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Defence Firms Facing Liberalization: Innovation and Export in an Agent-based Model of the Defence Industry

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Abstract

The paper presents an agent-based simulation model of the defence industry. The model resembles some of the key characteristics of the European defence sector, and studies how firms in this market will respond to the challenges and opportunities provided by a higher degree of openness and liberalization in the future. The simulation analysis points out that European defence firms will progressively become more efficient, less dependent on public procurement and innovation policy support, and more prone to knowledge sharing and inter-firm collaborations. This firm-level dynamics will in the long-run lead to an increase in the industry's export propensity and a less concentrated market.

Key words: Defence industry; liberalization; EU; export; innovation; agent-based simulation model

JEL codes: C6; F1; F5; L1; M2; O3

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1. Introduction

In the period from the end of the Cold War to the end of 1990s, several European countries have experienced a substantial decrease in their military budget and a significant loss of market shares *vis-à-vis* other international competitors. Defence firms and national authorities have reacted to these challenges by undertaking a process of restructuring and consolidation aimed at obtaining cost reductions through e.g. inter-firm collaborations, mergers and acquisitions. This process is currently coupled with the recent attempt of EU public authorities to introduce a greater degree of market liberalization in the future in order to avoid duplications and achieve stronger efficiency and international competitiveness in this market (Guay and Callum, 2002).

A recent EU Directive (*The European Union's Defence and Security Procurement Directive 2009/81/EC*) intends to provide a new framework for policy interventions in the European defence market by limiting the extent of national protection, extending cooperation and cross-border trade within the EU and eventually introducing a higher degree of market liberalization (Edwards, 2011). This EU Directive will be implemented by national Member States starting in early 2012, although it will probably face resistance and take some time until it will lead to a more open and more competitive EU defence market.

The future scenario of openness and liberalization does certainly represent an important change for firms in the European defence industry. How will defence companies respond to these new challenges and opportunities – will they be able to adjust their innovation and business strategies in order to be more competitive in international markets? And how will the impacts of market liberalization differ between large and smaller European countries?

Our investigation of these questions is rooted in the recent literature on firm heterogeneity and international trade, which has rapidly become the new paradigm in the international economics literature. This framework highlights the importance of firm-specific capabilities (e.g. productivity, innovative ability) to explain why, within each industry, some enterprises are able to export whereas others are not (Melitz, 2003; Helpman et alia, 2004).[1] Companies respond differently to the process of market liberalization, and *firm heterogeneity* has therefore rapidly become the key pillar of these new theoretical structures.

While broadly in line with this new strand of international economics literature, we make use of a different modeling approach to study the effects of market liberalization on the international activities of firms in the defence industry. Agent-based models and simulations (ABMS) provide a framework to analyze a set of heterogenous agents and the interactions among them (North and Macal, 2007; Macal and North, 2010). This modeling approach is well suited to investigate heterogeneity and complexity as key features of physical, biological and social systems. Among several other fields, this theoretical framework has recently found an increasing number of applications within economics and business research, e.g. in the fields of computational and evolutionary economics (Tesfatsion, 2002; Frenken and Nuvolari, 2004; Dosi et alia, 2010). To the best of our knowledge, however, the ABMS approach has not been used before to analyze the question of exporting firms' reaction to market liberalization, and, more specifically, it has never been applied before within the context of the defence industry.

A specific model of our interest is the so-called SKIN model (*Simulating Knowledge Dynamics in Innovation Networks*), introduced in a number of recent papers by

[1] A survey of this new strand of models is presented by Castellacci (2011).

Gilbert et alia (2007), Pyka et alia (2007) and Ahrweiller et alia (2011). This is an agent-based model that provides an accurate analysis of private firms' interactions and knowledge dynamics in high-tech (or knowledge intensive) industries. Our theory is rooted in this recent model and extends it further by applying it to the study of the defence sector, and shifting the focus to the relationship between innovation and export dynamics within a context of increasing market liberalization. While the main structure of our model follows the main basic pillars of the SKIN approach, our framework departs from it in some important ways, given the peculiarities and idiosyncrasies that characterize the defence industry.

In the ABMS model presented in this paper, heterogeneous agents (defence firms) in a given country compete in the market by producing new products. In any period *t*, the agents will sort in three distinct groups: (1) successful innovators that meet the requirement for receiving public R&D funding; (2) successful innovators that do not qualify for public support; (3) unsuccessful performers, which will try to adjust their performance by undertaking a new privately-funded R&D project or by imitating external knowledge and searching a cooperation partner.

The simulation analysis of this model points out that defence firms, when faced with a market liberalization scenario, will progressively become more efficient, less dependent on public procurement and innovation policy support, and more prone to knowledge sharing and inter-firm collaborations. This firm-level dynamics will in the long-run lead to an increase in the industry's export propensity. Further, the effects of market liberalization will differ in large and smaller European economies. Large countries are likely to experience greater overall benefits, e.g. in terms of reduced market and export concentration, but the impacts of market liberalization on their export propensity and international performance will take a longer time to realize its full potential.

The paper is organized as follows. Section 2 points out some key stylized facts that the model seeks to reproduce; section 3 presents the model; section 4 defines the firm-level and industry-level variables used in the simulation analysis; section 5 presents the long-run properties and main outcomes of the model; section 6 discusses some alternative policy scenarios; and section 7 concludes by summarizing the key results and implications of the work.

2. The defence industry: stylized facts

The defence industry is in many respects a peculiar branch of the economy. In order to achieve a proper understanding of firms' export activities in this sector, our model intends to resemble some of its key stylized facts and idiosyncrasies.

Stylized fact 1: Firm heterogeneity: Defence firms are highly heterogenous. They produce in a number of distinct market segments – ranging from tactical communications and crypto solution to ammunitions and military explosives, from tents and protective suits to aircrafts, vehicles, vessels and submarines – and they are therefore characterized by a wide spectrum of technical competencies and product portfolios.[2] In different market segments, large oligopolistic producers co-exist with smaller specialized suppliers of defence material and equipment (Markovski et alia, 2010).

[2] An accurate overview and classification of the different technological fields covered by firms in the defence industry is provided by the taxonomy developed by the European Defence Agency (EDA; see: http://www.eda.europa.eu).

Stylized fact 2: Stable and concentrated structure: The industry is typically characterized by a rather stable population of firms and little turbulence, and the entry and exit rates are much lower than in many other sectors. Most market segments are highly concentrated and characterized by an oligopolistic structure in which incumbents exploit their dominant position through high capital intensity and economies of scale and scope (Lichtenberg, 1995). The sector resembles closely the description of a Schumpeter Mark II type of innovation regime (Klepper, 1996; Malerba and Orsenigo, 1996).

