PUBLIC POLICIES AND CHANGING BOUNDARIES OF FIRMS IN A "HISTORY FRIENDLY" MODEL OF THE CO-EVOLUTION OF THE COMPUTER AND SEMICONDUCTOR INDUSTRIES

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In this paper, we explore the effects of alternative policies, ranging from antitrust to public procurement, open standards, information diffusion and basic research support on the dynamics of two vertically related industries in changing and uncertain technological and market environments. The two industries are a system industry and a component industry, and the evolution of these industries is characterized by periods of technological revolutions punctuating periods of relative technological stability and smooth technical progress. We have been inspired by the co-evolution of the computer and component industries from their inceptions to the 1980s. On the basis of that evolution, we have developed a history friendlymodel this co-evolution. In sum, this paper has stressed that various types of policies may sometimes have contrasting effects on the industry, mainly on concentration and technical change and innovation. It has also shown that the consequences of policies may spillover from one industry to another, and from one type of firms to another. Policies that aim at a specific industry may provoke major changes in a related industry through the product market, the changing boundaries of firms or knowledge and technological interdependencies. The policy maker has to be aware of that. Finally, a major point of the paper regards the unintended consequences of policies.

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1. Introduction

This paper examines the effects of different types of public policies - ranging from antitrust to public procurement, open standards, information diffusion and basic research support - on the co-evolution of two, vertically related industries in changing and uncertain technological and market environments. It does so by focussing on the specific cases of the computer and semiconductor industries and relying on a "history-friendly" model of the co-evolution of these two industries.

We concentrate on the dynamics of mainframes and personal computers and of the main generations of semiconductors used in computers: first transistors, then integrated circuits and finally microprocessors. The co-evolution of these two industries has shown periods of incremental technical progress punctuated by major discontinuities related to the introduction of a new type of computers (personal computers vs. mainframes) and semiconductors (integrated circuits vs. transistors and later microprocessors vs. integrated circuits). The coupled dynamics of the two industries has involved processes of integration and specialization by computer producers.

In the dynamics of the two industries, public policy intervened at different levels. First of all antitrust policy tried to act against IBM. But other policies were used in these industries: public procurement (e.g. military expenditures in the USA for early mainframes and for transistors and integrated circuits in semiconductors, or NASA policies); support of basic research in computers; attempts at favouring the diffusion of technological information; interventions promoting the entry of new firms (as done by many Governments in Europe, United States and Japan along the history of the industry).

In this paper we examine the effects of these policies on the dynamics of concentration and on the rate of technical change. We do not directly address the desirability of these policies[1]. Rather, we examine the effects of alternative forms of public intervention in dynamic, evolving and interacting markets. To anticipate the results, we show that different policies have quite different effects – or no effect at all - on some key policy targets such as market power or rate of technical progress; that there are major inter-industry effects of policies, transmitted vertically and horizontally across markets; and that the unintended consequences of policies may be significant. The degrees of efficacy of policies depend on 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 on the nature of the feedback reactions governing the coupled dynamics of vertically and horizontally related industries.

[1] We are also perfectly aware that possession of market power is in itself not objectionable under antitrust policy. Thus, in principle, we should explicitly model and examine anticompetitive behaviour. For simplicity, though, we analyze only the effects of antitrust policy, as if monopoly power implied anticompetitive behaviour.

The paper is organised as follows. Section 2 sets the conceptual background by briefly discussing problems that arise in the analysis of the effects of public policies in dynamic settings and the methodology of history friendly models used in this paper. Section 3 introduces a short history of the industries and the policies that the model purports to explain. Section 4 presents an outline of the crucial features of the model, while Section 5 examines our benchmark simulation, i.e. the "history-friendly" runs. Then section 6 broadly introduces the effects of alternative policies in a dynamic co-evolutionary setting, while section 7 presents a series of exercises regarding alternative forms of intervention on the evolution of market structure and on technological change in the computer and semiconductor industries. Finally, section 8 concludes the paper.

2. Industrial policies in co-evolving interrelated industries

2.1 The background

The analysis of the effects of industrial policies is often based on static, equilibrium models, with agents characterized by complete rationality. Moreover, such analyses consider in most cases, one specific industry, without fully taking into account the effects that public intervention might bear on related industries.

More recently, the growing literature on industrial dynamics and evolution has emphasized the subtle issues that arise when explicit dynamics, heterogeneous agents, increasing returns of various sorts and path-dependency figure prominently in the analysis. This literature has produced a substantial body of new results and it has deeply transformed the way in which industries are studied. Yet, even within this literature, policy implications have been by and large neglected, particularly as formal models are concerned.

Some major exceptions are to be found, of course, in the antitrust debate as it concerns the static vs. dynamic Schumpeterian efficiency trade-off between innovation and monopoly power; and – more recently – the dilemmas posed by network externalities. Audretsch, Baumol and Burke (2001) and Ellig and Lin (2001) provide a thorough verbal discussion of the main issues involved in competition policies in dynamic markets. And notably, these issues have been recently at the centre of the Microsoft case and of the ensuing debate (Gilbert and Katz, 2001). The main issues raised in these strands of the discussion have focused on the desirability of antitrust sanction of monopolistic positions in industries characterized by network externalities and increasing returns to adoption as well as on the appropriate methods for preventing further exploitation of anti-competitive behaviour. In these cases, it is argued, competition is not *within* the market, but *for* the market and it manifests itself as a series of temporary monopolies, provided that the entry of new potential monopolists offering potentially superior new technologies is not blockaded (Schmalensee, 1999). Thus, antitrust policies should consider not only the immediate effects of the existence of a monopolist and of its actions but also the predictions of alternative possible futures (which might be very hard to predict indeed) (Ellig and Lin, 2001). Discussion has concerned also the possible remedies, contrasting so-called conduct remedies (which attempt at constraining anticompetitive behaviour also in the future, e.g. use of exclusive contracts) with structural remedies (which create conditions within the market that would limit monopolistic power, e.g. divestiture of a monopolist into two smaller companies). While the former require heavy regulatory oversight and are susceptible to strategic intervention by competitors, the latter may fail if the required structure does not reflect an efficient organization of the industry. Moreover, structural remedies are likely to entail substantial costs of reorganization and they might impose indirect costs through their effects on the abilities of the new companies' abilities and incentives to cooperate, including pricing and product development (Gilbert and Katz, 2001). In all cases, it is widely recognized that the competitive dynamics of industries "challenges the ability of economic analysis to make precise and certain predictions about competitive effects" (Gilbert and Katz, 2001, p. 43).

Another policy area that has attracted the interest of researcher in the recent past within the context of evolutionary and dynamic models of competition concerns the effects of alternative intellectual property regimes (see Winter, 1993 and Yildizoglu and Vallè, 2005, among others). Other studies have focused instead on the design of appropriate market designs, especially as it concerns the electricity markets in ACE (Agent Based Computational Economies) settings as well in game-theoretic models (see Amin 2002; Widergren, Sun and Tesfatsion, 2006, for surveys of these efforts).

However, many other questions remain open and largely unexplored. They concern not also the desirability of intervention but also the efficacy of alternative policy measures designed not only to combat monopoly (if deemed appropriate on efficiency and political grounds) but also to promote industry growth and technological change. In general, little is known about the efficacy of industrial policies in dynamically related, co-evolving industries.

The joint recognition of the evolutionary character of economic processes and the interdependence between industries justifies and calls for analyses where the dynamic effects of those policies on the co-evolution of the industry and of the related sectors become the center of the analysis. This is what this paper aims to do by using a history friendly model of the evolution of the computer and semiconductor industries.

2.2 The methodology: history-friendly models

In this paper, we start to explore some of these tangled issues. Given the complex and often non linear nature of the relationships involved among the main variables, a simulation model is in our view an appropriate tool for such an analysis (For recent discussions, see Tesfatsion (2003), Windrum (2005), Dawid (2006)) . To do this, we use a modified version of a previous paper on the co-evolution of the computer and semiconductor industries (Malerba *et al*, 2006). That model had been built following the "history-friendly" approach (Malerba *et al*, 1999). The logic and the objectives of this class of models has been presented and discussed in several occasions (Malerba *et al*, 1999, Malerba *et al*, 2002, Malerba *et al*, 2005). Suffice it to remind it here that "history-friendly" models attempt to formalize the verbal appreciative theories about the main factors explaining the particular pattern of evolution of an industry or technology put forth by empirical scholars of that industry. Thus, these models tend to incorporate more industry specific details than is customary of models built by economists. Modelling the history of an industry necessarily implies a more rigorous dialogue with empirical evidence and with non-formal explanations of those histories, i.e. with "appreciative theorizing". The researcher is forced to spell out in a satisfactorily detailed way the hypotheses used as bases for an "appreciative" explanation of the evolution of a certain sector. This allows testing the robustness of those assumptions, clarifying the key hypotheses and causal mechanisms, identifying variables and relationships that were not adequately considered in non-formal models.

It is worth emphasizing that it is not the purpose of history-friendly modelling to produce simulations that closely match the quantitative values observed in the historical episode under investigation. The goal is to match overall patterns in qualitative features, particularly the trend behavior of the key descriptors of industry structure and performance that any industrial organization study would typically focus upon. Further, the goal is to achieve this in a manner that features some particular causal mechanisms – namely, those that have been proposed in the appreciative theories that have been put forward in connection with empirical studies of the historical episode. Finally, history-friendly models can also be viewed in abstraction from the motivating historical episode; like any formal model they seek to elucidate the joint consequences of some collection of plausible causal mechanisms. In that perspective, they are extensions of other history-free evolutionary models in the literature, both simulation models and analytical ones. They have results of a "comparative statics" or "comparative dynamics" kind that may be interesting in their own right.

Just as we do not attempt detailed quantitative matching to historical data, we also do not attempt detailed calibration of parameters. This does not mean that we are indifferent to plausibility, or reckless in the choices we make. Because most parameters fall into groups with a particular mechanism in the model, there is typically some common-sense guidance available for choosing plausible orders of magnitude – there is some reality-based impression of how that mechanism ought to behave. Many value choices for parameters involve implicit unit choices for variables, which means that the quantitative values are in the end arbitrary (or matters of convenience), but also means that relations among parameters affecting the behavior of the same variables have to be made with a view to consistency. It does not matter, for example, what range of numerical values represents the aggregate value of sales in our model industry, but the relationship of production costs or R&D spending to that sales total does matter. Further, some parameter values correspond to elasticities, which means that the choice of values is framed by the known qualitative significance of elasticity = 1. Finally, an additional constraint disciplining and orienting the choice of parameters values is provided by the time structure of the model. History-friendly models purport to generate sequences of events that take place in (approximations to) real time. And the definition of what "one period" means in real time (six months in this model) is crucial for establishing which actions take place at any one period, which follow, etc.. Hence, the time structure of the model imposes restrictions in order to respect consistency. Thus, for example, an interest rate equal to 3% on a yearly basis requires other important parameters in the model to conform to the specified time structure.

Moreover, the methodology of "history friendly" involves both establishing some runs that match the qualitative features of the historical patterns that the analysis is about, and some runs that do not match the historical patterns. Thus, to explore within a the model the proposition that e.g. a major reason an industry became concentrated is that there was a strong bandwagon effect on the demand side (due for instance to brand loyalty), the model must both be able to generate developing concentration with certain parameter values, and also generate time paths with far less concentration when the "bandwagon" parameter, or set of them, is set significantly smaller. In history friendly it is vital that one is able to identify some settings of parameters as significantly higher or lower than the parameter values that generate runs similar to the historical experience. Much of the choice of parameter values is oriented by the need to make these kinds of comparisons.

The computer and semiconductor industries provide also a useful empirical reference for grounding our discussion. We concentrate on the dynamics of mainframes and personal computers and the main generations of semiconductors used in computers: first transistors, then integrated circuits and finally microprocessors. The co-evolution of these two industries has shown periods of incremental technical progress punctuated by major discontinuities related to the introduction of a new type of computers (personal computers vs. mainframes) and semiconductors (integrated circuits vs. transistors and later microprocessors vs. integrated circuits). The coupled dynamics of the two industries has seen processes of integration and specialization by computer producers, in which IBM has played a major role. Moreover, in the dynamics of the two industries, public policy intervened at different levels. Antitrust policy with respect to IBM is an obvious example. But other policies have been used in these industries, ranging from public procurement (e.g. military expenditure in the USA for early mainframes and for transistors and integrated circuits in semiconductors, or NASA policies) to support of basic research in computers (as done by many Governments in Europe, United States and Japan along the history of the industry).

