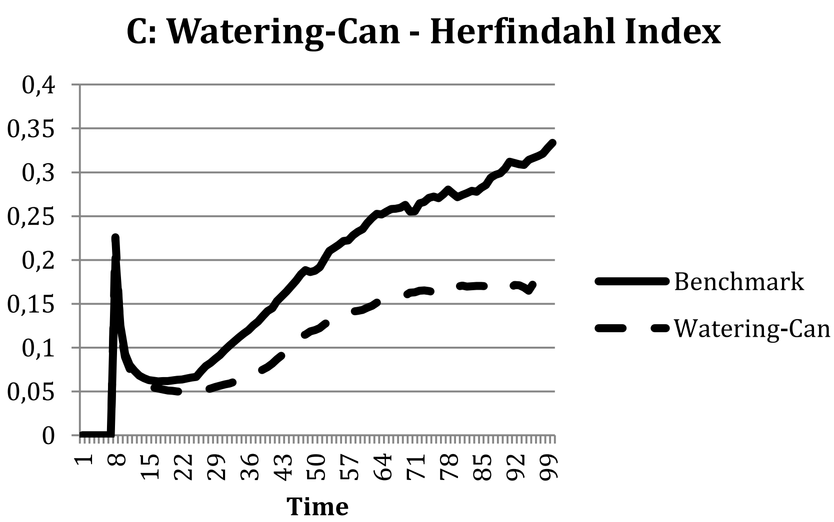


Figure 3: Timing of Watering-Can Policy

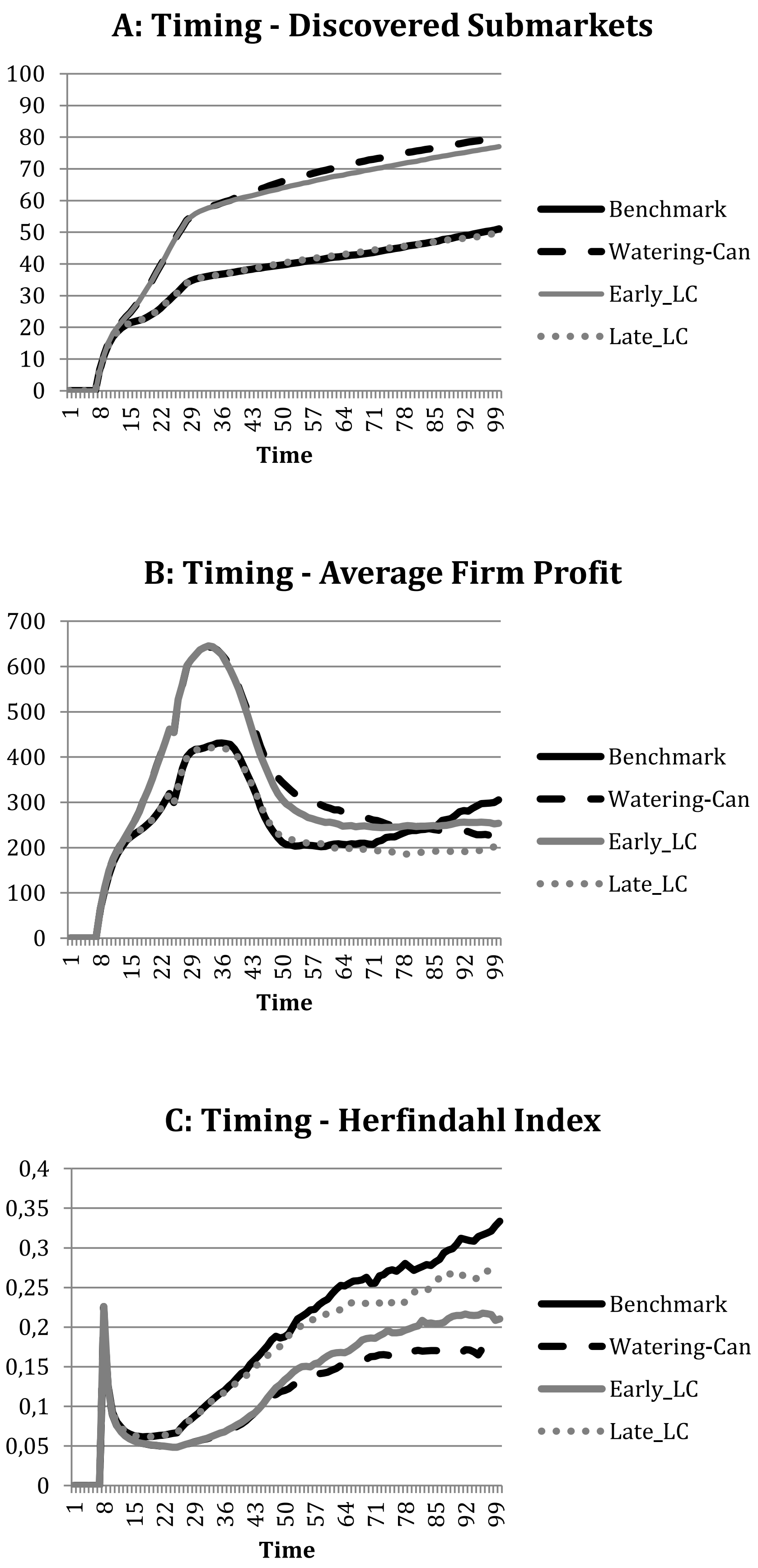