Stylized fact 3: High innovativeness: Technological innovation is as well-known a crucial ingredient in the production and commercialization of defence-related material. The industry is characterized by a very high share of enterprises with R&D activities (R&D propensity), and individual firms do on average spend a substantial amount of resources to develop new products and processes (R&D intensity). These technological activities are however characterized by a high degree of uncertainty and a long lag between the initial production of a new technology and its successful market commercialization (Lichtenberg, 1995; Mowery, 2010). Further, a substantial share of firms' R&D activities is financed through public funding, due to their strategic importance in terms of military capabilities and national security. Collaborations between private firms and public scientific organizations are frequent and important. In short, it is reasonable to characterize the defence industry as a *science-based sector* (Pavitt, 1984).

Stylized fact 4: High export propensity: The industry has on average a high share of firms that sell their products abroad (export propensity). Differently from the very skewed size distribution that characterizes most manufacturing industries, where only a few large enterprises within each sector are able to export (Melitz, 2003), in the defence market it is often both large enterprises and smaller specialized suppliers that seek to compete in international markets through export activities (Castellacci and Fevolden, 2011). Their export success is not so much based on the price they set and the related terms of trade, but rather on the quality of the products and their degree of technological sophistication. In fact, the demand for defence equipment typically sets strong requirements in terms of the precision and reliability of the exported products. Accordingly, cooperation agreements and interactions between user and producers are extensive (Malerba and Montobbio, 2003).

Stylized fact 5: Active public involvement: The defence industry plays a strategic role in terms of national military and security objectives, and it is for this reason heavily regulated and subject to an extensive and active public involvement. Public procurement, in particular, represents a traditional policy instrument through which defence authorities purchase a wide range of products and equipment from domestic firms. Public demand does therefore represent a stable and secure source of income for defence firms in a given country. International trade has also traditionally been actively regulated through so-called offset, counter-trade agreements and national favoritism (discrimination) such as the “buy-American act”, which impose restrictions to the amount and source of import and export activities (Markovski et alia, 2010).

Stylized fact 6: Towards increasing liberalization: From the end of the Cold War to the end of 1990s, many European countries experienced a substantial decrease in military budget and lost market shares *vis-à-vis* other international competitors. European defence firms and national authorities have reacted to this by undertaking a process of restructuring and consolidation aimed at obtaining cost reductions through e.g. greater cooperation, mergers and acquisitions. Further, EU public authorities are currently trying to introduce a greater degree of market liberalization in the future in order to avoid duplications and achieve stronger efficiency and international competitiveness in this market. The new EU Directive (2009/81/EC) mentioned above takes an explicit step in this direction (Guay and Callum, 2002; Edwards, 2011). Increased liberalization represents an important new scenario that European defence companies will soon be faced with.

3. The model

Agent-based models and simulations (ABMS) provide a framework to analyze a set of heterogenous agents and the interactions among them (North and Macal, 2007; Macal and North, 2010). This modeling approach is well suited to investigate heterogeneity and complexity as key features of physical, biological and social systems. Among several other fields, this theoretical framework has recently found an increasing number of applications within economics and business research, e.g. in the fields of computational and evolutionary economics (Tesfatsion, 2002; Frenken and Nuvolari, 2004; Frenken, 2006; Dosi et alia, 2010).

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Gilbert et alia (2007), Pyka et alia (2007) and Ahrweiller et alia (2011).[3] This is an agent-based model that provides an accurate analysis of private firms' interactions and knowledge dynamics in high-tech (or knowledge intensive) industries.

Our paper is rooted in this recent model and extends it further by applying it to the study of the defence sector. While the main description of the model follows the main basic pillars of the SKIN approach, our model departs from it in some important ways, in the attempt to reproduce the peculiarities and idiosyncrasies that characterize the defence industry described in the previous section. Figure 1 presents a diagram describing the behavior of agents (private firms) and their market interactions within any given period *t*.

< Figure 1 here >

3.1 Agents

Defence firms (business companies producing defence material, equipment and products) are the micro agents in the model. In line with our stylized fact 1 (*firm heterogeneity*), agents differ from each other in two main respects. First, they have different initial endowments of financial capital, which they use both for their productive and innovative activities. Large firms co-exist with SMEs in the defence market. Secondly, they differ in terms of their knowledge base, i.e. the pool of scientific and technological competencies and skills that the company employs in its innovative activities.[4] The model represents the firm's knowledge base as a set of units of knowledge. Each unit is a vector composed of three elements (or triple):

[3] An extensive presentation of this approach along with a complete list of project activities and publications is available on the SKIN model's website: http://cress.soc.surrey.ac.uk/skin/home.

[4] In the original version of the SKIN model, the knowledge base is labelled *kene*.

- The *capability* (C), which defines a domain or area within the defence industry (e.g. weapon production). It is represented in the model as a randomly chosen integer between 1 and 1000.
- The *ability* (A), defining a specific ability or skill that the firm possesses in this C domain (e.g aerodynamic design technologies for platforms and weapons). It is a randomly chosen integer between 1 and 10.
- The *expertise* (E), which indicates the level of expertise that the firm has in using the ability A. This is also represented as a randomly chosen number between 1 (lowest) and 10 (highest).

Defence firms compete in a highly innovative and technologically sophisticated environment (*stylized fact 3*). Our model assumes that all firms in the market actively use their knowledge base in the attempt to create new products and processes. Innovative activities are represented in the SKIN model in such a way that, at any period *t*, each company formulates an *innovation hypothesis*, i.e. an idea or a plan for developing a new product or process. The model represents this innovation hypothesis (IH) as a subset of the firm's knowledge base, i.e. the enterprise focuses on a specific subset of its technological competence (capabilities, abilities, expertise) that it finds particularly promising and worth developing further. The subset of expertises (E_i) used in the innovation hypothesis are assumed to increase by one unit in the period, whereas those that are not used decrease by one unit (*learning by doing* and *forgetting* mechanisms).

3.2 Economic environment

In any period *t*, each enterprise uses its innovation hypothesis to try to develop a new product. The outcomes of the innovative process are subject to a high degree of uncertainty and introduce an important stochastic element in the model. The new product is characterized as an index number that depends on the number of capabilities and abilities entailed in the innovation hypothesis according to the function:

$$P = (\sum C_i \cdot A_i) \bmod N \qquad (1)$$

where N is the maximum number of different products. The product is therefore characterized by the *breadth* of the innovation hypothesis, i.e. the number of different capabilities and abilities that the firm masters and it is able to combine in the development of the new artifact. By contrast, the quality of the product depends on the *depth* of the innovation hypothesis, i.e. it is a function of the enterprise's specific abilities and expertise. Specifically, product quality is defined as an index number obtained by multiplying the abilities and expertise levels for each of the vectors composing the innovation hypothesis and then normalizing the result. In other words, the key characteristic and value added of a new product does not depend on how broad the firm's technological competence is, but rather how deep and specialized the company is in a specific sub-set or market niche. As explained below, this trade-off between competence breadth *versus* depth is an important characteristic driving the model's outcomes.