However, this paper uses a history-friendly model as a basis for exploring more theoretically oriented issues. Thus, after replicating the history of the computer and semiconductor industries and looking at the effect of policies in the history-friendly setting, we subsequently change the model – both simplifying it and adding new assumptions and features- in order to examine in more detail problems that might have a broader theoretical interest.

3. The Evolution of the Computer and semiconductor industries and the role of public policies

This paper is inspired by the evolution of computer and semiconductor industries, and by the role of policy during this evolution. In particular, within computers we will look at the history of mainframe and personal computers, and within semiconductors we will concentrate on transistors, integrated circuits and microprocessors. We will mainly focus mainly on the industry in the United States and the role of public policy in that country. Only briefly we will mentioned developments in other countries such as Europe and Japan. Given space constraints, in this section we can recount only a stylized history of the computer and the semiconductor industries and of public policies. The more interested reader may have a look at Malerba (1985), Flamm (1988), Langlois (1990), Bresnahan and Greenstein (1999), and Bresnahan and Malerba (1999) for a more detailed discussion.

The history of the computer industry shows continuous improvements in machines that serve particular groups of users –for example mainframes for large users and personal computers for individual uses - punctuated from time to time by the introduction of significant new semiconductor technologies – such as transistors, integrated circuits and microprocessors - which not only permitted the needs of existing users to be met better, but also opened up the possibility of designing machines that serve new classes of users whose needs could not be met using older technology. In the United States these punctuations were associated with the entry of new firms into the computer and into the semiconductor industries. This happened to a significant lesser degree in Europe, and hardly at all in Japan.

The evolution of the computer industry began in the 1940s with the early experimentation with computers few companies, universities and public research laboratories which culminated in computer designs sufficiently attractive to induce the production of the first computers and their purchase by large firms with massive computation tasks, as well as by scientific laboratories. This opened the era of mainframe computers. The role of public policy was relevant in this stage. During World War II and the years just after, Governments in several countries funded a number of projects with the aim of developing computers useful for Governmental purposes. Universities were also quite active in basic and applied research on computing and computers. In the late 1940s and early 1950s a number of companies, in the United Sates as well as in Europe, began investing their own funds hoping to develop a computer sufficiently attractive to win the market of scientific laboratories, large firms, and other organizations who had large-scale computation needs. The early 1950s saw the entry into the industry of IBM--then a major punched-card and tabulating machinery company, but with significant capabilities in electronic computing derived in good part from government R&D contracts--and the rest of the Bunch (Burrows, Univac Rand, NCR, Control Data, Honeywell), as well as GE and RCA. These companies differed in the strategies they took, and in their success in developing machines that would sell at a profit. By the mid 1950s IBM began to pull ahead of the Bunch, and in the early 1960s it came to dominate the world market for accounting machines. IBM dominated not only in the American market, but in Europe, and Japan. A small-scale domestic industry was able to hold on in Europe, and later in Japan, only by virtue of a combination of government subsidy, a guaranteed government market, and protection.

Along with the emergence and evolution of the early computer industry mainframe, a key role was played by the emergence and evolution of the semiconductor industry, because semiconductor technology allowed major improvements in mainframes, as well as contributed to create new computer types. In mainframes, transistors had been used since the early 1950s instead of vacuum tubes. They were produced by both new specialized (merchant) firms and large existing electronic producers. These developments enabled significant improvements in mainframe performance, and some reduction in cost. The invention and development of integrated circuits enabled even further improvements in mainframe computers. With this major technological discontinuity, several new merchant semiconductor firms entered the industry, particularly in the United States. Also in this case, the American government - in particular the military and NASA - greatly supported technological change, entry of new firms and the growth of integrated circuit industry through public procurement and R&D support. Integrated circuits opened the possibility of designing computers that had a considerable amount of power, and that could be produced at a much lower costs than mainframes: minicomputers. Minicomputers opened up a new demand class which had not been tapped by mainframes, which included medium-sized research laboratories, manufacturing firms, and some small businesses. IBM lagged in getting into minicomputers, and never achieved there the dominance it achieved in the mainframe market. While the availability of integrated circuits provided an opportunity for European and Japanese firms to get into the minicomputer market, as in the earlier case with mainframes, firms in Europe and Japan lagged. American firms took a considerable fraction of the minicomputer market in Europe and Japan. With the introduction of integrated circuits IBM became fully vertically integrated into semiconductors, first with a hybrid integrated circuit technology (SLT) and then with monolithic ones. As a vertically integrated company, during the 1960s IBM continued to enjoy a major market predominance in the world's mainframe computer market.

An indirect influence on the industry was the governmental anti-trust suit carried on for more than a decade by the American Justice Department against IBM. In the mid-1960s the Justice Department undertook a suit against IBM for unfair business practices and it was sponsored by Control Data, one of the IBM competitors. The final effect (that ended only in 1982) was to push IBM "to unbundle" its software and peripherals that before were sold together as a package to the costumers.

The introduction of the microprocessor in the mid-1970s marked another punctuation in the history of the semiconductor and the computer industries. Microprocessors enabled significant improvements in mainframes. In addition they permitted the design of reasonably powerful computers that could be produced at low cost: personal computers. With microprocessors a wave of new merchant firms entered the semiconductor industry. Some of them grew very rapidly and became large international firms such as Intel. New firms entered also the personal computer industry: these included prominently specialized PC design and manufacturing firms (such as Apple, Commodore, Tandy, and Compaq). Established mainframe and minicomputer producers were slow in seeing the new market and the needs of users in that market. Interestingly, when IBM did get into microcomputers, it did so with external alliances: Microsoft for operating systems software, and Intel for microprocessors. IBM strategy was to enter as a specialized company and establish a common standard in the market through the production of a successful microcomputer (the PC). In this respect, IBM decided to buy its own components, peripherals and software from outside suppliers instead to build them internally. In this way, however, Microsoft and Intel were able to conquer the respective software and microprocessor markets in few years. IBM did manage to seize a significant fraction of the personal computer market, but never was as dominant there as it had been in mainframes. Just as in the case of minicomputers, in Europe and Japan few firms entered. And, except where there was heavy government protection or subsidy, American firms came to dominate domestic markets for personal computers.

With the introduction of microprocessors and other types of semiconductor devices - such as very large scale integrated circuits, and RAM and ROM memories - those computer producers that were vertically integrated (including IBM) exited more or less completely from large scale production of semiconductor components. Disintegration took place because the new demand for semiconductors coming from personal computer producers as well as from other uses and demand had grown greatly and in response to that a variety of highly advanced components were introduced by several merchant microelectronics firms. In addition a key firm -Intel- emerged as the industry leader for microprocessors, thus determining a de-facto standard in the semiconductor industry to which computer producers complied.

In sum, during the evolution of semiconductor and computer industries public policy has intervened in various ways: public procurement, R&D support, antitrust, support for basic research and protection of national champions (this last policy was mainly adopted in Europe). In the following pages we will examine the effects of alternative policy interventions which have or might have influenced the evolution of the computer and semiconductor industries. Before discussing these policies, we are going to present the basic structure of the model.

4. The Model

We cannot provide here a full account of the model. The reader is referred to Malerba et al. (2006) for a complete presentation of the formal model and for the details.

4.1 Computers

At the beginning of the simulation, a given number of firms enters the market and begin to design and sell computers. Computers are made by combining systems and components, i.e. semiconductors. The former are designed internally by computer producers while the latter can be also bought by specialised suppliers on the marketplace. The design of semiconductors is based on the available component technology, i.e. at the beginning, transistors, later on integrated circuits and subsequently microprocessors. A computer delivers to consumers a mix of characteristics, cheapness (i.e. the inverse of price) and performance. Their combination defines the merit of design (Mod) of any particular brand of computers.

4.2 Demand for computers

Customers of computers are characterized by their preferences about these two attributes. In the model there are two customer groups, one consisting of “big firms” who are especially interested in performance, and care less about cheapness, and the other of “small users” who are especially concerned about cheapness, and who value performance less than do big firms. These differences in preferences show up in terms of how performance and cheapness “trade off” in terms of customer evaluation of merit. However, in this model “big firms” buy only mainframes and “small users” buy only microcomputers: the two markets are completely separated in this respect. Moreover, the market for microcomputers opens up only with the introduction of microprocessors. Before that, it is technically impossible to design microcomputers.

Each customer group ("big firms and "small users") consists of a large number of heterogeneous subgroups2. Within a particular subgroup customers – a submarket - buy computers valuing its "merit", compared to other products. However, markets are characterized by frictions of various sorts, including imperfect information and sheer inertia in consumers behaviour, brand-loyalty (or lock-in) effects as well as sensitiveness to firms' marketing policies. In addition, network externalities are present: consumers – given their preferences - tend to buy products that have a larger market share. These factors are captured in a compact form by a "bandwagon effect", i.e. the share of computer brands in overall sub-markets at time t-1: the larger the share of the market that a product already holds, the greater the likelihood that a customer will consider that product. Finally, there is a stochastic element in consumers' choices between different computers.

4.3 The market for components

At the beginning of the simulation and at the time of each technological discontinuity a new cohort of firms enters the market, producing components with the latest available technology.

In each technological era the demand for components, faced by component specialized firms, comes from two sources. First, demand for components comes from users different from computer firms (e.g. consumer electronics, the military, the automobile industry, etc). The size of this external market is exogenous and different for each component technology. This external market is modelled in the same as the computer market, i.e. there is a number of submarkets to which component firms may sell. A firm gets therefore probabilistically a fraction of the total value of the external market as a function of its merit of design and of its market share.

Second, demand for components comes from computer firms which have decided to outsource component production (specialized computer firms).

When a computer firm decides to outsource components production, it starts to scan the market for potential suppliers. Suppliers are chosen by computer firms on the basis of a ranking of the merit of design of the components produced by each supplier. Given uncertainty and imperfect information, this choice is partly stochastic. Moreover, as for of computers, the demand for components is influenced by bandwagon and lock-in effects.

After having selected a particular supplier, the computer firm is contractually tied to this company for a certain number of periods. When this period expires, a new supplier might be selected, using the same procedure.

[2]These subgroups can be interpreted as collections of consumers having similar preferences or even as individual consumers.

4.4 Profits and prices and technological progress

Firms' sales determine their profits and their market shares. Prices are determined by adding a mark-up on production costs3.

By investing profits in R&D, firms improve the merit of their products. R&D expenditures are calculated following a simple rule of thumb, i.e. a constant fraction of profits. Technical progress is modelled through the "double draw scheme" used in Nelson and Winter (1982). There are two draw schemes, one for the components and one for systems, which differ only as it concerns the mean and variance of the distributions from which draws are taken4. In each period firms draw the value of their merit of design from a normal distribution. The number of draws that any one firm can take is set proportional to its R&D spending. In each period, the values of the Mod obtained through the firms' draws are compared with the current merit of design, and the higher among these values is kept. Thus, more draws increase the likelihood to get a higher merit of design for both systems and components.

The extent to which technical progress is possible for each firm, i.e. the mean of the distribution from which they draw, is defined as a linear combination of two variables: the level of publicly available knowledge (e.g.. published academic research, technical information available in specialized journals, etc..) and the value of the Mod achieved by the firm in the previous period: in other words, technological change is partly cumulative at the firm level.

4.5 Technological discontinuities

Industry evolution is marked by technological discontinuities in component technology. At the beginning, transistors are used in mainframes. Then integrated circuits become exogenously available and after some time, microprocessors.

When a new technology is introduced, a new public knowledge function becomes available. The initial level of the public knowledge associated to a new basic component technology is lower than that reached by current technology, but then it grows faster and after a certain time it overtakes the public knowledge of the older technology. As time goes by, the rate of growth of public knowledge

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[3] Costs are derived from the achieved Mod and – in the case of computers – they must be equal to the inverse of cheapness While the production costs of integrated computer producers are a function of the achieved Mod, the production costs of specialized producers are instead determined as the costs of the system plus the cost of buying the components on the marketplace, i.e. the price charged by the particular supplier from which the computer company is buying. In the model, we assume that an integrated and a specialized firm having the same computer Mod have also the same production costs for a computer. For a given component Mod, the cost of internally produced components is equal to the cost of the externally produced components. The additional costs that would be associated to the mark-up charged by component suppliers and which are "saved" by an integrated firm - are invested in R&D by integrated producers and treated as a cost.