Figure 4: Merit-Based Policy

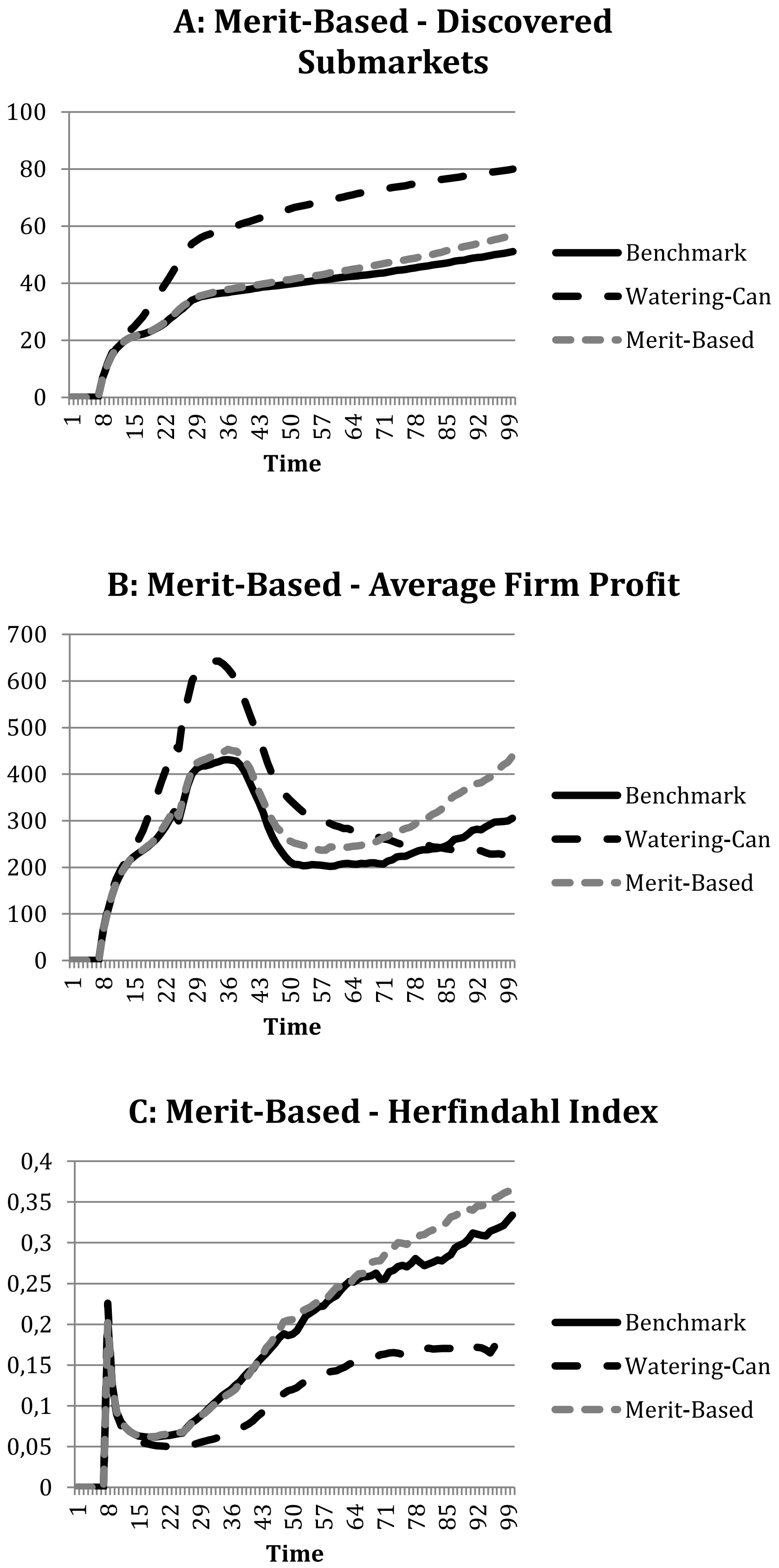


Figure 5: Ex-Ante Selection Policy