In order to produce the new product, the firm searches for inputs (e.g. capital equipment) in the market. The type of input it needs depends on the characteristics of the product it wants to develop (P), and it eventually purchases the one with the lowest price and, *ceteris paribus*, the highest quality. If the enterprise does not find any input in the market at a price it can afford, it will not enter the production process. Once the product is ready for market commercialization, the firm sets its price by applying a mark-up (profit margin) over the total costs. Depending on the market demand available for this product, an adjustment mechanism tends to increase (decrease) its price over time if the demand level is high (low).

More specifically, the model assumes that demand patterns differ for different segments of the defence industry. On the one hand, intermediate products are sold to other firms within the defence sector and their price is subject to the adjustment mechanism noted above. On the other hand, new products that are destined to the end users are always absorbed by the market. This assumption is in line with the fact that, in the defence industry, public procurement assumes a pivotal role, i.e. defence authorities typically purchase a substantial amount of new (or existing) defence products and material from domestic firms in order to secure military capabilities and so achieve national defence strategic objectives.

Given these market interactions and outcomes, at any period *t* the firm achieves a certain level of profit – which is largely dependent on the characteristics and quality of the new product it sells. We further assume that if the enterprise's profits are large enough to cover sunk export costs (i.e. above a given profit threshold), then the enterprise is able to start the commercialization of its product also to foreign markets. This is in line with the key idea of the recent literature on firm heterogeneity and international trade (e.g. Melitz, 2003; Helpman et alia, 2004), according to which only the most successful and productive enterprises within each sector are able to pay sunk export costs and overcome trade barriers in international markets, whereas most other companies will only produce for the domestic market.

3.3 Performance adjustment and feedback loops

After having produced and commercialized its product, the firm looks at its current market performance (i.e. the profits it has realized at time *t*), and decides whether this is satisfactory or not, and how it can be improved in the future. The model's parameter *success threshold* (defined in further details in section 4) indicates the profit level that marks the distinction between successful *versus* unsuccessful performance. This parameter is exogenously set at a given level for all firms in the market. For simplicity, we start by assuming that this success threshold corresponds to the mean profit level in the industry: enterprises whose profits are above (below) the industry-level mean will be satisfied (not satisfied) with their current performance.

There are two ways in which an enterprise can improve its performance over time. One can only be pursued by successful innovators, whereas the other is followed by unsuccessful performers.

New publicly-funded R&D projects: If a firm is satisfied with the profits it has realized, it may decide to apply for public funding for improving its product further (publicly-funded incremental innovation). Public defence authorities typically finance a substantial amount of domestic R&D activities through public procurement (*stylized fact 5: Active public involvement*). We assume that this public funding is granted to the applicant according to two complementary criteria: (1) The quality of the firm's product has to be above a given *product quality threshold*; (2) The firm's technological and competence breadth (i.e. the number of capabilities C in its innovation hypothesis) has to be above a given *competence breadth threshold*. The intuition behind this public funding allocation mechanism is in line with the practice that public defence authorities typically follow. Put it simply, when policy-makers evaluate the possibility to finance a company to develop a new product, they look at both: (1) the quality of its current product, which gives them an indication of the likelihood that the firm will be able to produce a successful incremental innovation of it in the future; and (2) the breadth of the firm's expertise in several different areas, since large multi-product and multi-competence enterprises are those that have presumably received public funding already in the past and thus previously developed a reliable user-producer relationship with public authorities. All in all, the possibility for successful firms to apply for new publicly-funded R&D projects introduce a source of cumulative causation in the model, since in any period *t* there will be a limited number of successful companies that will be able to qualify for public R&D support, which is likely to lead to further incremental innovation and satisfactory profits for them in the future.

New privately-funded R&D projects and cooperation: If a firm is not satisfied with the profits it has realized, it will try to improve its performance by starting to search in a new direction (Nelson and Winter, 1982). An enterprise can apply two different search strategies to adjust its performance. (1) If its current product was sold in the market but the demand level was not sufficient to realize a satisfactory profit level, the company will undertake a new R&D project funded through its own internal resources (financial capital). The new R&D project will aim at improving one of the abilities (A) in its innovation hypothesis – or, put it differently, to achieve a better specialization and technological sophistication in the technological space on which it is currently focusing (i.e. an increased technological *depth*, given its current *breadth*). (2) By contrast, if the firm's current product did not meet any demand in the market (hence leading to negative profits), this gives a clear indication that the firm's current innovation hypothesis is not well suited to the user requirements, and that it must be adjusted. The enterprise can do this by searching for an external partner for cooperation. The firm will first search among its previous partners, then its suppliers and users, by looking at the capability sets they possess as indicated by their respective innovation hypotheses and market product characteristics. When a firm finds a collaboration partner, it can add the partner's innovation hypothesis triples to its own, thus achieving a broadening up of its capability set and knowledge base. Put it differently, cooperation enables the exchange of knowledge among different agents, and this is likely to improve the performance of these by augmenting their respective knowledge bases and technological competencies. All in all, the two strategies pursued by unsuccessful performers – privately-funded R&D and cooperation – introduce in the model a catch up mechanism, since firms lagging behind the technological frontier may improve their technological position and adjust their market performance by means of such R&D and imitation strategies.

A summary and overview of the model (see figure 1) highlights the following two key features of this theoretical framework. First, in any period *t*, the agents will be sorted in three distinct groups: (1) successful innovators that qualify for public funding (see figure 1, *loop 1*); (2) successful innovators that do not meet the criteria for public support (*loop 2*); (3) unsuccessful performers, which will either undertake a new privately-funded R&D project or imitate by searching a cooperation partner (*loop 3*).

Secondly, the overall dynamics of the model, as shown in the next section, depends on the combination of two different mechanisms: (1) a cumulative causation mechanism according to which the best performers will tend to get public support and hence strengthen their market position even further in the future; (2) a catch up mechanism through which less successful companies will be able to adjust their performance and possibly achieve a leading market position in the future. Section 5 will analyze how these mechanisms shape the long-run properties of the model, and section 6 will then investigate how future policy changes towards liberalization (see stylized fact 6) may shape export dynamics and market opportunities in the defence industry.