[4] Thus, integrated firms have two technical progress functions, while specialized computer firms and component firms have only one technical progress function, respectively for systems and for components

starts to slow down until it reaches its asymptotic level. An integrated computer firm decides to adopt the new technology when the mean of its own distribution becomes inferior to the level of the public knowledge of the new technology.

New component technologies allow for the entry of new semiconductor firms. First, transistor firms enter. As they invest in R&D and the new technology improves, they will gradually become more efficient than competitors producing transistors, eventually displacing them. After some more time microprocessors are introduced and again new component firms enter the market. Microprocessors however make it possible not only to design better mainframes but also to design a new typology of computers which appeal to groups of customers relatively more interested in the cheapness rather than in the performance of the machines: microcomputers. A new generation of computer firms enters the industry, opening up the new market for microcomputers.

4.6 Vertical integration and specialization

Over the evolution of the industry, computers producers may decide to vertically integrate into the design of components or to specialize buying semiconductors on the marketplace.

The decision to produce component in-house is driven by considerations related to the relative achievable quality of the components designed in-house as compared to those offered by the specialist suppliers. However, computer firms can only conjecture about the quality of the components they might end up designing. So, the decision to vertically integrate is led (probabilistically) by the relative size of computer firms vis-à-vis the largest component producer. If computer producers are larger enough as compared to extant suppliers, they can fund a much larger flow of R&D expenditures and achieve better quality. Second, fears of supply shortages may induce vertical integration. This is likely to be the case if semiconductor firms are small. Third, the decision to vertically integrate depends probabilistically on the age of the component technology. In the early stages of development of the new technology, when specialized producers are likely to control the new technical developments of semiconductors, technical change is fast and comes from every quarter. Given the risks of getting stuck in an inferior trajectory, a computer producer is not likely to vertically integrate; rather, firms would wait and see how the new technology develops. Instead, if the technology for designing and producing components is settled along relatively well defined and established trajectories, the probability that new, superior generations of components may be frequently invented by component suppliers is lower.

Integrated producers enjoy some coordination advantages as compared to specialized producers, because they can produce components tailored to their system. As a consequence, the productivity of their R&D efforts on components is enhanced as if it were augmented by a certain factor, or spillover.

The decision to specialize is not symmetrical to the decision to vertically integrate. It is driven probabilistically by a comparison between the merit of design of the components produced internally and the quality of the best component available on the market (Best Mod), which can be directly observed. Thus, a computer firm will probabilistically sign a contract with a specialized semiconductor producer when the latter is able to design better components. This is more likely to happen in the early stages of the development of a new component technology and as semiconductor producers grow big enough to sustain a high level of R&D expenditures. The process of selection of the component supplier has been already described in Section 3.3. After signing a contract, the computer producer is tied to the component firm for a given number of periods. But, after the established length of the contract has expired, a specialized computer firm may decide to change its supplier. A specialized computer producer checks if a better supplier is available than the current one. If this is the case, a new supplier is chosen using again the rating mechanism described in the discussion of the demand module (Section 3.3).

4.7 Entry, exit and industrial dynamics

As mentioned previously, a number of firms enters the computer and semiconductor industries, when a new component technology becomes available. Firms will compete and gain sales, profits and market shares as a function of their merit of design and of their current market share. By reinvesting profits in R&D firms can improve their products. Thus, some firms will grow and other will shrink. These processes entail increasing returns on both the supply and demand side: technical progress is partly cumulative at the firm level and the probability of selling products is boosted by the bandwagon effects captured by the current market share. The larger these effects, the faster will a firm become dominant in either or both the computer and semiconductor markets.

Computer firms exit the market when their market share falls under a certain minimum threshold, which is a function of the market share that would have been held by n equal firms at the beginning of the simulation. For the semiconductor producers the probability of exiting is an increasing function of the number of consecutive periods in which it does not sell to a computer producer.

When a technological discontinuity appears, a new cohort of component firms enters competing with the older generation companies. In the initial stages, the quality of their products will be lower as compared to the incumbents. But, if the growth of public knowledge and the size of the external market are large enough, they will sooner or later displace the older generation. Otherwise, especially if the external market is small, new firms will not be able to produce competitive products and overcome the barriers posed by the bandwagon effects in demand. Similarly, integrated computer producers will adopt the new technology as soon as the level of the public knowledge is high enough.

Thus, the degree of concentration and the identity of industry leaders may change depending on the size of increasing returns on the supply and demand side, on the size of the external market for component producers and on the extent to which the new technology is superior to the old one.

The introduction of microprocessors allows also for the entry of a new brand of computer producers and the opening of a new market, i.e. microcomputers. Again, depending on the extent of increasing returns in the various markets, a dominant firm may emerge.

The relative growth of firms in the computer and semiconductor markets, and therefore the co-evolution of the degree of concentration in the two industries, will also influence decisions to vertically integrate or specialise by computer producers, thereby creating a further feedback in the model.

The decision of a computer producer to vertically integrate subtracts sales to component firms. Vertical integration will occur with a higher probability if a monopolist exists in the computer industry. If this missing demand is large – and this is the case of monopoly -and external markets are small, semiconductor firms will find it harder to make profits and to innovate. They will shrink, triggering further vertical integration by computer producers and in the end the component industry as a whole may even disappear. Conversely, a rapid growth of semiconductor firms, fuelled by the external market and/or by the demand of specialized computer producers, will allow faster innovation. This will create further incentives towards specialisation and further growth of component suppliers. If increasing returns are strong, a monopolist will be likely to come to dominate the industry, selling to all computer firms. As a consequence, the merit of design of the computer producers will become less unequal, because all of them have access to the same components. Concentration might therefore decrease.

The opening of the personal computer market adds a new twist to these patterns. Initially these new firms are quite small and, if the new producers of microprocessors enjoy a large external market and grow, they are likely to specialize creating a new demand for the component producers and fostering their further growth- and possibly the emergence of a monopolist. The personal computer industry might instead remains competitive. But, if increasing returns are high in this segment of the computer market, concentration will increase here too, possibly leading to disintegration..

5. The benchmark simulation: the history friendly case

5.1 Factors and basic mechanisms affecting the history of the industry

In order to provide a setting where the effects of policies can be conceptualised and analysed in a sufficiently transparent way, we start from a particular parametrisation of the model. Coherently with the history-friendly approach, a natural candidate appears to be a setting that attempts at reproducing the main qualitative features of the historical evolution of the computer and semiconductor industries on the basis of the causal relationships that according to the historical accounts and the interpretative framework discussed earlier (Sections 3 and 4) generated them. Thus, the history-friendly simulation will constitute the bench-mark for our policy analysis.

The story can be recounted in the following way. In the early stages of their evolution (transistor period), the two industries experienced a shake-out and concentration increased. In the computer sector, a company – IBM – soon gained the leadership and an almost monopolistic position. Concentration increased also in the component market, but no firm acquired a clear dominance. The rise of a monopolist in mainframes was sustained by significant “lock-in” effects on the demand side, which magnified early technological advantages and protected the leader from competition. The growth of the leader led quickly to vertical integration. Conversely, semiconductor producers could not exploit large lock-in effects in demand and the extent of the external market was not so big to spur an increase in their size comparable to that experienced by computer producers. Thus, a dominant firm semiconductor company did not emerge.

When integrated circuits were introduced, new component producers entered the market mastering the new technology. However in the computer market, the large dominant company retained its monopoly power. It only faced pressures towards vertical disintegration, to the extent that new component firms were able to produce better components. However, since the external market for semiconductors was still not large enough, specialized component producers remained relatively small and could not innovate as quickly as the computer leaders. Computer companies were also able to adopt integrated circuits technology very rapidly and thus they ended up producing in house again their own components.

The third technological discontinuity – microprocessors and personal computers– involved instead different conditions. First, the new cohort of component producers could benefit from a much larger external market and could then invest more in R&D. Thus, they could grow quickly and achieve high levels of quality. Second, lock-in effects in the demand for components – both in the computer market and in the external market - were much more significant in the case of microprocessors as compared to integrated circuits and transistors. As a consequence, a dominant component producer emerged in this era. Third, the introduction of microprocessors marked a sharp technological discontinuity, which allowed to design much better components than those based on integrated circuits. Thus, the new entrants could supply vastly superior products so that catching up by integrated mainframe producers was slower. Fourth, microprocessors made it possible to design and start selling a new – previously unattainable – type of computers: personal computers. Thus, a whole new class of customers, who attribute much more value to cheapness than to performance, started buying the new type of computers: the PC market opened up and grew rapidly. Quite soon a large dominant specialized microprocessor supplier began to emerge, as a consequence of the demand by PC makers and of the presence of large external market. The rise of a strong and large microprocessor firm soon made it costly and risky for mainframe producers to continue to design and produce their own microprocessors. This led to vertical disintegration also in the mainframe industry. Fifth, lock-in effects on the demand side were less important in the case of PCs as compared to mainframes: hence, no PC producer could establish and maintain a dominant position becoming large enough compared to the leading microprocessor producer to make vertical integration reasonable. As a result, PC computer firms remained specialized.

5.2 The history- friendly simulation

In sum, the history-friendly simulation is based on the following assumptions on the relevant variables and parameters and on their values: the size of the external market is relatively small in the case of transistors and integrated circuits and significantly higher for microprocessors; lock-in effects in demand are very important for mainframes and much less so for microcomputers; demand for microprocessors is subject to much stronger lock-in effects as compared to transistors and integrated circuits; the introduction of microprocessors allows much higher improvements in component designs as compared to the older technology: this technological discontinuity is much sharper than the previous one.

// FIGURES 1 AND 2 ABOUT HERE //

Under this parametrization, this "bench-mark" simulation replicates the key aspects of the story. Figures 1 and 2 show averages over 100 runs[5] of the Herfindhal index and the integration ratio (the ratio of number of vertical integrated firms over the total number of firms in the industry). A dominant firm emerges quickly in the mainframe (MF) industry and tends to become vertically integrated relatively early. In the semiconductor (CMP) industry, concentration rises as demand from computer producers exert selective pressures and firms leave the market. At the time of the introduction of integrated circuits (IC), new semiconductor companies enter the market and

[5] We ran 100 simulations, as it is almost customary in the literature, even if the variance of the results stabilizes at very low levels after 30 runs. To provide a rough idea of the magnitudes involved, the variation coefficients (standard deviation/mean) computed at the end of the simulation is equal respectively to .0001 for the Herfindahl index in the mainframe market, .03 for the Herfindahl index in the PC market and to .13 for the Herfindahl index in the semiconductor market. Similar values are obtained for the best and average merit of design. The variation coefficient is somewhat larger for the integration ratio, although it varies substantially over the periods of the simulation.

concentration drops sharply. However, the dominant mainframe firm remains vertically integrated, because the external market is not large enough to sustain a significant growth of the new entrants and of the quality of their components. The absence of a demand from the mainframe producer induces a shakeout and concentration gradually begin to increase again in the semiconductor market. When vertical integration is complete in the computer market, the semiconductor producers are left with no demand and exit this market. As a consequence, concentration falls to zero. The third technological discontinuity sets in motion a different story. Microprocessors (MP) constitute a major technological advance as compared to integrated circuit and a large external market supports significant improvements in the quality of the new components. Moreover, the PC market opens up, generating a substantial new demand and fuelling further advances in the merit of the components. As a consequence, the computer leader decides to specialize, adding a new large demand. Finally, lock-in effects in the demand for microprocessors are now significant. Hence, a dominant firm emerges also in the semiconductor market. The establishment of a monopoly in the supply of components contributes however to maintain competition in the PC market, since all firms get their microprocessors from the same source: concentration increases but no firm comes actually to dominate the market. In the last periods of the simulation, as the microprocessors technology matures, the incentives towards specialization become slightly less compelling and, in some simulations, the mainframe firm and some PC producers decide to vertically integrate[6].