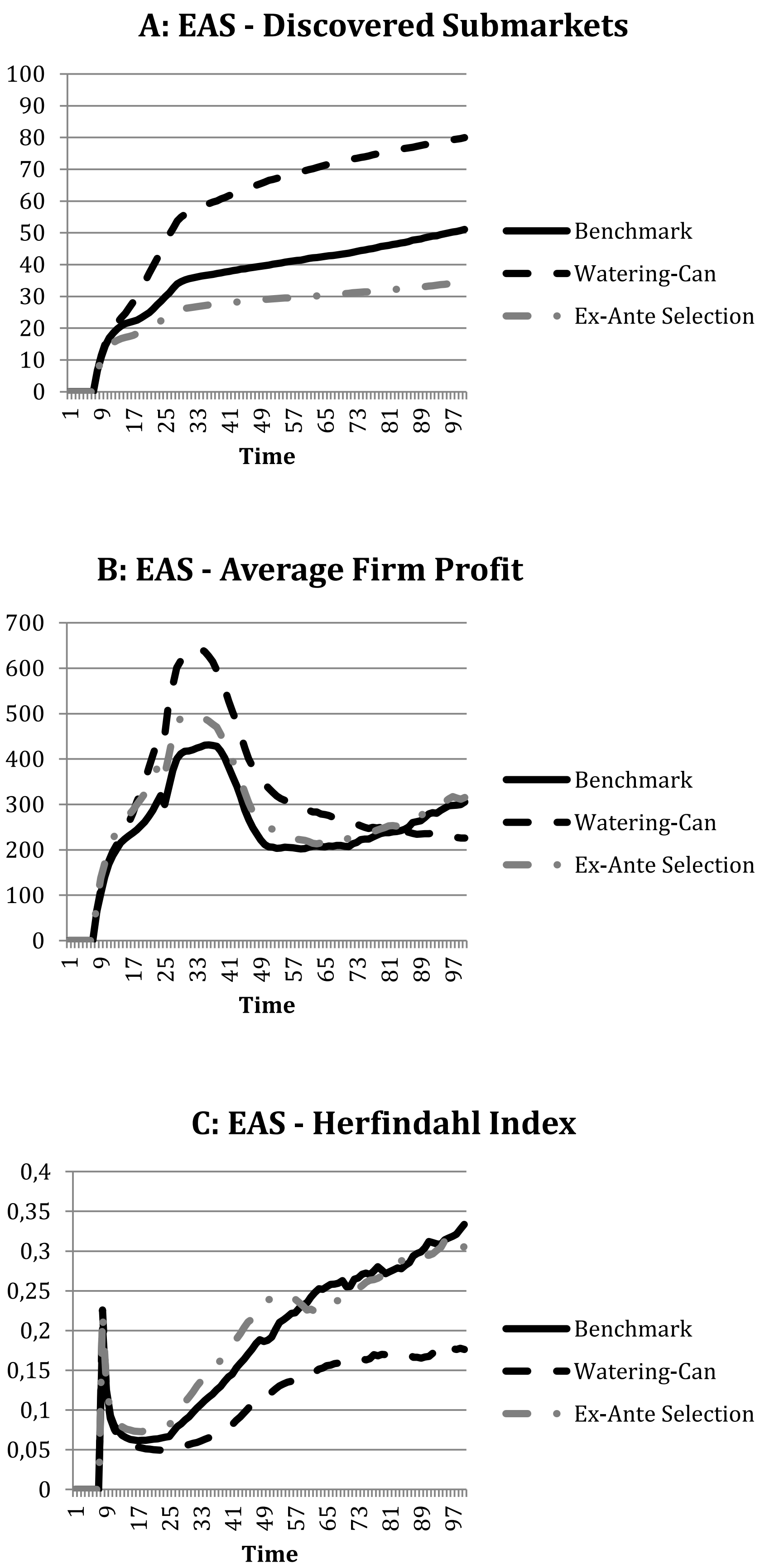


Figure 6: Timing of Ex-Ante Selection Policy

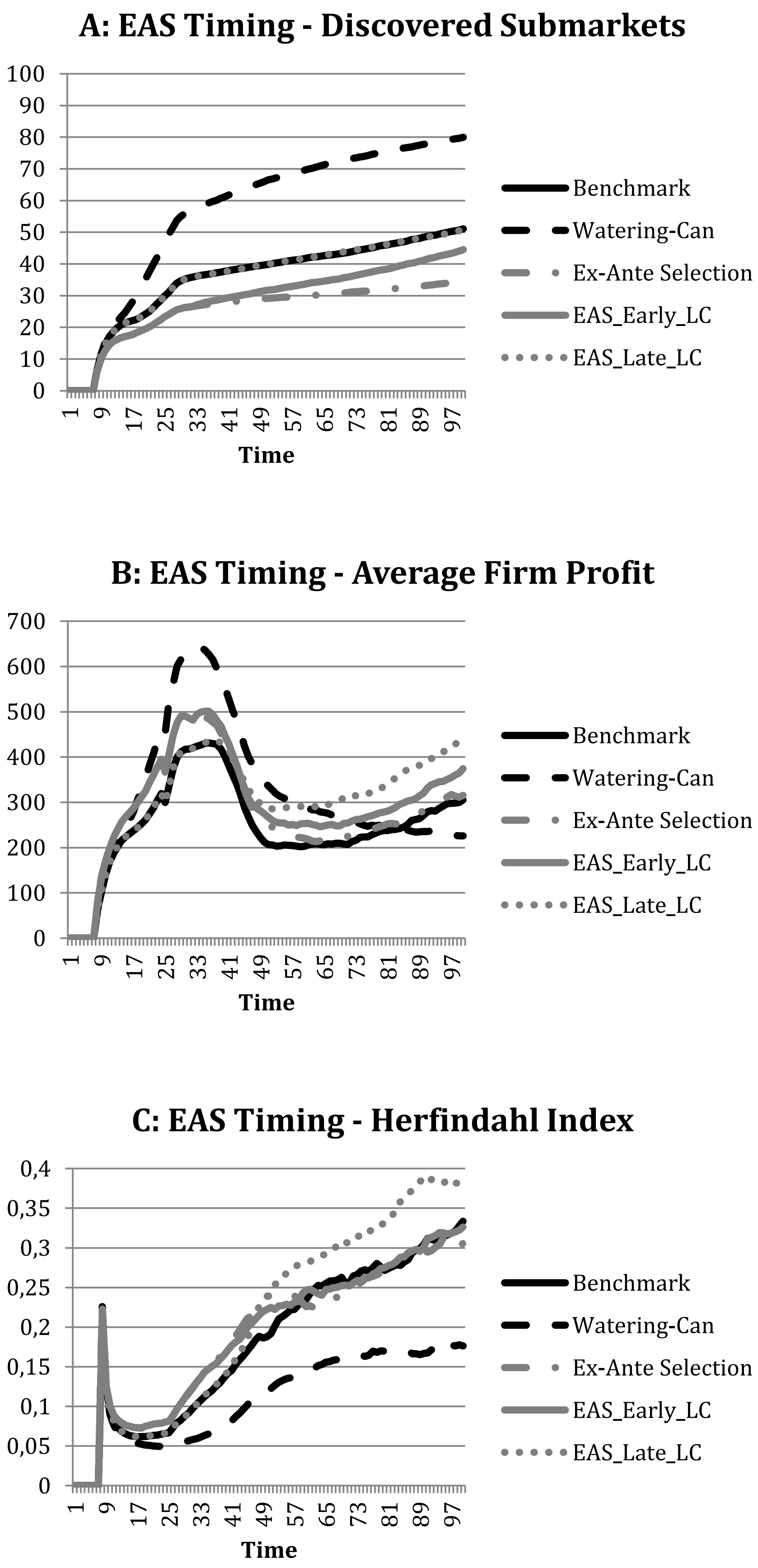