4. Variables and indicators

4.1 Key parameters: environmental and policy characteristics

The following four parameters describe some key characteristics of the economic environment in which agents operate, which may be affected by policy actions and strategies over time. They represent the main explanatory variables of interest in our simulation analysis.

Cooperation propensity: This defines the extent to which agents are willing (and able) to cooperate with others in the same market, i.e. their collaboration propensity. This parameter ranges on a continuous scale from 0,50 (lowest cooperation propensity) to 0 (highest propensity).

Success threshold: This indicates the threshold above (below) which firms consider themselves satisfied (not satisfied) with their current market performance (e.g. corresponding to the mean profit level in the industry). The parameter is defined in the profit space ranging from 0 to 12 000. This parameter is largely dependent on the extent and intensity of market competition, i.e. the success threshold is higher (lower) in a more (less) open and competitive market, because agents must compete with a greater (smaller) number of competitors (including foreign firms) in order to maintain their market position. In other words, in a more (less) open and competitive market companies tend to be more (less) demanding because they are aware they face a stronger (weaker) competition.

Public funding requirement I: Product quality threshold: This is the first of the two criteria set by public authorities to grant public support to private defence firms. It ranges on a continuous scale defined on the quality domain between 0 (loose quality requirement, easy to get public funding) to 10 (strict quality requirement, difficult to get public support).

Public funding requirement II: Competence breadth threshold: This is the second requirement for qualifying for public support. The parameter ranges on a continuous scale defined on the innovation hypothesis domain between 0 (narrow technological competence, easy to get public funding for most firms) to 10 (broad technological competence, difficult to get public support for many narrowly specialized companies).

4.2 Other model parameters

These parameters do also represent environmental characteristics affecting the industry dynamics. However, they may not be influenced by policy actions in the short-run. We will not report the results of the simulation analysis for these variables in order to save some space (these are available upon request).

Number of firms: Total number of enterprises in the market.

Number of products: Total number of products that are sold in the market.

Share of large firms: Number of large enterprises as a percentage of the total number of firms in the market.

Share of end products firms: Number of enterprises that produce final products as a percentage of the total number of firms in the industry.

4.3 Key aggregate (industry-level) outcomes

The following six variables are aggregate outcomes of the model, i.e. emergent properties that are observed at the industry-level as the result of micro-level behavior and agents' interactions. They represent the key variables defining the performance of the defence industry, and thus the main factors we seek to explain in our simulation analysis.

Export propensity (%): Number of exporters as a share of the total number of firms in the industry. This is the variable typically highlighted by recent models of firm heterogeneity and international trade (e.g. Melitz, 2003; Helpman et alia, 2004). As explained in the previous section, only firms that are above a given profitability level are assumed to be able to cover sunk export costs and export their products in foreign markets, whereas most other enterprises will continue to produce only for the domestic market. This is the main variable of interest in our simulation analysis, since it is typically used as an indicator of the export performance of an industry for a given country.

Mean product quality: It is the industry-level average of the index measuring each firm's product quality.

New privately-funded R&D projects (%): Number of companies that undertake new privately-funded R&D projects as a percentage of the total number of firms.

New publicly-funded R&D projects (%): Number of enterprises that qualify for publicly-funded R&D projects as a share of the total number of firms.

Concentration index: We use the C5 concentration index, defined as the total financial capital owned by the five largest firms in the market as a share of the total financial capital in the defence industry.

Export concentration ratio (%): We define this as the E5 export concentration index, i.e. the total value of export obtained by the five largest firms in the market as a percentage of the total value of export in the defence industry.

5. The long-run properties of the model

We have carried out the following set of simulation exercises in order to analyze the long-run properties of the model. We have focused on the six key aggregate (industry-level) outcome variables (listed in section 4.3), and investigated how each of them is affected in the long-run by variations in the set of the four explanatory variables (the key policy and environmental parameters listed in section 4.1). Specifically, for each explanatory variable, we have run a set of 200 simulations (each of which lasting for a 300-period time horizon[5]) where the variable takes all possible values in its definition domain (from the minimum to the maximum). In each simulation, we have recorded the value of the six (industry-level) outcome variables at the end of the simulation run (t = 300), and then plotted on a two-dimensional graph the relationship between each explanatory variable and the resulting (long-run) value of each outcome variable. The results of this analysis are presented in figures 2 to 5. Each figure focuses on one explanatory factor and its relationships to the six aggregate outcome variables. These graphs point out the four main long-run properties of the model, which we briefly outline as follows.

Result 1: *A logistic relationship linking the cooperation propensity and the export propensity*.

The first panel of figure 2 shows this positive long-run relationship between the cooperation and the export propensity. The intuition behind this result is that when the cooperation propensity is very low, its effects on firms' export activities are on average limited. Among the firms that register an unsatisfactory market performance,

[5] We have decided to stop our simulation run at period 300 because the model dynamics gets remarkably stable from that period onwards.

only a small share of them are able to find an external partner for cooperation, so the overall extent of imitation and intra-industry knowledge spillovers is limited, and it does not affect substantially the export propensity of the industry. By contrast, above a certain threshold of the cooperation propensity parameter (< 0,30), unsuccessful firms are much better at exploiting external knowledge opportunities, and, thanks to the related spillovers effects, they may be able to catch up with the technological frontier in the industry and even export their products abroad. Put it differently, referring to the model flow chart previously presented in figure 1 (section 2), when the cooperation propensity increases over a certain threshold, a good number of unsuccessful firms (loop 3) are able to escape their "poverty trap" and enter one of the more virtuous circles (loops 1 and 2) that may lead them to export activities.

This model dynamics is mirrored and further explained by the other panels of figure 2. An increase in the cooperation propensity parameter also leads to an increase of the industry's product quality (as a result of this catch up dynamics), a smaller share of new privately-funded R&D projects and a larger share of publicly-funded R&D activities (since more firms are satisfied with their performance, and on average better at meeting the requirements for receiving public innovation support). Further, the last two panels of figure 2 show a decrease in the C5 industry concentration index (more firms catch up with the technological frontier and the market becomes less concentrated) and also a decrease in the E5 export concentration ratio (SMEs increase their export shares *vis-à-vis* large oligopolistic exporters, which worsen their international performance).

This first result has an important policy interpretation and relevance. When a higher degree of liberalization will be introduced in the European defence market in the future – i.e. with the implementation of the new EU Directive by national Member

States – each national market will be characterized by a higher cooperation propensity, as defence firms will progressively become more aware of the external sources of technological opportunities available in an enlarged and more integrated economic environment and thus more prone to collaboration agreements and knowledge sharing. Therefore, this first result may be seen as an indication of how the export propensity in each national market will react in the long-run to this policy change and the shift towards liberalization.