6. The effects of alternative policies in the model: some general remarks

6.1 The effects of public policies in a dynamic co-evolutionary setting

In a dynamic co-evolutionary setting such as the one examined in the history friendly model presented above, a first fundamental issue has to do with the dilemmas involved by the presence of path-dependency in the evolution of industries and technologies characterized by network externalities. As vividly illustrated by Paul David (David 1986), here the policy-maker can be described as a “Blind Giant” (small interventions in the early phases of the development of competing technologies are likely to bear long-lasting and possibly permanent effects, as they push dynamics along one of the possible paths and towards one of the multiple equilibria); facing “narrow windows” of opportunities (policies can simply have no effects and/or be too costly if a specific, irreversible path has been already established itself). But monopolies generated by path-dependent processes can be weakened and even

[6] We conducted analyses of variance, sensitivity and robustness on the history friendly simulation with satisfactory results. These results are reported in Malerba *et al* (2006)

destroyed if major technological discontinuities occur frequently enough and agents are sufficiently heterogeneous (Bassanini and Dosi 2006)[7].

In a similar vein, in a previous paper concerning the evolution of the computer industry (Malerba *et al*. 1999) we examined the effects of the timing of antitrust policy. “Early” intervention had almost no effect in that model, because a new monopolist emerged very soon. “Late” intervention succeeded in generating a duopoly, because increasing returns on the supply side were fading away by that time. In general, anti-monopolistic action had only small and transitory effects. The reason of this “policy ineffectiveness” result lay in the strongly cumulative nature of the market. Small initial advantages tend to grow bigger over time and catching up is almost impossible. Leaders do not only have a “static” advantage: they run faster than laggards. Thus, traditional antitrust policies in a static equilibrium framework are somehow designed to “leveling the playing field”. But this may not be sufficient. In order to get results, some form of “positive discrimination” may be necessary . That is to say, policies should make competitors able to run (much) faster than the monopolist, and not just remove static disadvantages.

Thus, understanding the efficacy of alternative policies characterized by both increasing returns on both the supply side (cumulative technological change at the firm level) and on the demand side (network externalities) coupled with sudden (and unexpected) technological discontinuities and heterogeneity in demand (presence of differentiated preferences for products embodying different characteristics) is intrinsically difficult and important, both for theory and for practice.

On top of this discussion one has to notice that public policy should not be limited only to antitrust policies. Industries and firms are subject to other types of relevant policies, which have a variety of effects on several industry and firm variables. We just mentioned public procurement. In the USA, public procurement has been acting in several occasions as a tool for fostering innovation and has had as indirect consequence the entry and growth of new highly innovative firms, although it has often not been considered as an explicit industrial policy. In Europe, several programs have been traditionally used for supporting firms’ competitiveness and innovativeness, either selectively or at the level of the industry as a whole. Other policies have been trying to affect the entry rates of new innovative firms in an industry. In addition support for basic research and for the diffusion of new technologies are also systematically used policies that may produce unexpected results. Also in these cases the side effects of policies could be relevant. Thus, for example, public procurement in an upstream sector might sustain the growth of specific companies and even the emergence of dominant

[7] Bassanini and Dosi (2006) show that asymptotic patterns of the dynamics of competing technologies depend on the relative impact of unbounded increasing returns and the degree of heterogeneity of the population of adopters. Moreover, in a market characterised by high technological dynamism, technological shock can occur before convergence to the notional limit market share of the dominant technology has been actually approached.

firms. The presence of a monopolist in this industry might further impact on the downstream sector in ways that depend crucially on the specific nature of the linkages between technologies and firms in the two industries. Conversely, public procurement could allow for the growth of firms and new technologies which could not otherwise survive, leading to vertical disintegration in the upstream industry and perhaps stronger competition.

Within the history-friendly model presented above, alternative policy interventions might have rather different effects according to the specific parametrization that is used. However, on the basis of both the history of the industries and of the discussion of the model, it is possible to identify a few crucial policy objectives, instruments, variables and processes that are likely to influence the transmission mechanism of policies and their effects.

The key policy objectives are here competition and technological change. However, these two goals may well entail the classical Schumpeterian trade-off, if large firms are more innovative than small ones.

The policy instruments that we going to examine are those that figured prominently in the history of the computer and semiconductor industries. It is useful – and customary in the literature- to distinguish among interventions on the supply side and on the demand side. Supply side policies are support of basic research, diffusion of knowledge among firms, antitrust and actions favouring entry of new companies. Demand side interventions are support of open standards and public procurement.

The main variables that in the model can affect the efficacy of these interventions are in turn:

a) the strength of forces that create increasing returns, i.e. the degree of cumulativeness in technological change and the bandwagon effect on the demand side;

b) the timing of the arrival of the technological discontinuities and their magnitude, i.e. how better they are and how fast they become superior as compared to the old technology;

c) the degree of heterogeneity of agents, in particular as it concerns consumers;

d) the interactions between the upstream and downstream industries.

A first key set of factors is given by the forces that create increasing returns, i.e. the degree of cumulativeness in technological change and the bandwagon effect on the demand side. When the coefficients of these variables are high, tendencies towards monopoly are strong. Interventions to curb monopoly power that do not change the underlying conditions are likely to have at the very best only temporary effects, because the forces leading to concentration will continue to operate recreating quite soon new monopolists. Thus, support of basic research- in the form of higher rates of growth of public knowledge- is likely in this case to increase the rate of technological change, but to have a very little impact on the degree of concentration, to the extent that knowledge is accessible to everybody. If anything, concentration might increase, since industry leaders can magnify their advantages through higher innovative opportunities, and consequently also the gap between best practice and average practice.

Under these conditions, antitrust intervention might be efficacious only –or mainly – in the sense of making monopoly power contestable, to the extent that the former monopolist is not able to regain dominance. As mentioned above in the general discussion, the timing of the intervention may be important in this respect. Early intervention might be likely to be more successful in displacing a dominant firm and in allowing competition to select a new leader. However, in practice, antitrust actions that take place before a monopolistic position has actually been attained are obviously very hard to justify.

When technological change is highly cumulative and the bandwagon effect is strong, also policies supporting firms – either in favouring the entry of new firms are likely to be ineffective: entrants may find insurmountable barriers to their survival and growth, unless they are carriers of superior technologies, i.e. especially at times of technological discontinuities.

Conversely, policies that weaken the sources of increasing returns are likely to be more effective. Thus, interventions aiming at favouring the diffusion of knowledge could limit the tendencies towards concentration because they attenuate one of the forces generating increasing returns: the ability of firms to take advantage of their innovations is reduced. Similarly, support to open standards – as it curbs bandwagon effects – should significantly impact on monopoly power. The overall effect on the rate of technological change depends then on the size – if any –of the Schumpeterian trade-off.

Both monopoly power and the rate of technical change can be deeply affected by the timing of arrival and by the magnitude of technological discontinuities. If radical technological breakthroughs occur frequently, monopolistic positions are inherently threatened, at least unless industry leader are able to adopt quickly the new technology. However, the take-off and the subsequent diffusion of the new technologies depend on how better they are as compared to the old generation and on the existence of markets, like external markets and/or consumers interested in the specific features characterizing the new technology (such as cheapness rather than performance in our model). The external market and the microcomputer market might allow the new technology to improve and become competitive. Thus, policies are likely to be more effective at times of technological ruptures, even though they might be less needed (monopolistic positions are already under threat) and more difficult to design (is the new technology really better than the old one?)

Finally, all these effects are crucially mediated by the feedbacks between the upstream and downstream industries, i.e. in the model the rules governing vertical integration and specialisation. These interactions determine how policies in one sector transmit their effects on the other. Thus, as argued previously in Section 2.1, policies directed towards one industry may induce consequences – sometimes unintended- that might weaken or strengthen the initial effect.

6.2 The indirect and the unintended consequences of policies

Issues become even more difficult to examine if one considers also the side-effects of policies on horizontally and vertically related sectors. Some of these “indirect” consequences may be hard to predict and surprising, but very important in practice and perhaps perverse in evolutionary, dynamic environments characterized by increasing returns and heterogeneous agents. In a previous paper (Malerba et al. 2005), we discussed for instance how the existence of heterogeneous consumers and of a horizontally related market (e.g. computers and PCs) can allow for the survival and eventual dominance of new, superior technologies that would otherwise have failed to take-off. In this context public procurement can play the role of some of these (key) heterogeneous consumer and therefore be responsible for the emergence of new superior technologies.

A similar issue refers to the unintended consequences of policies. For example, the destruction by policy of a monopolistic position in a downstream industry could entail the unintended consequence of bringing about the emergence of a new monopolist in an upstream sector which supplies components to the downstream industry. This might happen if increased competition in the upstream industry (consequent to e.g. the divestiture of the downstream monopolist) induced vertical disintegration and hence the rapid growth of a dominant upstream supplier, fueled by cumulative innovation and lock-in effects on the demand side. Conversely, antitrust intervention might kill two birds with the same stone: the elimination of an upstream monopolistic supplier could leave room for the growth of new products and technological solutions that allow new competitors to grow and challenge the dominant position of a downstream monopolist. There could be cases in which the interaction between horizontally and vertically related markets might induce even more drastic consequences of policies, like the disappearance of an entire upstream industry. For example the elimination of a monopoly in the upstream industry which serves only a downstream market may induce vertical integration by all firms in the downstream industry and thus the elimination of the entire demand directed to the specialized upstream producers.

7. The simulations of public policies in dynamic interdependent markets

As mentioned previously in Section 6, the policies examined in this paper have the goal to increase the rate of technical change and/or to foster competition and reduce monopoly power. In the current parametrization of the model there is actually a Schumpeterian trade-off between the two objectives: larger firms can invest more in R&D, thereby increasing the chances to obtain technological improvements. As mentioned earlier, we also distinguish supply side and demand side oriented policies.

The first group – supply side policies – includes:

A) higher support for public basic research, in order to increase the rate of technological change;
B) fostering the diffusion of knowledge among firms, with the goal of facilitating the access to knowledge and – possibly – to weaken the tendency towards monopoly;
C) break monopolies, in order to foster competition;
D) support the entry of new actors, so that a monopolistic position can be challenged.

The second group – demand side policies – includes:

E) support open standards so that lock –ins are avoided;
F) use public procurement in a selective way, so that the most advanced technologies are supported;
G) use public procurement as an additional market, in order to provide larger markets and opportunities for firms' growth and innovation.

We will first examine these policies with reference to the benchmark (the history friendly) simulation.

As mentioned above, we will examine the effects of policies on two policy targets: rate of technical change (in terms of best technology and average technological level in the industry) and market concentration. However we will also observe the changes in the boundaries of firms. These may not be a direct policy target; however a consequence of policies may have profound effects on the degree of vertical integration and specialization and thus affect the disappearance or growth of specialized firms.

Policies may target the system industry (computers) or the component industry (semiconductors), or both. We will discuss the type of policy that present the most interesting results. Our exercises will report results of averages over 100 runs[8].

[8] Also for the policy simulations, we conducted analyses of variance, sensitivity and robustness. Results do not differ from the ones obtained for the history friendly simulation.

7.1 Policies on the supply side

7.1.1 Support for basic research

Public policy may support public investments in basic research in the system and in the component industries. Results of advancements in basic research become available to all firms. In the model, this is implemented by increasing the rate of growth of public knowledge in both system technology and component technology.

As expected, the support for basic research has a major effect on the technological performance of both the best technology (merit of design - Mod - in the language of our model) and the average technological level of the industry (average merit of design –AvMod- in the language of our model) of both computers and semiconductors increase compared to the standard case. (Figures are not reported here). As a consequence of the logic of our model, the gap between the best and average practice increases.

However, this intervention has no effect on concentration: higher levels and faster growth of public knowledge raise the basic opportunities for innovating, but increasing returns on the supply and demand side continue to create tendencies towards concentration[9]. Thus, in the mainframe market, a monopolists emerges again quite soon, obtaining a higher level of merit of design in both its internally produced components and in its systems. Therefore, after each discontinuity in components (and particularly with microprocessors) the vertically integrated mainframe monopolist is able to remain integrated for a while – instead of specializing soon. Over time, however, microprocessors produced by merchant producers driven by the PC market and the external markets have a higher quality than the microprocessors produced internally by the vertically integrated mainframe producer and lead the computer monopolist to disintegrate. In the same vein, no changes in concentration appear in the personal computer market with respect to the benchmark simulation.