Figure 7: Ex-Ante Imperfect Selection Policy

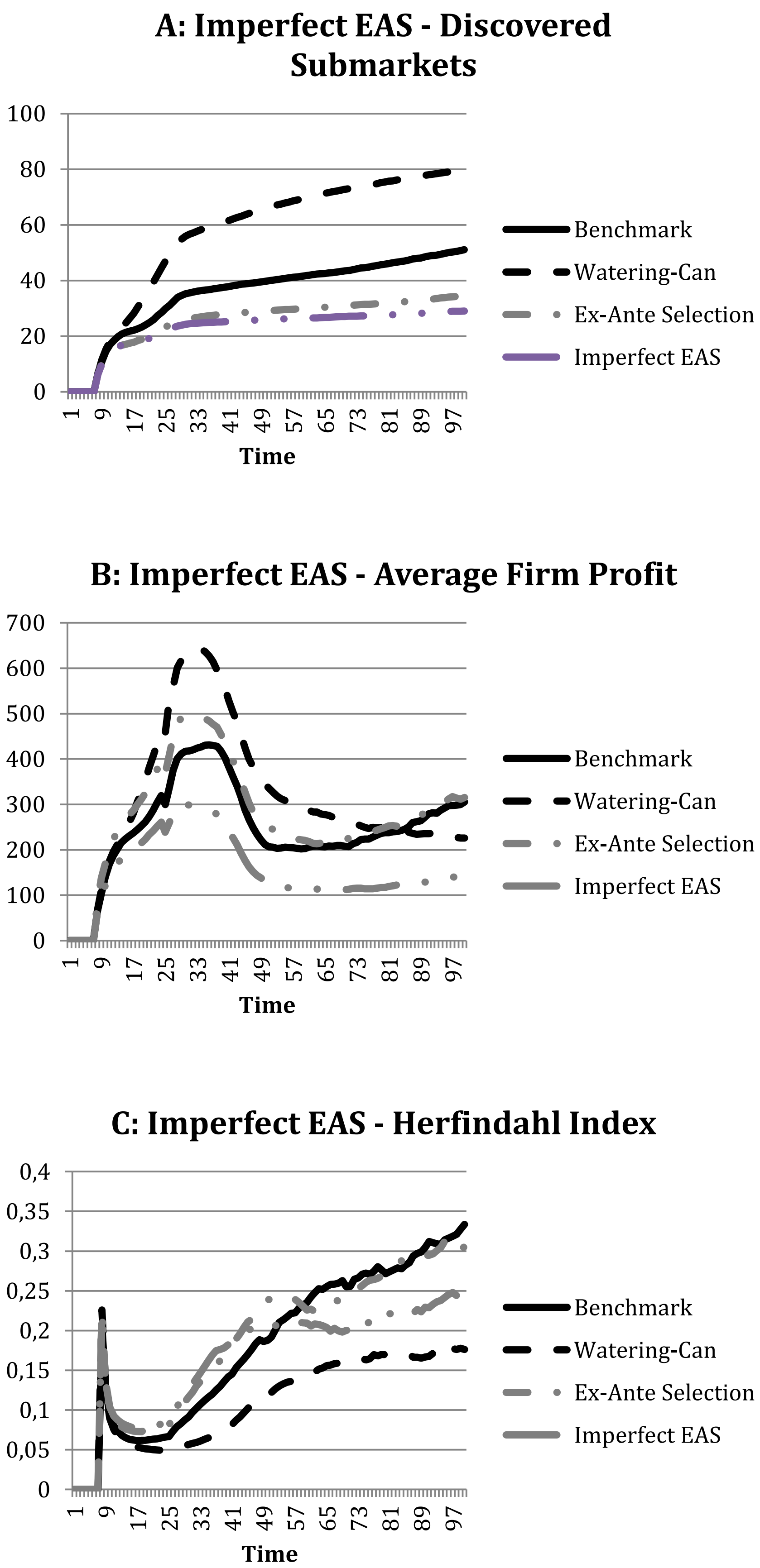