< Figure 2 here >

Result 2: *An inverse U-shaped relationship between the success threshold and the export propensity*.

Figure 3 (first panel) illustrates this second result. When the success threshold is low, firms are on average satisfied with their market performance. To illustrate, if the industry is characterized by very low openness and competition intensity, domestic enterprises are arguably not too concerned about the threat of international competition, and are therefore likely to continue their business-as-usual activities without feeling too much pressure to become more productive or explore different technological trajectories. Under these conditions, the mean product quality in the industry is relatively low, and the firms are not under pressure to increase their product quality by means of cooperation and new privately-funded R&D projects (firms in loop 3) or publicly-funded projects (firms in loops 1 and 2). The export propensity in the industry is therefore low: the enterprises are relatively satisfied with their domestic position and performance, and do not have the ambition and capability to sell their products abroad.

However, as the market becomes more open and competitive, the success threshold increases and these outcome variables tend to respond positively: firms increase their private R&D efforts (loop 3), their product quality and their ability to attract public funding (loops 1 and 2). As a result, a larger number of firms will be able to achieve high profitability and export their products in international markets.

Nevertheless, this type of dynamics will not continue indefinitely. After a certain limit (> 9000), the success threshold and market competition intensity will be so high that the enterprises will not be able to improve their performance any further. This happens when the entry of foreign productive firms into the domestic market makes it too hard for domestic enterprises to continue to produce. After this point, further increases in the success threshold (market competition) will therefore result in a stagnant product quality dynamics and a decrease in the industry's export propensity. Similarly to the previous, this second result does also have a direct policy interpretation, since the progressive increase of our success threshold parameter simulates the possible effects of the introduction of a higher degree of market liberalization and competition in the future enlarged EU defence market.

< Figure 3 here >

Result 3: *A logistic relationship linking the product quality threshold (public funding requirement I) and the export propensity*.

Figure 4 reports this emergent property of the model. Although the shape of the logistic pattern identified by result 3 is analogous to the one pointed out for result 1, the underlying mechanism is different, since it focuses on the dynamics of public support rather than the effects of knowledge spillovers. Put it simply, when public defence authorities set a low quality threshold that firms have to satisfy in order to receive public R&D funding, this makes it easy for many defence companies to apply and get this type of policy support. This has two effects. The direct effect is of course that there is a large share of firms in the industry that are able to undertake new publicly-funded R&D projects (including both successful and less successful companies). The indirect effect, though, is that in such a generous and protected environment, less successful firms will not actively seek to increase their performance through product quality improvements, since public funding easily provides them with a mean to achieve their desired profit target. In this environment, the industry will tend to be more concentrated – successful firms outperform less successful enterprises – and the overall export propensity is on average low.

However, if public authorities become more restrictive and set a higher quality threshold for allocating R&D funding, the indirect effect will progressively become stronger and counterbalance the direct effect. That is to say, even if a lower share of firms will be able to meet the requirements for attracting public funding, a greater number of firms will increasingly feel under pressure to adjust their performance through product quality improvements rather than public procurement, and for this reason the industry will progressively become less concentrated and more exportoriented. Here again, the policy interpretation of this result is clear: when the new EU Directive will gradually limit the extent of national protection and make domestic public procurement tenders more open to international competition, domestic firms will face the threat of foreign competition and will therefore have to invest more actively in technology and quality upgrades in order to maintain their competitive position.

< Figure 4 here >

Result 4: *A flat linear relationship (weak correlation) between the competence breadth threshold (public funding requirement II) and the export propensity.*

The first panel of figure 5 shows this pattern. An increase in the competence breadth threshold, the second of the two criteria used by public authorities to allocate R&D grants, does not lead to any visible increase in the export propensity of the industry in the long-run. The reason for this is that in our model export activities and profits are mainly dependent on the quality of the product sold by the firm (*technological depth*) rather than the number of different capabilities mastered by the enterprise and used for the production of the new variety (*technological* or *competence breadth*). This implies that, when policy makers decide to make this second criterion more restrictive, they will start to allocate R&D funds mainly to large multi-product and multi-competence enterprises, which already have a dominant position in the market. By contrast, it will become increasingly difficult for SMEs, specialized in more narrow industry segments and market niches, to meet this public funding requirement. The overall effect is that, differently from what pointed out for result 3, there will not be any indirect effect counter-balancing the reduced number of publicly-funded R&D projects, i.e. defence firms will not start to invest more actively to upgrade their product quality, so that the industry's mean quality and export propensity will on average not increase. This is explained by the fact that public authorities, by emphasizing competence breadth as the key criterion to apply for public R&D funding, do not give a clear and explicit signal to firms that they should actively improve their product quality, i.e. the funding allocation mechanism (*competence breadth*) is not in line with the key market requirement for achieving an internationally competitive position (*technological depth*).

For this fourth result too, the policy interpretation and implication is quite explicit. Undertaking a process of reform towards market liberalization, national defence authorities will progressively have to make the criteria to allocate public R&D support more restrictive and demanding, since foreign firms will also be gradually invited to participate in public procurement tenders (as the new EU Directive indicates). If policy-makers will decide to increase public allocations mainly for large multi-product and multi-competence enterprises, this will tend to make these oligopolistic producers stronger and more competitive but will not lead to any increase in the number of exporting firms in the industry (result 4). By contrast, if the authorities decide to emphasize the first allocation criterion (product quality), this will have a visible effect and act to increase the industry's mean quality and export propensity (result 3).

< Figure 5 here >

6. Simulation of different policy scenarios for EU countries

This section makes use of these four long-run properties of the model to analyze and compare six different policy scenarios. The exercise is intended to compare the current situation – in which the European defence industry is characterized by a high level of national protection and a low degree of market liberalization – with five possible future scenarios, which will be realized when public defence authorities in European countries will start to implement the new EU Directive and thus introduce a stronger degree of openness and liberalization in this market.

The *current scenario* is obtained by calibrating the model in order to fit the dynamics of an industry with an export propensity between 35 and 40%, which corresponds on average to the real percentage of exporting firms in national defence markets in Europe. Specifically, we present two versions of our calibration exercise, one for a small country (e.g. Sweden, Netherlands, Norway) and the other for a large economy (e.g. France, Germany, UK). The small country version has 150 defence enterprises, 60 products and an average export intensity of 50% (i.e. we reasonably assume that in a small domestic market exporting firms do on average sell a substantial share of their defence products abroad). The large country version has instead 500 enterprises, 400 products and a 10% mean export intensity (i.e. if the domestic market is large, exporting firms sell on average a greater share of their products at home and a smaller share abroad).