7.1.2. Increase the diffusion of knowledge

Public policy may want to favor the diffusion of knowledge among firms within both the system and the component industries, so that a relatively high technological base is common to all system and component firms. In the model this policy is represented by making technical change less cumulative at the firm level, so that the rate of growth of the merit of design depends mainly on the growth of the public knowledge[10].

[9] A fundamental result obtained in Nelson and Winter (1982) model was that higher innovative opportunities led to higher levels of concentration, because innovators could make bigger technological advances and on these bases obtain larger market shares. Cumulativeness in technological change compounded this effect. In our model, this effect is less visible simply because concentration is already extremely high.

[10] Literally, the implementation of the simulation has increased the role of public knowledge compared with private one, more than actually diffusing knowledge among firms.

Not surprisingly, policies favoring knowledge diffusion have indeed the effect of reducing the gap between best and average practice and therefore also the overall level of concentration in the semiconductor market in the era of microprocessors and in the PC market (see Figure 3). To put it simply, an important source of increasing returns has been weakened. Yet, no effect on concentration appears in the mainframe industry, where monopoly continues to exist. Here, the bandwagon effect is so strong that concentration remains unaffected.

However, these policies have also the effect of reducing the rate of growth of both the average Mod and especially of the highest Mod of computer and component producers. Lower levels of cumulativeness imply that firms find it harder to do much better than public knowledge This effect becomes particularly important as times goes by after each discontinuity has occurred, i.e. when cumulativeness in innovation begins to exert its impact.

// FIGURE 3 ABOUT HERE //

7.1.3 Antitrust policies on the supply side

Antitrust policies have the aim of reducing a high level of concentration in the market. In our model antitrust authority intervenes only once as soon as the monopolist reaches a share of 70% of the market[11]. It acts by breaking the monopolist in two. The two new firms originating from the old monopolists have half of the size and half of the resources of the previous monopolist. They maintain however the same position in terms of the merit of design of the previous monopolist. In our model antitrust intervenes mainly in the system market (mainframes) and in the component market (microprocessors).

Antitrust intervention does not have any effect on market concentration. The reason is that the new firms originating from the monopolist are still larger than competitors and have higher technological capabilities (merit of design). Thus, one of the two firms gains very quickly advantages over the other one, driven by the bandwagon effect in demand, and the market concentrates quite soon again. Results (not reported here) show that the Herfindahl index, the average Mod and the boundaries of firms do not change with respect to the benchmark simulation.

In the setting of this simulation, antitrust has only the effect of making monopoly contestable, even though a new monopolist still originates form the old one. In order to maintain competition, antitrust should intervene each time a firm gains a monopolistic position or even before that. This kind of behaviour would be in practice quite difficult to justify.

[11] Given the feature of our model, the 70% share could be set higher or even somewhat lower without changing the features of the results.

7.1.4 Support for entry of new firms

Policies may support the creation of new firms (e.g. through programs funding new risky initiatives) in order to increase competition and to foster a variety of approaches to technological advance and product development. In our case, these policies are modelled in two ways: by doubling the number of firms entering after each discontinuity in the computer and in the component market; or by having every forty periods twelve new firms entering each market. In this latter case, new firms enter having the average merit of design present in the industry.

The increase in the initial number of firms in the mainframes and in microprocessors markets does not provoke any significant change with respect to the benchmark simulation, in terms of both the rate of technical change and concentration. One leader emerges in any case, due to the bandwagon effect at the demand level and to cumulativeness of technical advances, although the initial growth in concentration is slower compared to the benchmark simulation. The case of periodic entry generates different results in the microprocessor industry, but not in mainframes. In microprocessors, periodic entry does not change the leadership of the largest firm, but reduces industry concentration by greatly increasing the number of firms that are active and survive in the industry (see Figures 4 and 5). The reason is that bandwagon effects are weaker than in the mainframe market and the new emerging semiconductor leader cannot exploit from the beginning such a large market share as the one already conquered by the mainframe monopolist. Hence, new entrants in the component markets compete with a leader which is still building its dominant position and they are therefore able to survive. The later cohorts of entrants, though, find it increasingly difficult to compete.

This case illustrates the relevance of the timing of intervention and the subtleties involved in this respect. In industries characterized by strong increasing returns, a larger initial number of firms can at its best slow down the process of monopolization, but it has no impact in the long run. Laggards will exit soon from the industry, as their merit and design and market share cannot grow much as compared to the leader. The result concerning continuous entry in the microprocessors market is more puzzling and interesting. Why can instead the entry of new firms – as contrasted with an increase in the initial number of firms - limit the tendencies towards monopoly even in the long run? Given that increasing returns are sufficiently weak to allow for a gradual process of concentration, the early new cohorts of firms enter with a level of the merit of design which is higher than that attained by initial laggards and sufficiently high as compared to what has been achieved by the emerging leader, to provide them with a chance of surviving. Moreover the market size for microprocessors is rather large, because it is composed by the demand coming from the specialized mainframe producers and PC producers, and by the external market, so that the survival and growth of successful new firms is possible. In simulations (not reported here) where the new cohorts of firms enter with a merit of design lower than the average, they will not in fact be able to survive. In any case, the latter cohorts of entrants are so small in terms of market shares as compared to the now established leader that they cannot compete any longer.

On the contrary, no ma major change in concentration takes place in the personal computer industry and in the degree of vertical integration of computer producers. Finally, because new firms enter with an average mod, the average mod of the industry is slower that in the benchmark simulation[12].

FIGURES 4 AND 5 ABOUT HERE.

7.2 Policies on the demand side

7.2.1 Reduction of lock-ins and support for open standards

This type of policy on the demand side aims to break lock-ins effects and to promote open standard in both computers and components. In the model, the bandwagon effect – the main source of increasing returns and hence of concentration in the model - has been eliminated in both the computer and component markets.

The effects on concentration are significant. The Herfindhal index in both the mainframe and microprocessor markets drops significantly. As a consequence of the reduction in concentration in microprocessors, also concentration in personal computer is lower, because no microprocessor leader is present boosting the growth of some PC firms (although the difference is not as strong as in the case of mainframes (see Figure 6)).

Also the effects on the boundaries of firms are significant. The reduction in concentration in mainframes reduces the size of the leading computer firm and therefore also the degree of vertical integration (see Figure 7).

A consequence of this policy however is a reduction in the best and average merit of design of mainframes. In fact the leader is not big enough to support high R&D expenditures, and therefore technical advance is not so high as in the benchmark case.

This case illustrates the critical Schumpeterian trade-off between innovation and concentration involved also in a policy that aims to reduce demand lock-ins and support open standards. We shall come back to this issue in the next section.

// FIGURES 6 AND 7 ABOUT HERE //

[12] This discussion on entry did not explicitly consider one of the key features of entry: the possibility that entry increases the variety of approaches in terms of new compositions in the product characteristics space (in terms for example of cheapness and performance). The current version of the model presented in this paper does not allow to test for this possibility without adding new complications. Such an analysis would require another paper.

7.2.2 Selective public procurement

Public policy may also intervene through public procurement: for example, government agencies purchase components or computers from one specific firm in the market. In the simulation, this case is represented as a selective public procurement buying from the best component producer for a certain number of periods. Specifically, the government buys from the producer with the best merit of design for ten consecutive periods. We examine this policy particularly when a dominant leader does not exist. This is the case of transistors and integrated circuits. In mainframes and microprocessors a leader emerges and this policy would obviously amplify its advantages.

In components (transistors and integrated circuits) the result of this policy is a higher merit of design (in terms of best and in terms of average merit of design). However, the increase in the merit of design of the best semiconductor producer has also the additional effects of an increase of concentration in the component industry: this is again the Schumpeterian trade-off at work. Higher concentration in components in turns leads to a decrease of vertical integration by mainframe producers, since the high merit of design achieved as a consequence of public procurement by the best semiconductor producer induces some vertically integrated mainframe firms to specialize (Figures 8, 9 and 10).

In sum, selective public procurement has two effects on the market – an increase in the merit of design of semiconductors and an increase in the number and importance of specialized merchant producers in the component market-. However these two effects take place at the expense of creating temporary monopolists in semiconductors.

When public procurement stops however, the leading mainframe producer regains a major size advantage over the component monopolist and vertical integration takes place again - as in the benchmark history friendly simulation. Thus, in this model public procurement has to be permanent in order to be effective on the merit of design and specialization.

// FIGURES 8, 9 AND 10 ABOUT HERE//

7.2.3 Permanent public procurement as an additional market

Compared to the previous one, a different public procurement policy is the creation by the government of a permanent additional demand for components. This additional demand is satisfied by competing firms in the industry. In this case, the government creates an “external” market which represents an addition to the demand coming from computer producers. Again, for reason similar to the ones presented above, it is interesting to examine the effects of this type of policy in transistors and integrated circuits.

Results are striking. During the transistor period, when an external market is added, the mainframe industry is not highly concentrated yet and not strongly vertically integrated. The result of this policy is to increase the survival of a higher number of transistor firms as compared to the benchmark case.

On the contrary, when an external market is added during the integrated circuit period, concentration in mainframes is already very high, with a leading monopolist. This large firm is already buying components from few component producers, who have become market leaders also due to their relationship with the mainframe monopolist. The effect of public procurement is to reinforce the existing leadership in components, thereby increasing concentration in the component industry. Thus, the new additional market created by public procurement increases the merit of design and the size of the leading semiconductor producer. This in turn curbs the tendency to vertical integration of the mainframe monopolist, and fosters specialization in computers and in components (Figures 10, 11 and 12)

// FIGURES 10, 11 AND 12 ABOUT HERE //

8. The unintended consequences of public policy: some exercises

8.1 The Schumpeterian trade off

A first type of consequence in the same industry refers to the classic Schumpeterian trade-off. In industries with high technological opportunities and increasing returns, policies aiming at reducing market power or aiming at increasing the rate of technical change may reach their goals, but at the same time they may create a new policy problem. A reduction in market power (due to antitrust policy or other policy competition increasing) might be associated with a reduction in the rate of technical change because the size of the leading firm is greatly reduced, investments in R&D are lower and technological advance is consequently reduced. Similarly, policies aiming at increasing the rate of technical change by supporting the most innovative firms may end up generating market power and monopolies because the advantages given to the most innovative firms generate market power and lead to dominant positions in the market. In our paper, cases of Schumpeterian trade-offs have already been shown in the case of reductions of lock-ins at the demand level and selective public procurement

8.2 The creation of open standards in computers leads to the emergence of concentration in components

However, policies may have unintended consequences across horizontal and vertical markets due to inter-industry interdependencies. One example is the following. Let's suppose that a policy aiming at fostering open standards through the elimination of the bandwagon effects reduces concentration in all industries. However, lower concentration in mainframes may have as a consequence a reduction in vertical integration and an increase in the demand for microprocessors from the previously integrated large mainframe producers. As a further consequence, a de-facto standard concerning the interfaces between components and systems might arise, showing itself in the form of the emergence of a bandwagon in component demand. This market-driven increase in bandwagon in microprocessors created by the additional demand from large specialized computer producers may generate concentration in the microprocessor markets. (Figures 13 and 14) This is indeed an unintended consequence of policy.

// FIGURES 13 AND 14 ABOUT HERE //

8.3 Antitrust policy in computers leads to the emergence of a monopolist in a related system market and the disappearance of a the merchant component industry.

Another case of unintended consequences may refer to the disappearance of a related industry as a consequence of public policy. If an antitrust policy breaks the mainframe monopolist in two and if one of the two producers diversifies into personal computers, a new large producer enters this industry with a relevant brand name. Because of its size, reputation and marketing capabilities, this producer is able to increase the level of the bandwagon effect in the personal computer industry and become the leader in this industry. This is a first unintended consequence of public policy.

In addition, the new personal computer monopolist may become vertically integrated into microprocessors. This may lead to the disappearance of the microprocessor industry, if there are no other external markets for semiconductors. This is the second unintended consequence of the policy (Figures15 and16). Thus, a policy intended to curb monopoly power in a system industry provokes the diversification of the ex-monopolist from one system industry to a related system, the creation of monopoly in that second system industry, a drive towards vertical integration and the total disappearance of the merchant component industry.