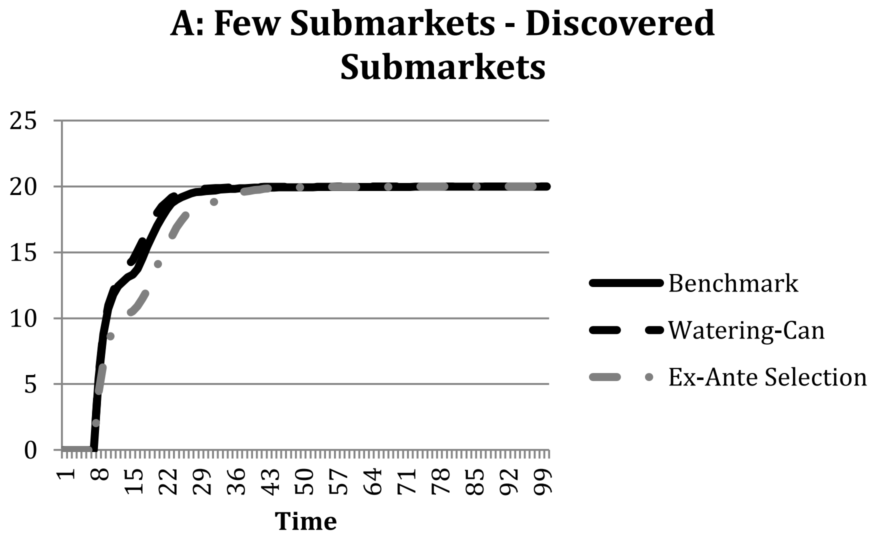
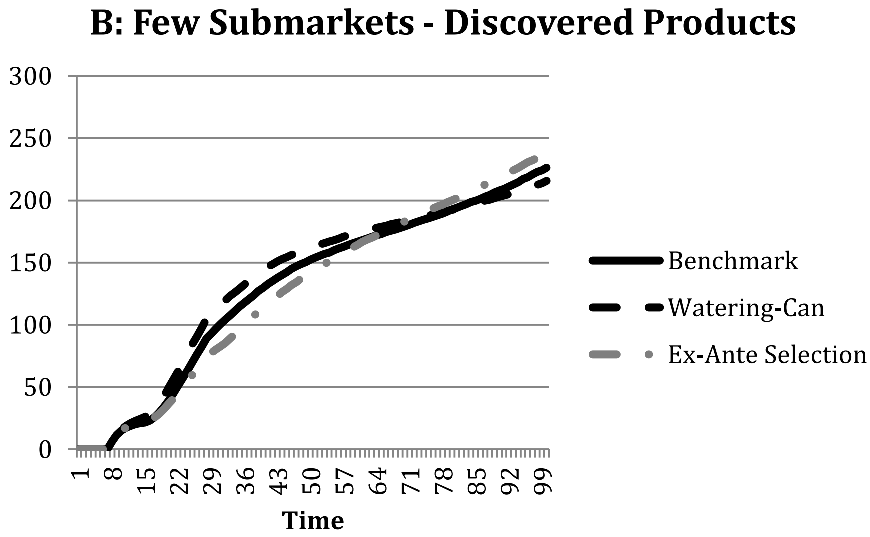
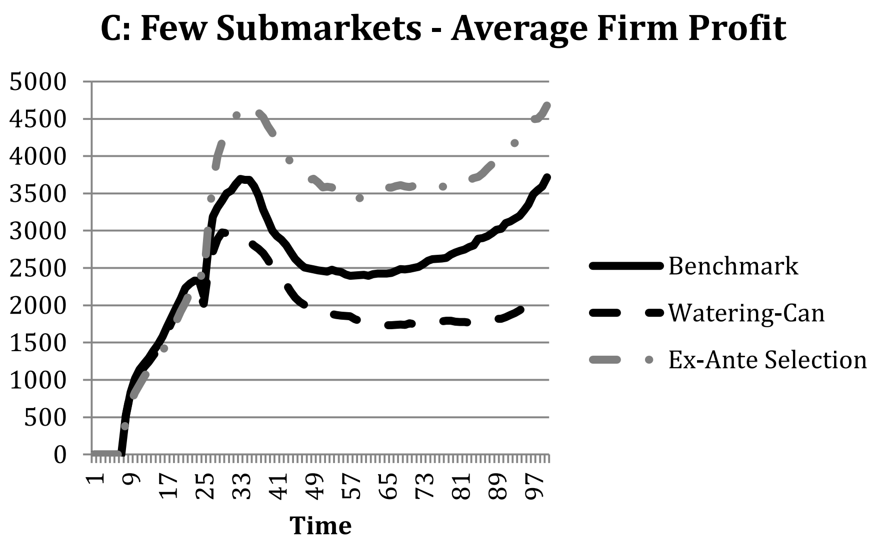