The specific values that we have used to calibrate these three parameters (number of firms, number of products and export intensity) are purely indicative and do not correspond to real data for the defence industry in European countries (which are not available). The idea is to set up a stylized and simple comparison between a large and a small national defence market, and see whether and the extent to which these country-specific differences affect the outcomes of the model. It is important to notice, however, that the results described below do not depend on the specific parameter setting that we have used to calibrate the large- and small-country cases, but are general and hold also for different configurations of the parameters set that we have experimented with.

After setting up the *current scenario*, we have then constructed five future scenarios that represent different possible trajectories that the industry may follow in the future as a result of different policy strategies in terms of the implementation of the new EU Directive. These five scenarios differ in terms of how rapidly and actively defence authorities of national Member States will decide to implement the new Directive and introduce market liberalization, i.e. the typology goes from a softer and more gradual implementation towards a more rapid and radical market reform.

(1) *Higher success threshold scenario*: This represents a situation in which national policy-makers of, say, country X do not introduce any significant and active reform towards liberalization. However, the increased openness of other EU countries' defence sectors naturally induces a stronger degree of competition in country X's domestic market. Faced with the challenge posed by the entry of other European firms into the domestic market, country X's enterprises will react by adjusting their success threshold upward.

(2) *Higher cooperation scenario*: If national defence authorities introduce measures aimed at promoting inter-firm collaborations (within and across countries), defence firms will tend to increase their cooperation propensity and, hence, their ability to exploit knowledge spillovers effects.

(3) *Higher product quality threshold scenario*: Policy-makers may also decide to change public procurement mechanisms and modify the criteria they use to allocate

public R&D funds to defence companies. This may be a natural consequence of the fact that foreign EU enterprises will be allowed to participate in national public procurement tenders, thus making these much more competitive and demanding for domestic firms. In particular, if national authorities decide to emphasize the first allocation criterion, they will increase the product quality threshold that firms have to satisfy in order to qualify for public support.

(4) *Increased competence breadth threshold scenario*: By contrast, if they decide to focus on the second allocation criterion, they will increase the competence breadth threshold, and hence start to allocate more funds to large multi-product and multi-competence firms and fewer resources to smaller specialized suppliers.

(5) *Market liberalization scenario*: Finally, if all the policy strategies indicated by the previous four scenarios are combined and implemented together, we obtain a full market liberalization scenario. This may be thought of as the most rapid and most radical way of introducing market liberalization in the defence industry.

Figure 6 reports the results of the policy simulation analysis. Each panel of the figure focuses on one of the six industry-level outcome variables, for the small- and large-country versions of the model respectively. In each graph, we report the time path of a given variable for the six different scenarios outlined above and for a 150-run period.[6]

The first panel of figure 6 focuses on the dynamics of export propensity in the defence industry. The *current scenario* shows the basic working of the model. Over time, firms tend to learn and improve their technological performance by means of learning by doing, cooperation and R&D activities, so that the number of exporters in the industry does gradually increase as time goes by. Correspondingly, the other graphs

[6] We have repeated each exercise for a total of 20 replications in order to make sure that our results are robust to the presence of stochastic shocks related to R&D activities and outcomes. Each point reported in the various graphs in panel 6 is the average of these Monte Carlo replications.

indicate that in this basic scenario the mean product quality in the industry will increase over time, the number of firms receiving public funding will increase, and the concentration level will therefore decrease. However, a comparison between the current scenario and the other five shows that the former is the one characterized by the worst performance in the long-run (i.e. lowest product quality and export propensity at t = 150). Specifically, we observe the following five patterns.

(1) In the *higher success threshold scenario*, companies are on average more responsive to market opportunities and more actively investing in product quality and technology upgrading *vis-à-vis* what they tend to do in the current scenario (for the reasons explained in result 2, see section 5). This second scenario is therefore characterized by a more rapid increase of export propensity over time, which eventually stabilizes at a value around 40%. This is also the scenario where firms undertake the greatest number of new privately-funded R&D projects in order to adjust and improve their technological performance. A comparison of the small- and large-country versions of the model indicates that the main difference is in terms of the two concentration indexes (see last two panels of figure 6). The decrease in the C5 and E5 concentration indexes over time is much stronger in a large country than in a small economy.

(2) The *higher cooperation scenario* is the one where defence firms, due to their higher collaboration propensity, exploit more actively the opportunities provided by external learning and knowledge spillovers effects (see result 1). This explains why this scenario outperforms the current one leading to a much higher export propensity (around 50%). Due to the strength of this imitation-based catch up mechanism, a substantially number of firms are able to attract public funding for carrying out R&D activities. Many of these SMEs and catching up enterprises are also able to start to

export their products abroad, so that the E5 export concentration ratio decreases significantly over time (for the large country the decrease is visibly more pronounced than for the small-country).

(3) The *higher product quality threshold scenario* also leads to a higher export propensity in the long-run (between 40 and 45%) and a lower market and export concentration. Differently from the previous, though, in this policy scenario enterprises are able to strengthen their market position over time despite the fact that public funding opportunities decrease (result 3). The increase in the export propensity and the decrease in the market and export concentration are stronger in the large- than the small-country version of the model. The reason is that the competition and selection mechanisms triggered by product quality enhancing investments are magnified and arguably have stronger effects in a large market than in a small economy.

(4) The *increased competence breadth threshold scenario* does not lead to any substantial change as compared to the current scenario. This is because, as pointed out by result 4 (section 5), this second public funds allocation mechanism (*technological breadth*) is not aligned with the crucial market requirement for competing in international markets (*technological depth*). Hence, this will end up by strengthening the leading position of large oligopolistic producers but will not increase export opportunities for most other SMEs in the market. In this scenario, no main difference emerges between the large- and small-country simulations.

(5) Finally, the *market liberalization scenario* clearly outperforms all other policy strategies considered in figure 6, since this is obtained by combining together all four previous scenarios, representing the possibility that national defence authorities will opt for a rapid and radical reform of the defence market towards openness and full

liberalization. This would lead, according to this model, to a substantial increase in the number of exporting firms and a more competitive and less concentrated market in the long-run. It is also interesting to note that the effects of full market liberalization on export propensity are more rapid in the small-country version of the model, whereas in the large-economy version the market liberalization scenario takes a substantially longer time (between 50 and 100 runs) before overtaking the others.