// FIGURES 15 AND 16 ABOUT HERE //

8.4 Open standards in systems lead to the emergence of a merchant component industry

A final case refers to a policy intervention in a highly concentrated computer industry, characterized by high bandwagon effects in both the mainframes and personal computers markets. Therefore, the two industries are highly concentrated, with large firms that are vertically integrated. Let's suppose that there is no external market for components: therefore no merchant component industry is present (one could take the outcome described in Figure 15 and 16 as this initial situation of the industry). A policy of open standards in both mainframes and personal computers (which drastically decreases the bandwagon effect) has the consequence (as seen before) of increasing competition in the computer industries. An unintended consequence of public policy however could be the following. The reduction of concentration and the decrease of the size of the leading computer firms lead to a decrease of vertical integration and the switch to specialization by the system industry. The new demand coming from the now specialized computer producers create a new market for components and the emergence of an independent merchant component industry. (Figure 17 and 18)

// FIGURES 17 AND 18 ABOUT HERE //

9. Conclusions

This paper has examined the role of policy in dynamics, interdependent markets, characterized by heterogeneous agents, cumulative technical advance at the firm level, major technological and demand discontinuities and demand with lock-ins and network effects. We did that by using a history-friendly model of two related industries- computers and semiconductors. Within this context we have explored the effectiveness of different types of public policies.

In particular, we have shown that public policies on the supply side have different (and contrasting) effects on the various policy targets. We have shown that support for basic research increases industry technological performance. On the contrary, policies that favor the diffusion of knowledge reduce the gap between the best and the average practice in the industry, but also the growth of the best design in the industry. Policies that favor the entry of new producers have the effect of decreasing concentration - but not of changing the market leader in the market - only if they take place on a continuous base. Antitrust policies do not have a major effect on concentration, because the rate of technological change coupled with strong bandwagon effects at the demand level soon recreates a monopolistic situation. In general, policies on the demand side seem to affect concentration more than supply side interventions. In particular, policies of open standards diminish lock-ins and reduce concentration, and at the same time they increase firms specialization in the industry. Selective public procurement focusing on the best firm may indeed foster the development of products with a higher quality, but they have long term effects only if they are done on a permanent basis. Public procurement acting as an additional “external” market for semiconductors increases product quality, and at the same time increases specialization.

We have also shown that in the same industry the side effects of policies might be extremely relevant. The conventional Schumpeterian trade off between technological change and industrial concentration is a first example. In industries that have the characteristics presented above the reduction of concentration usually implies a lower the rate of technical change. Relatedly, policies fostering a very high rate of technical advance may end up creating a highly concentrated industry. This represents a key policy dilemma in dynamic industries, that have to be examined with a finer grained analysis.

Finally, we have stressed the potential unintended consequences of public policy across horizontal and vertical markets. In dynamic interdependent markets policies that aim at a specific industry may provoke major changes in a related sector through the product market, the changing boundaries of firms and technological interdependencies.

Clearly, our results are very specific to the particular model that we have been using and to its parametrization. Different conclusions would be reached for analyses of different industries and alternative models. In this respect, history friendly models offer – we believe – a useful starting point for discussions of the effects of policies in other sectors and – on these bases – for attempts at generalizations. However, even within the scope of the model used in this paper, this discussion highlights the complexity of policy analysis and design in dynamic, co-evolving markets. Further work is needed to understand better these difficult but important issues.

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FIGURES

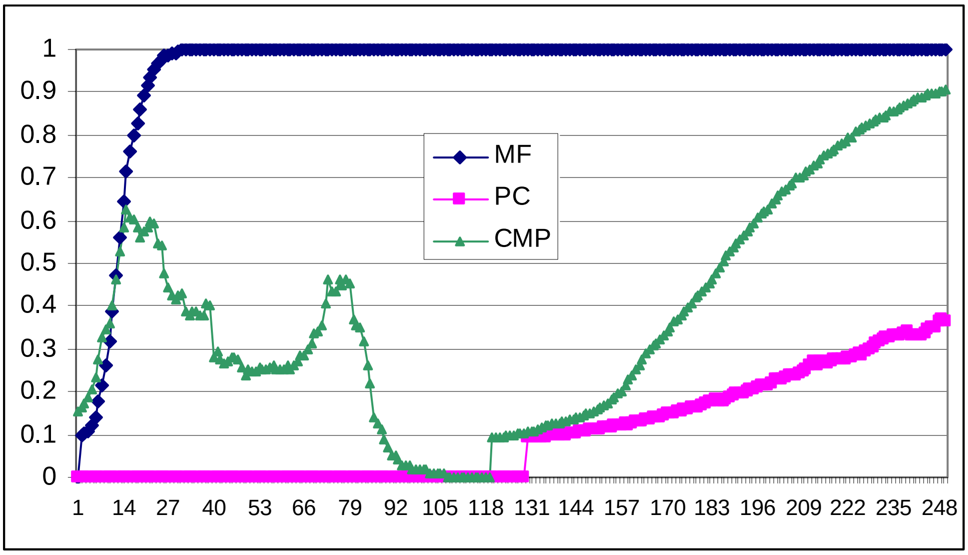

Figure 1 – History Friendly simulation: Herfindahl index in mainframes MF, personal computers PC and components CMP

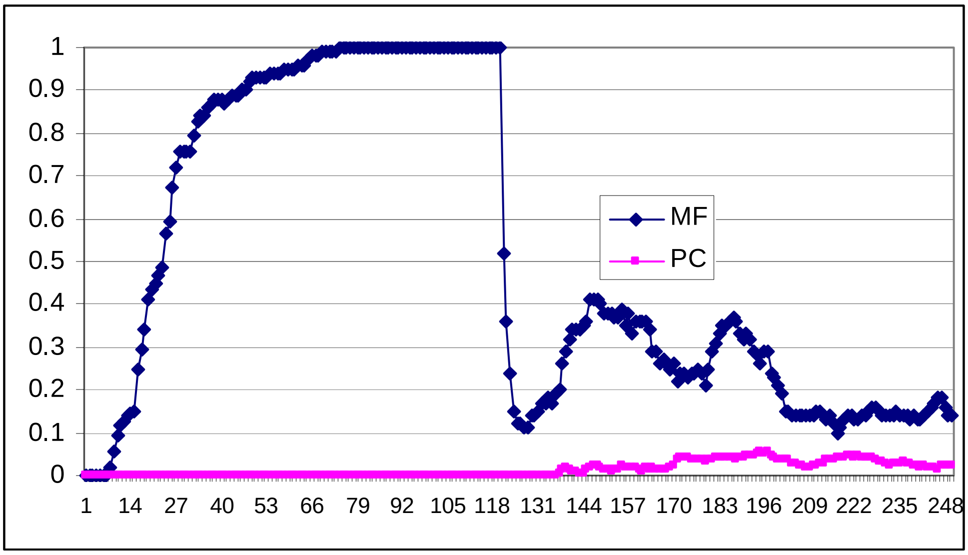

Figure 2 – History Friendly simulation: integration ratio (ratio of number of integrated firms over total number of firms)

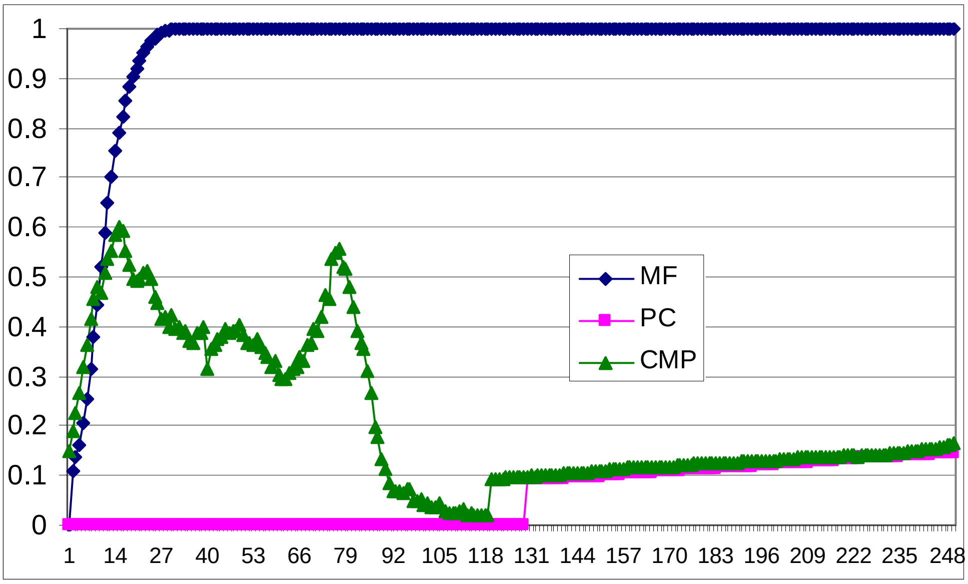

Figure 3 – Increase the diffusion of knowledge: Herfindahl index

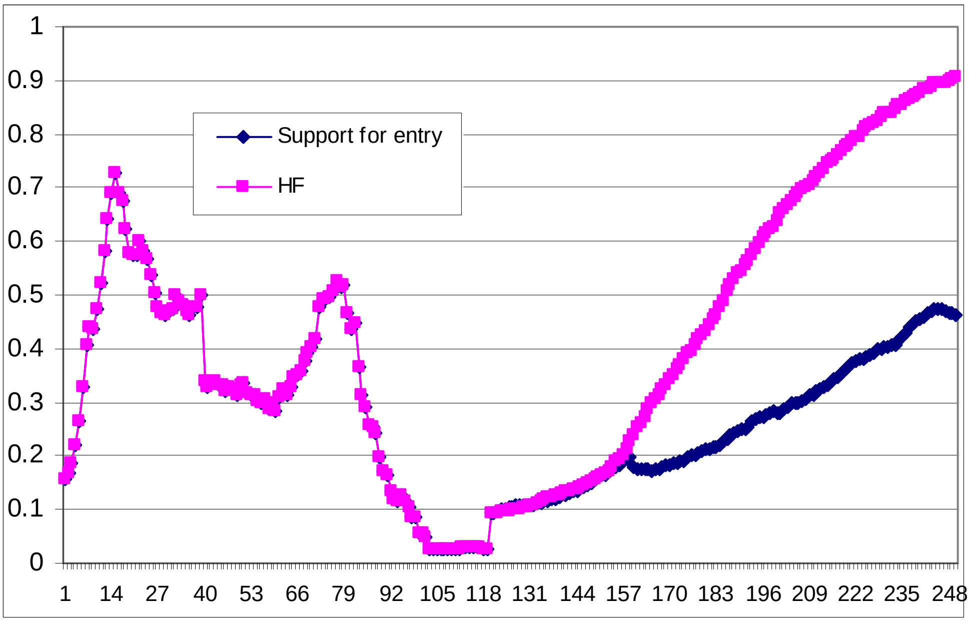

Figure 4 – Support for entry of new firms in microprocessors: Herfindahl index

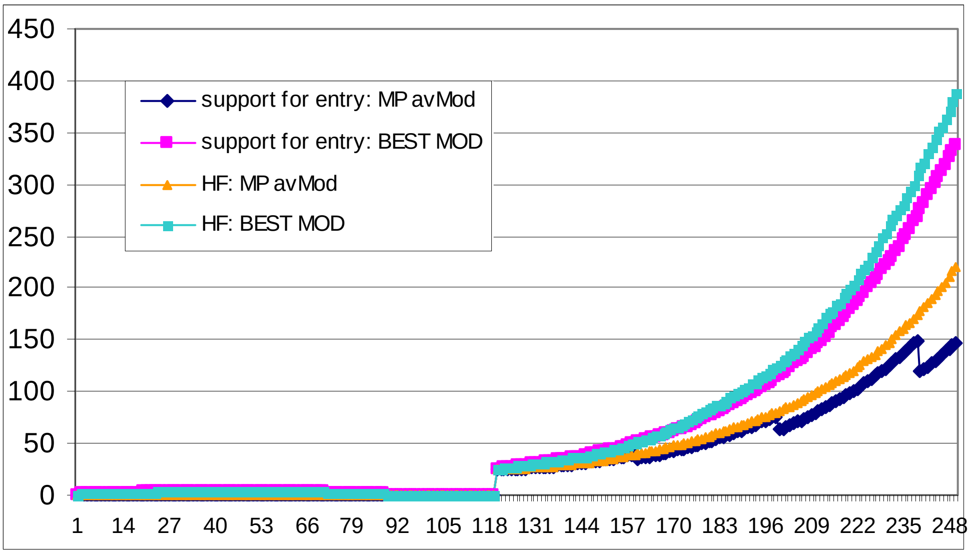

Figure 5 – Support for entry of new firms in microprocessors MP: average Mod (avMod) and best mod (BEST MOD)