Figure 8: Few Submarkets






C: Few Submarkets - Average Firm Profit
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
9
17
25
33
41
49
57
65
73
81
89
97
Time
Benchmark
Watering-Can
Ex-Ante Selection

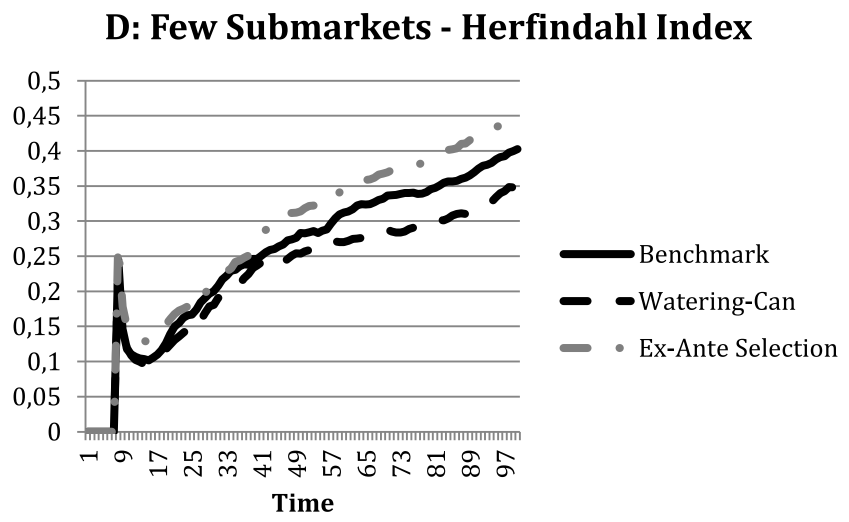

D: Few Submarkets - Herfindahl Index
0,5
0,45
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
1
9
17
25
33
41
49
57
65
73
81
89
97
Time
Benchmark
Watering-Can
Ex-Ante Selection

Figure 9: Surviving firms over time as a function of the number of potential entrants