We conclude our simulation analysis by presenting the results of one final exercise that is useful to summarize and highlight one key fact outlined by this model. Table 1 presents the results of four panel data regressions that point out the statistical relationship between firms' performance (profits and export participation), on the one hand, and technological *breadth* and *depth*, on the other. The regressions are run on the set of simulated data produced by two of our model's scenarios: the current one and the market liberalization scenario. These are firm-level panel dataset (150 firms for a 200-period time span) obtained from our small-country model calibration. We make use of panel fixed effects estimators to analyze this reduced-form relationship that characterizes agents' behavior in our model.

The results, as shown in table 1, are in line with the main intuition already discussed along the paper. In both scenarios, firms' performance is positively and significantly related to their product quality, and negatively linked to the length of their innovation hypothesis. In other words, the model points out the existence of a trade-off between technological *breadth* and *depth*: it is the latter factor that makes firms internationally competitive in a given industry segment or market niche. If policy makers aim at increasing the export propensity of the industry, it is product quality, and not firm size or competence breadth, the key firm-level factor they should target and try to foster.

< Figure 6 and table 1 here >

7. Conclusions

The paper has presented an agent-based simulation model of the defence industry. The model is set up in such a way that it resembles some of the key stylized facts and idiosyncrasies of the defence sector, and studies how this may react when a higher degree of openness and liberalization will be introduced in this market. In particular, the exercise is valuable and timely in a European context, given that the new EU Directive (2009/81/EC) has recently introduced a new policy framework that will gradually lead to a progressive liberalization of the defence market. It is therefore important to investigate how micro-level agents (defence firms) in each domestic market will respond to these new challenges and opportunities. The results of the simulation analysis of this model highlight four main results and implications.

First, as the EU defence sector will gradually become more open and integrated, firms in each national market will start to adjust their own performance criteria and expectations upward, i.e. their *success threshold* will increase as the industry becomes more open and competitive. This external environmental pressure will induce firms to invest more actively in technology and product quality upgrading, thus increasing the overall industry performance and export propensity in the long-run. This is likely to happen, according to our model, even in the absence of explicit actions of national policy-makers intended to introduce reforms towards market liberalization in their respective country.

Secondly, if national defence authorities will instead decide to undertake a more active strategy, e.g. by introducing schemes intended to foster inter-firm collaborations (within and across countries), this will substantially improve the performance of the industry. Defence enterprises will become more prone and better able to exploit the opportunities provided by external learning and knowledge spillovers, and this will eventually lead to a higher product quality and export propensity in the industry.

Thirdly, national policy-makers may also contemplate the possibility to change public procurement rules and revise some of the criteria they use to allocate R&D support to private firms. The new EU Directive does in fact intend to introduce a higher degree of openness in public procurement tenders, by allowing other foreign (EU) firms to participate in the public procurement tenders announced by a given national Member State. If national policy makers will allow for this, they will inevitably have to revise their public funding allocation criteria making them more restrictive. They may do that in two different ways. They may either increase the product quality threshold that the applicant firms have to satisfy (which depends on the degree of specialization or *depth* that the firm has in a specific industry segment), or increase the minimum competence *breadth* that the applicant must have (which is directly related to the firm's size). Our model shows that emphasizing the first criterion will lead to a substantial improvement in the industry's performance in the long-run, whereas the second will not. The reason for this is that the first criterion provides defence firms with a clear signal that product quality is the key factor to compete in international markets (more firms will then become exporters), while the second tends to concentrate public R&D funding opportunities in the hands of a limited number of large oligopolistic enterprises. In this way, these dominant enterprises will arguably strengthen their international position, but the total number of exporting firms in the industry (export propensity) will stay the same.

Finally, our simulation results indicate that the effects of market liberalization in this sector will differ in large and smaller European economies. On the one hand, large countries are likely to experience greater overall benefits in terms of reduced market and export concentration, due to the fact that the catching up, competition and selection dynamics of the model are magnified in the presence of a larger and more populated market. On the other hand, however, the positive effects of market liberalization unfold more rapidly in a small economy and more slowly in a larger country. The policy implication of this fourth result, in our view, is that large European countries should take the lead in the implementation of the new EU Directive and pursue a more active and more rapid process of market liberalization than small European countries.