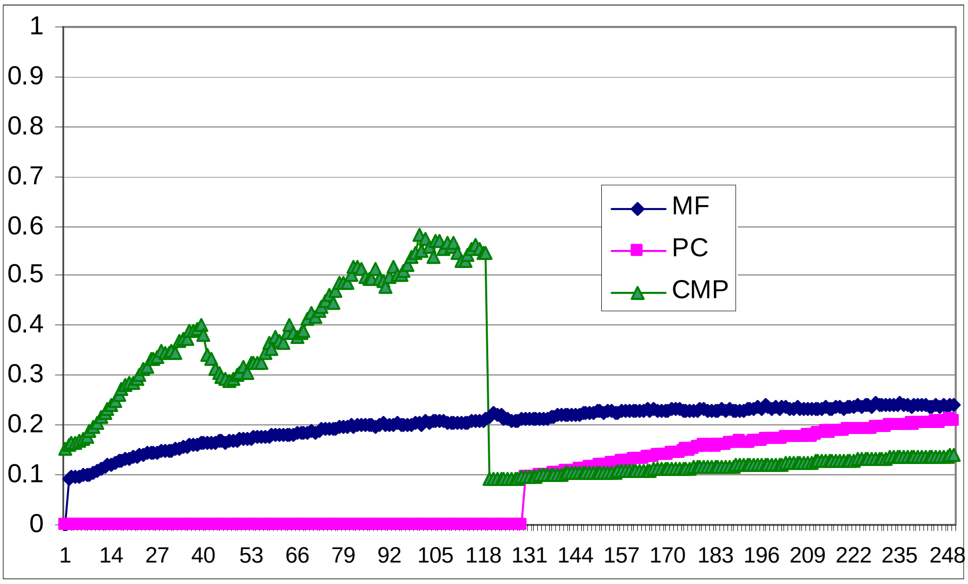

Figure 6 – Support for open standards: Herfindahl index

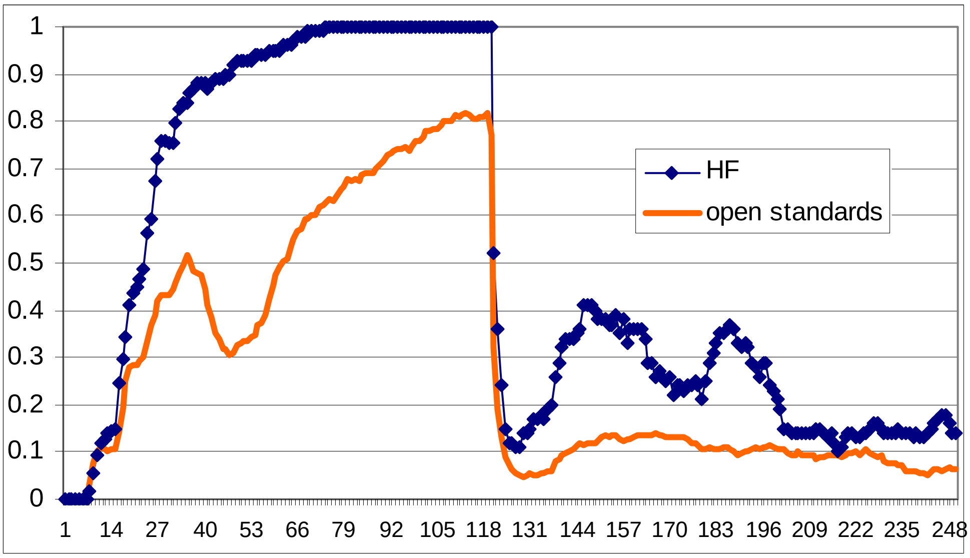

Figure 7 – Support for open standards: integration ratio

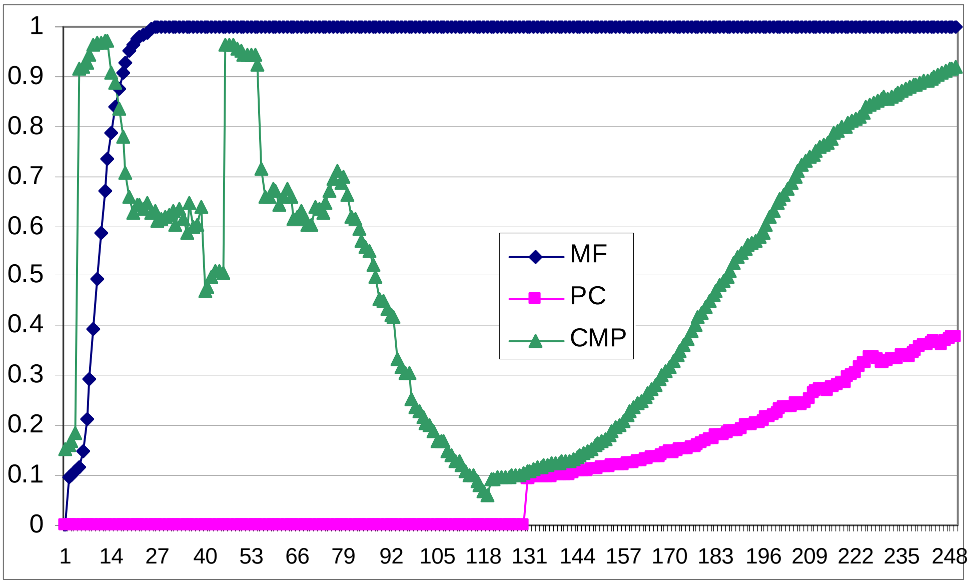

Figure 8 – Selective public procurement in transistors and integrated circuits: Herfindahl index

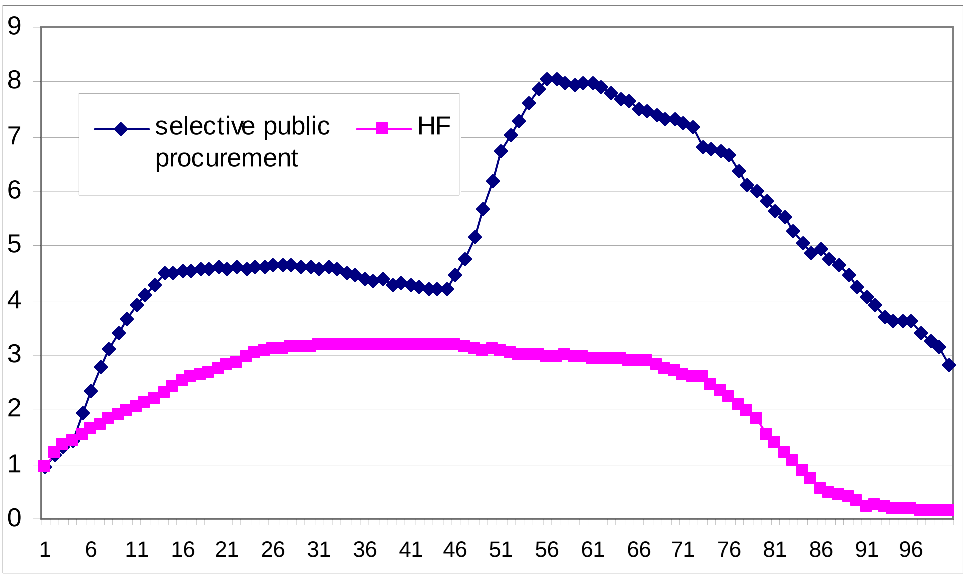

Figure 9 – Selective public procurement in transistors and integrated circuits: best mod

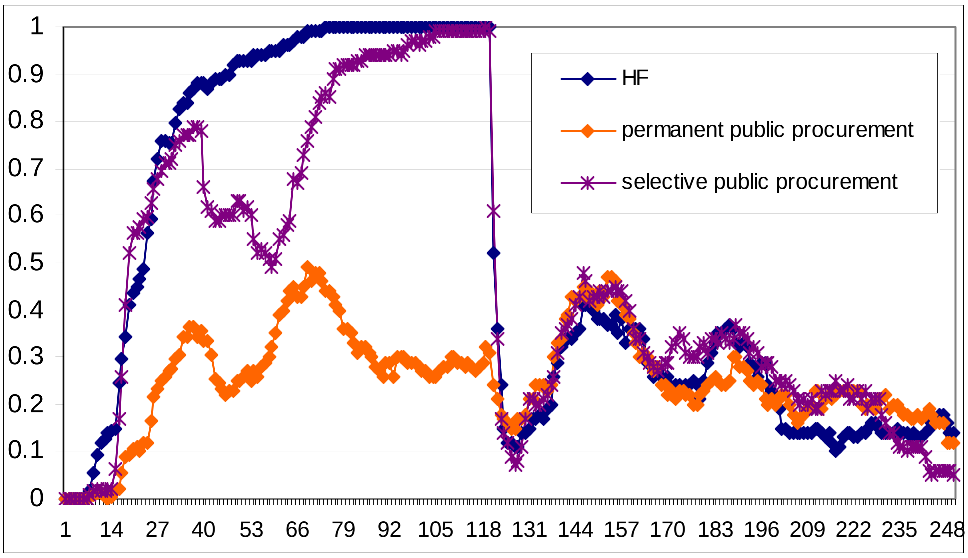

Figure 10 - Permanent and selective public procurement: integration ratio

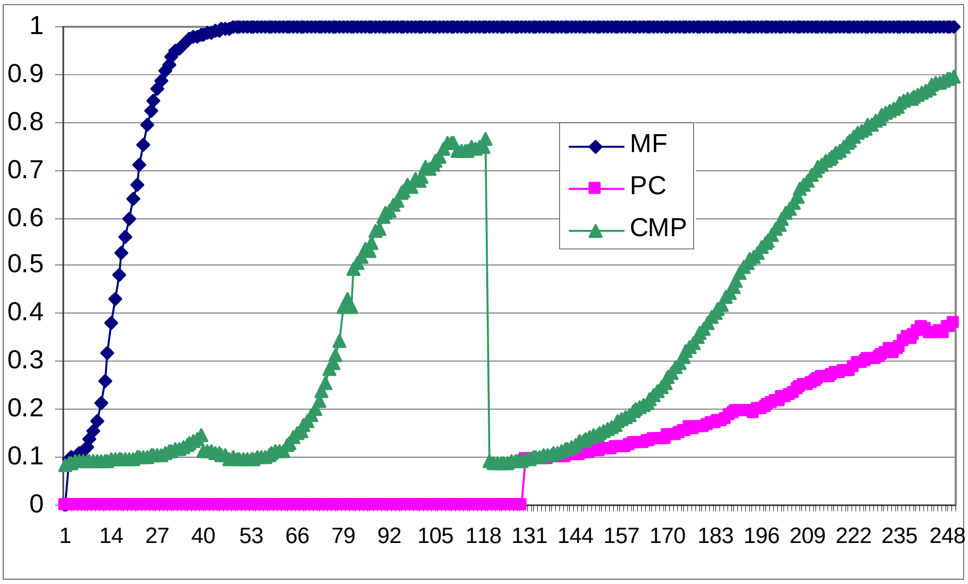

Figure 11 – Permanent public procurement as an additional market: Herfindahl index