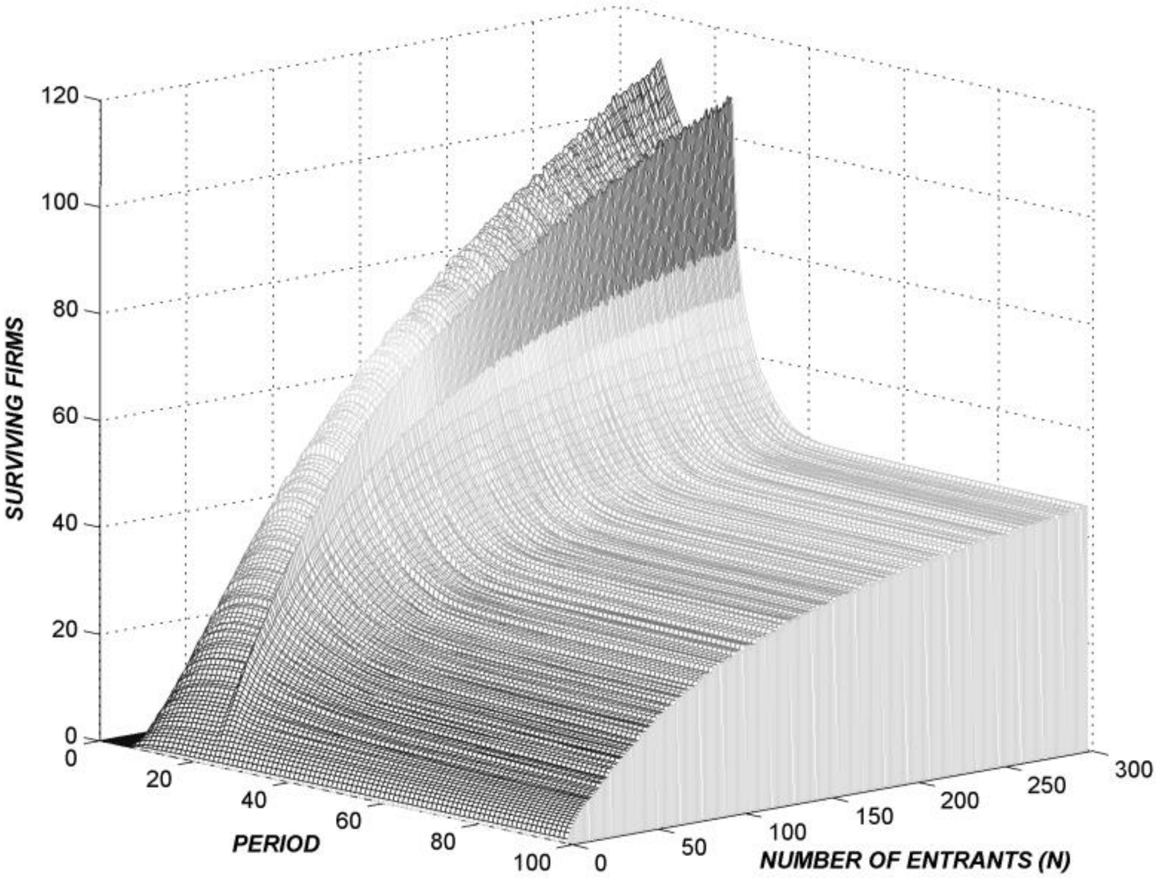


Figure 10: Surviving Firms in Downstream Market

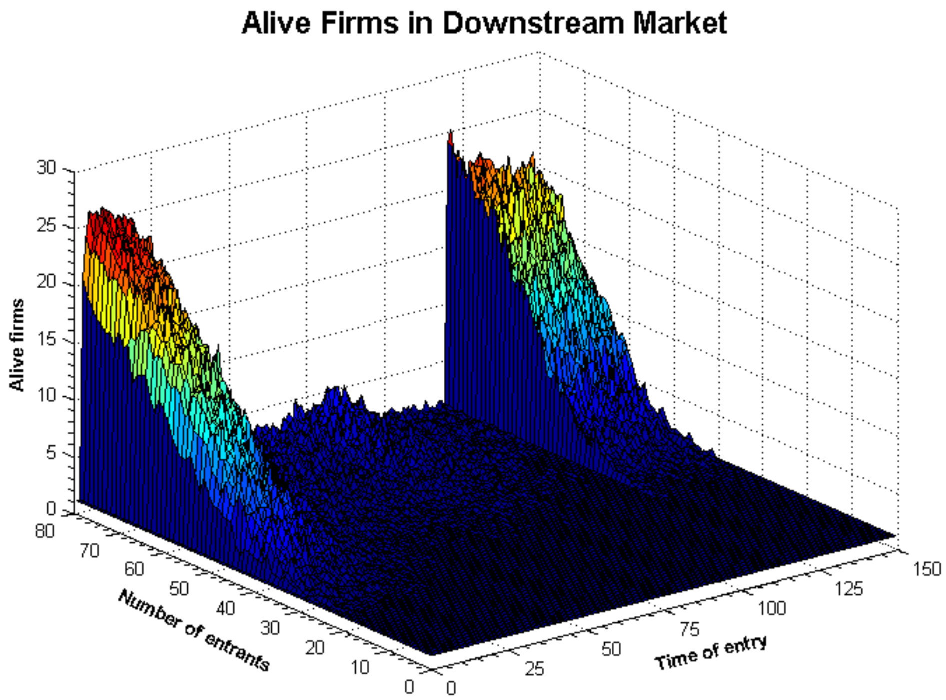


Figure 11: Herfindahl Index in Downstream Market

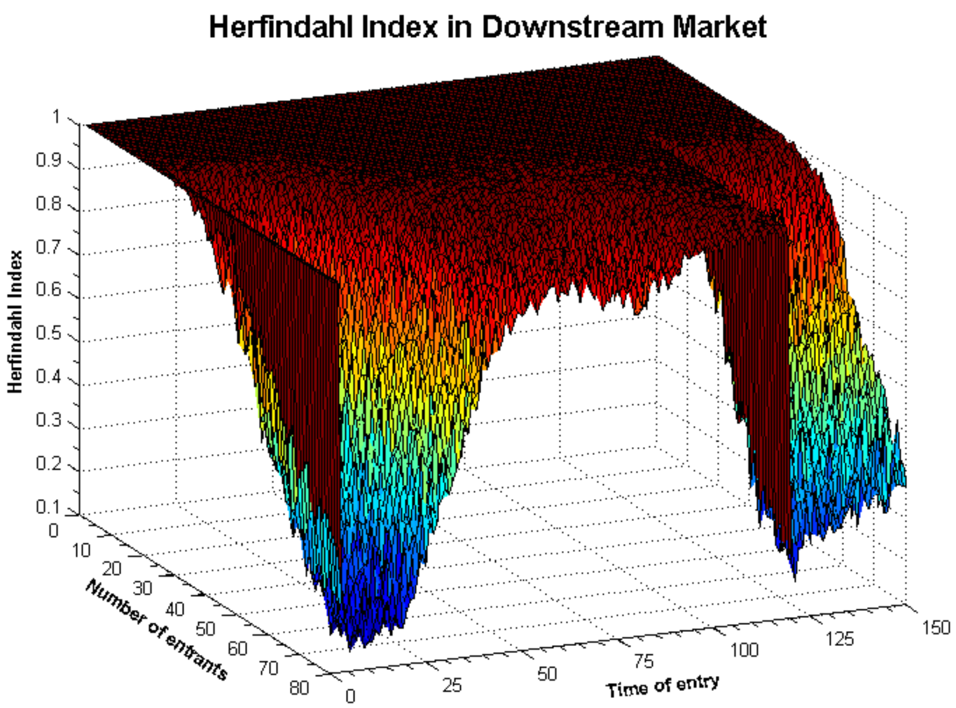


Figure 12: Herfindahl Index in Upstream Market

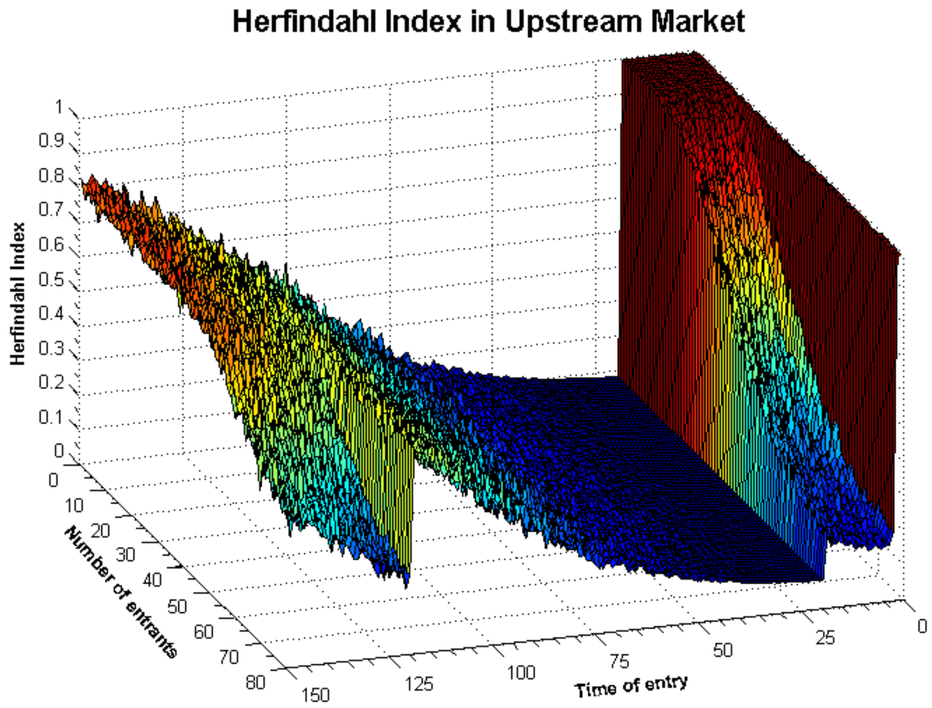


Figure 13: Alive Downstream Firms and Upstream Firms at Entry in the First Technological Discontinuity Era

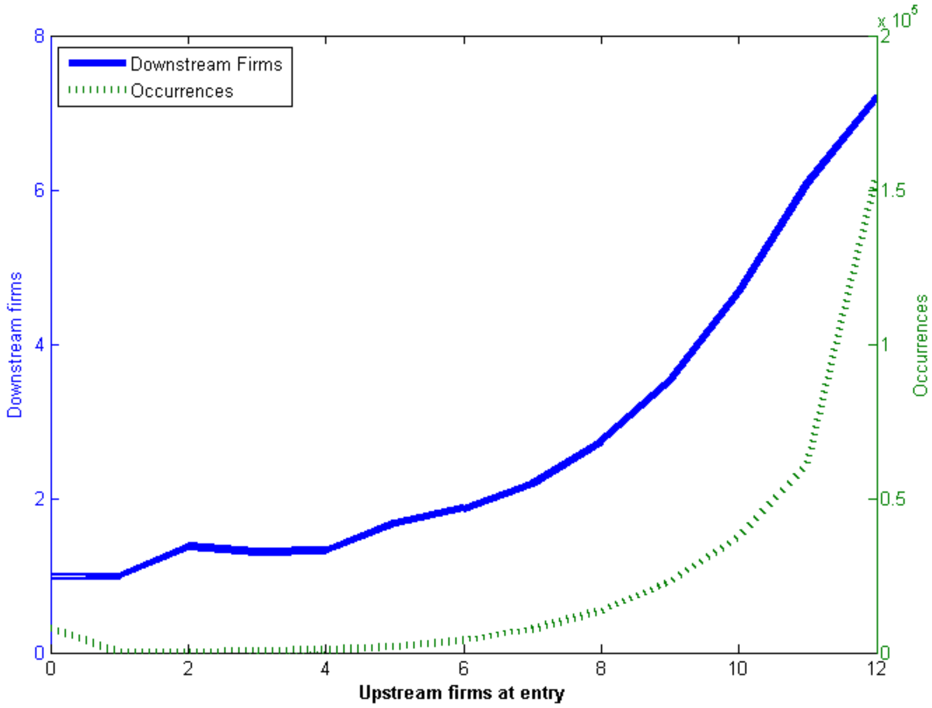


Figure 14: Alive Downstream Firms and Upstream Firms at Entry in the Second Technological Discontinuity Era