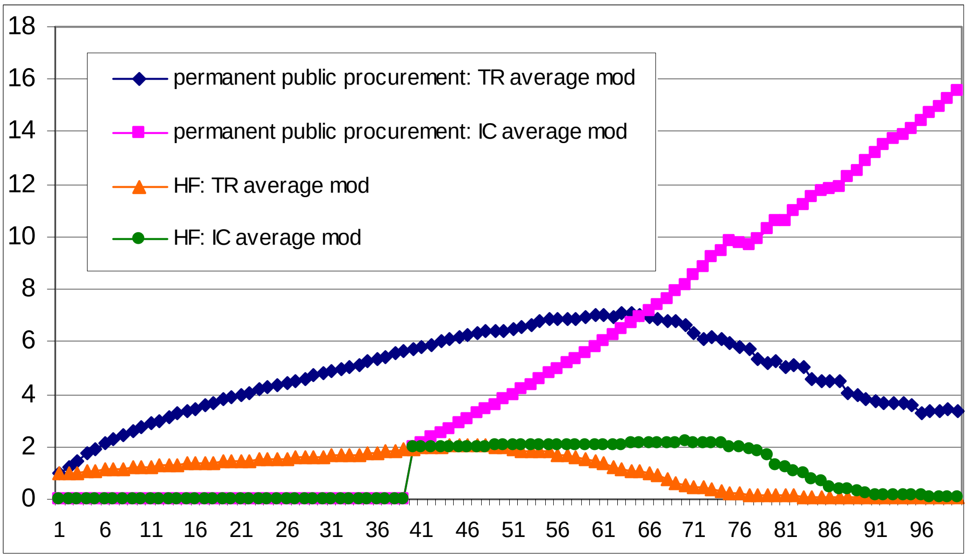

Figure 12 – Permanent public procurement as an additional market: average mod in transistors TR and integrated circuits IC eras

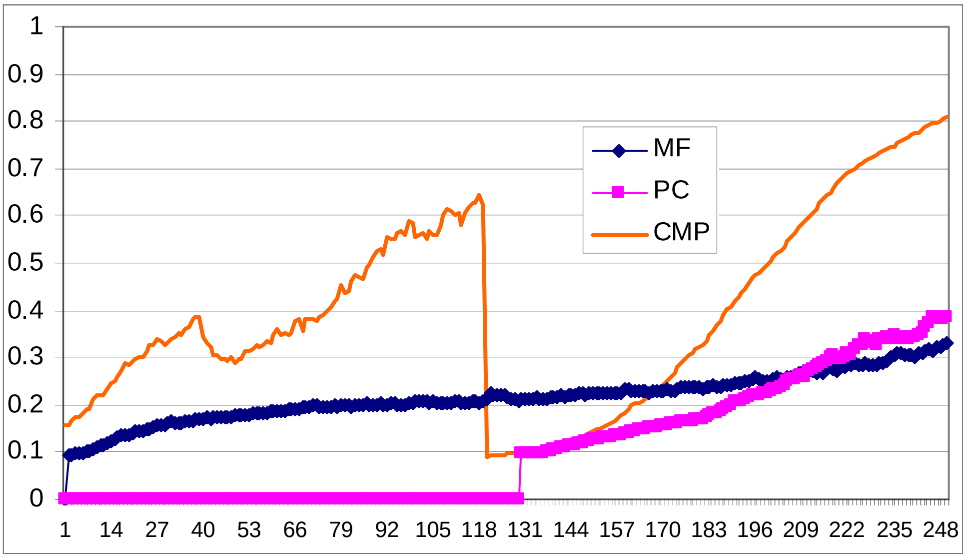

Figure 13 – Unintended consequences: open standards and concentration. Herfindahl index

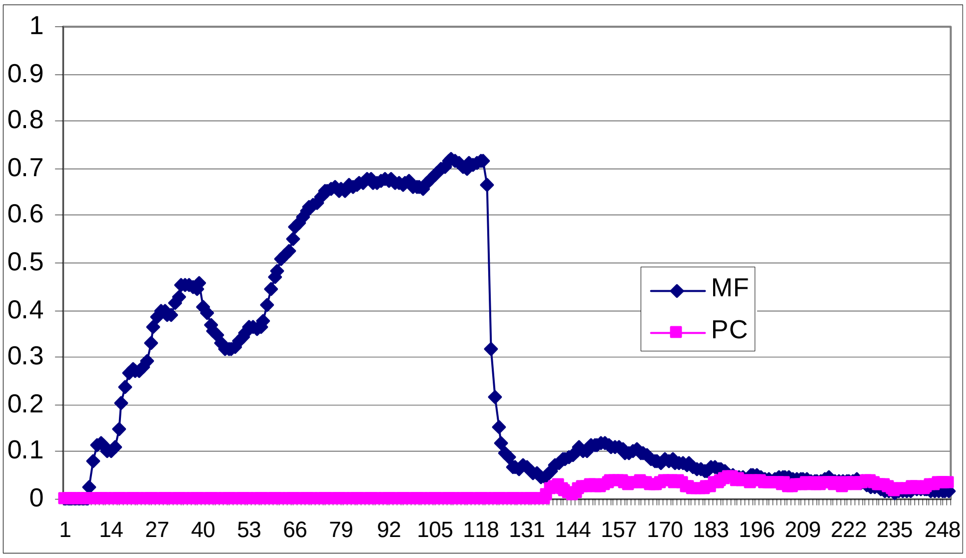

Figure 14 – Unintended consequences: open standards and concentration. Integration ratio

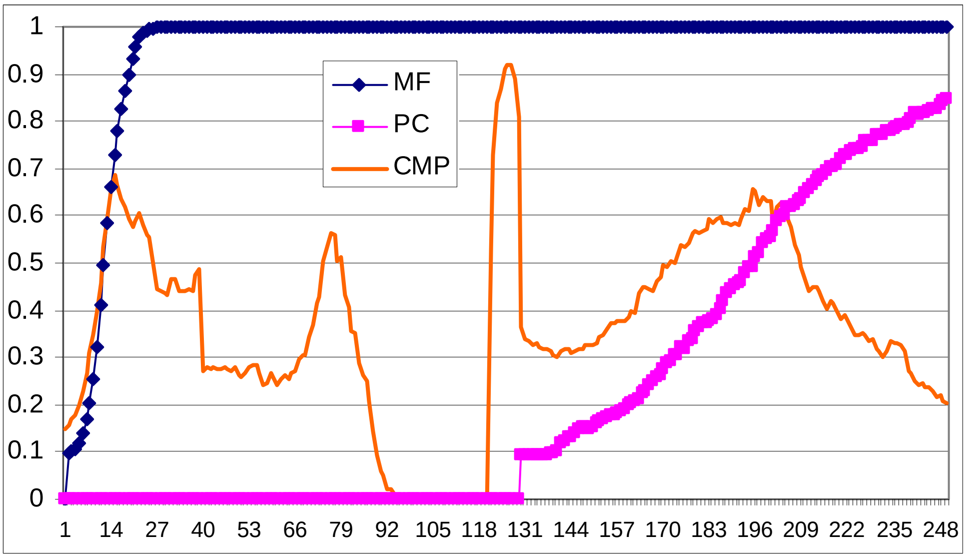

Figure 15 – Unintended consequences: antitrust, diversification and disappearance of the component industry: Herfindahl index

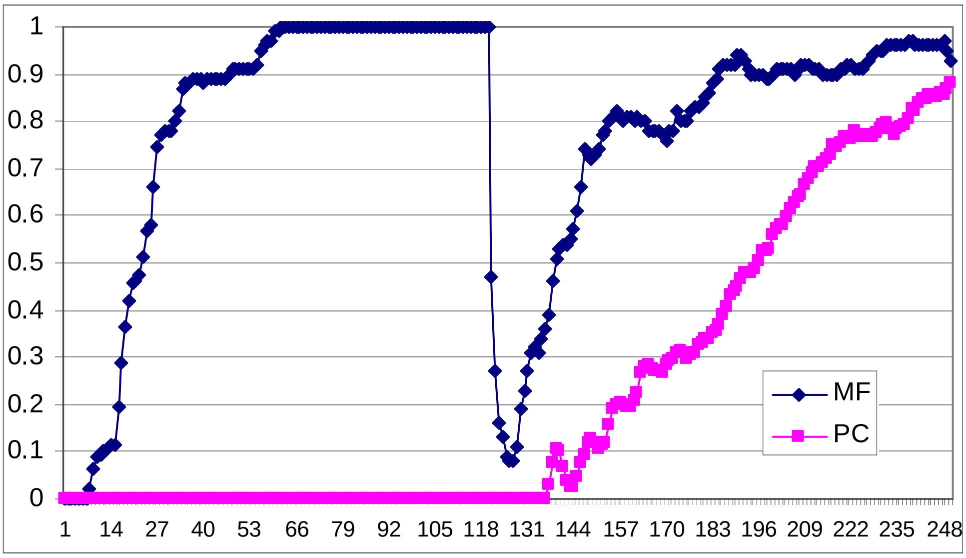

Figure 16 – Unintended consequences: antitrust, diversification and disappearance of the component industry. Integration ratio

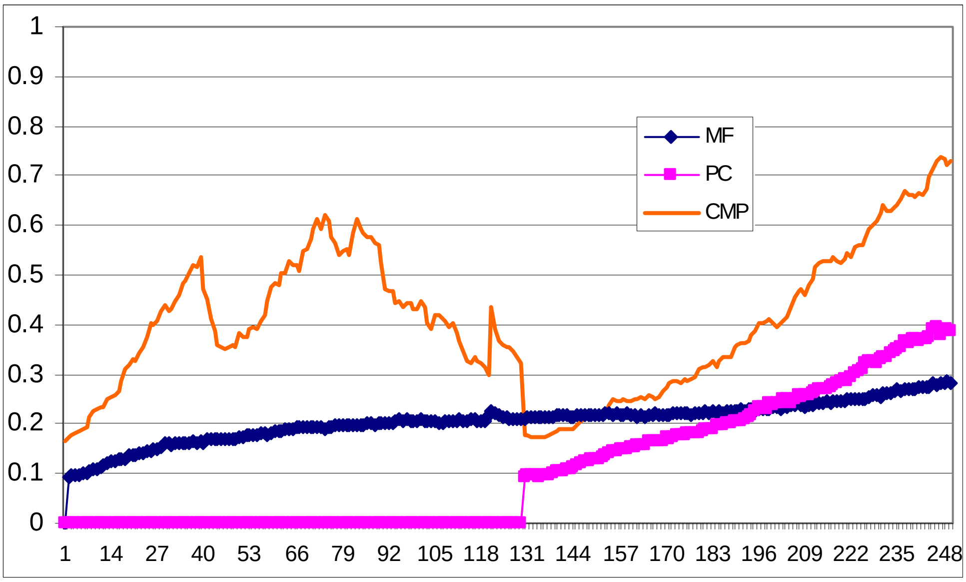

Figure 17 – Unintended consequences: open standards lead to the emergence of a component industry. Herfindahl index

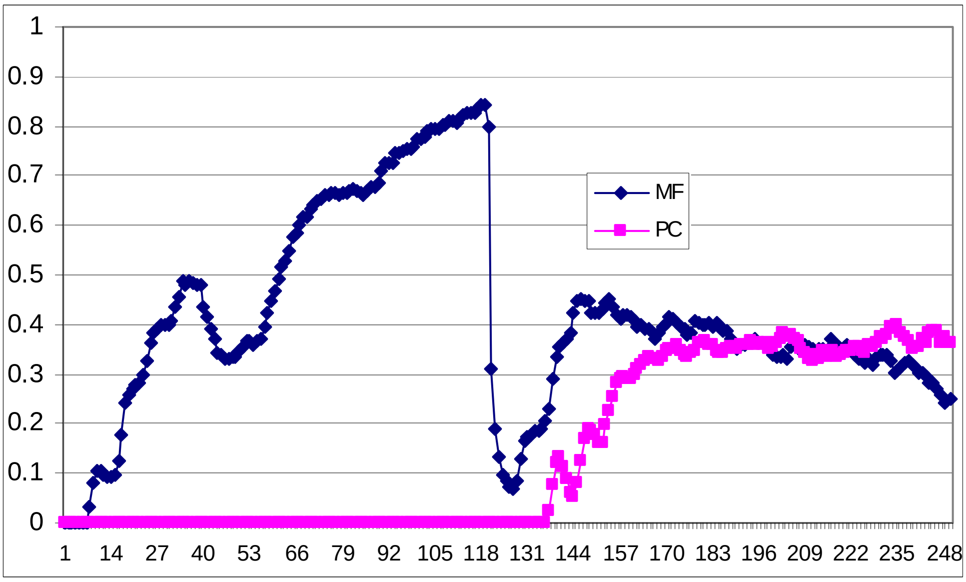

Figure 18 – Unintended consequences: open standards lead to the emergence of a component industry. Integration ratio