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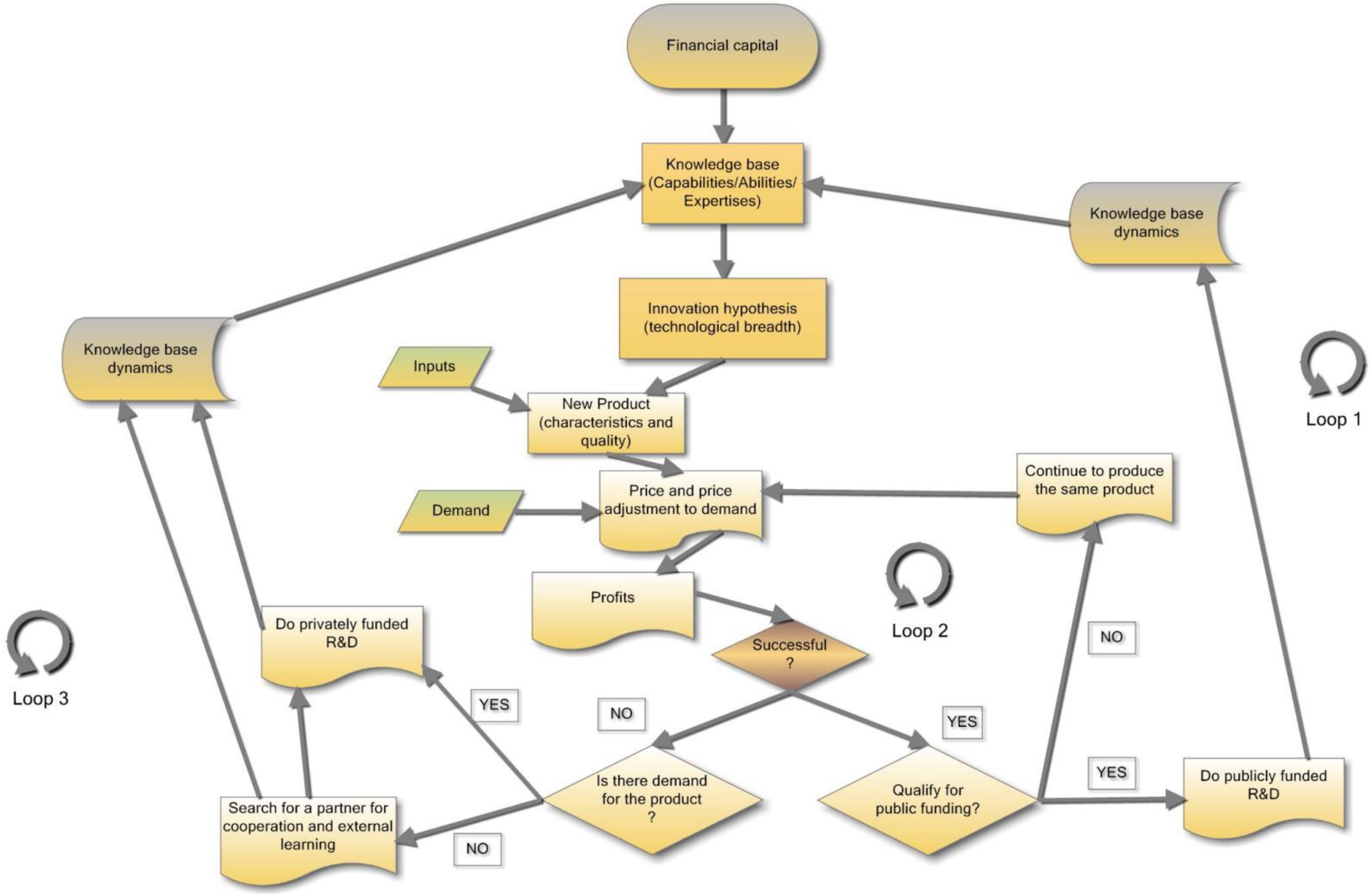
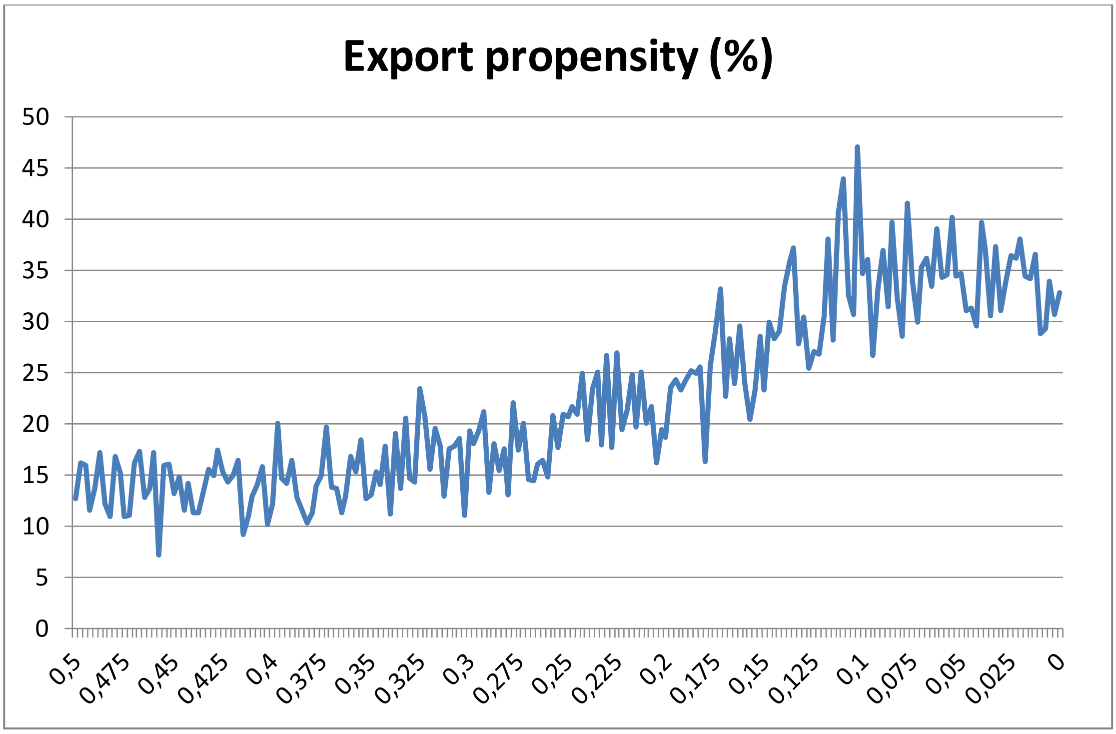
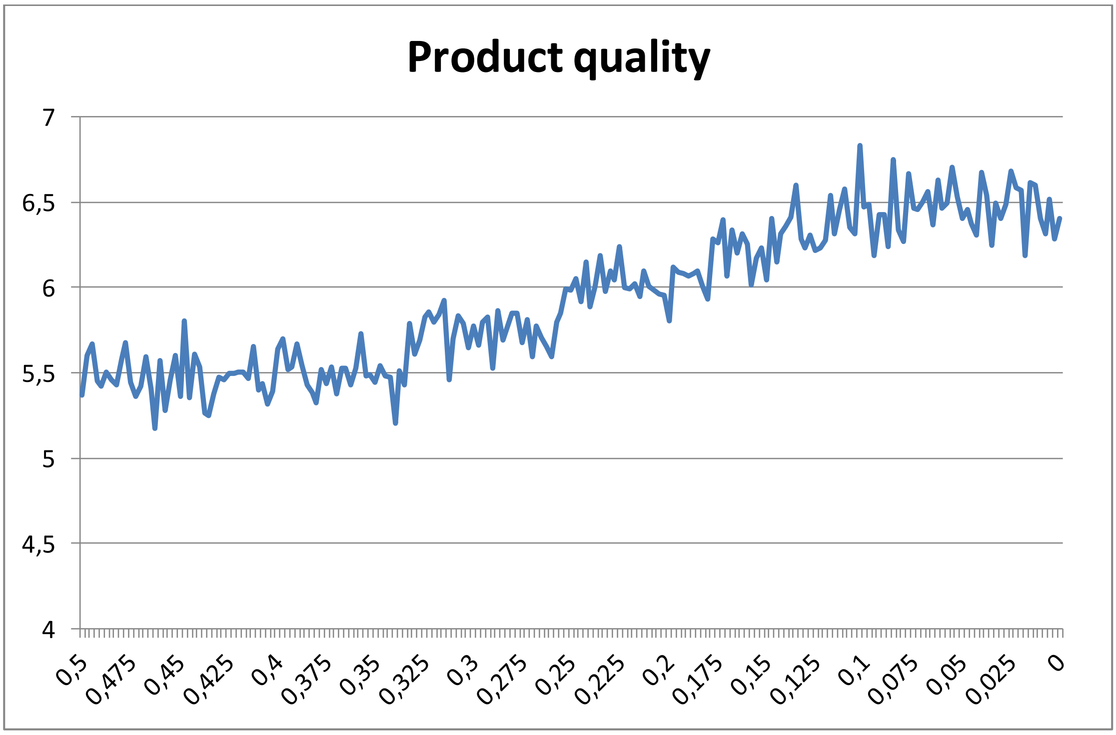
Figure 1: Model flowchart

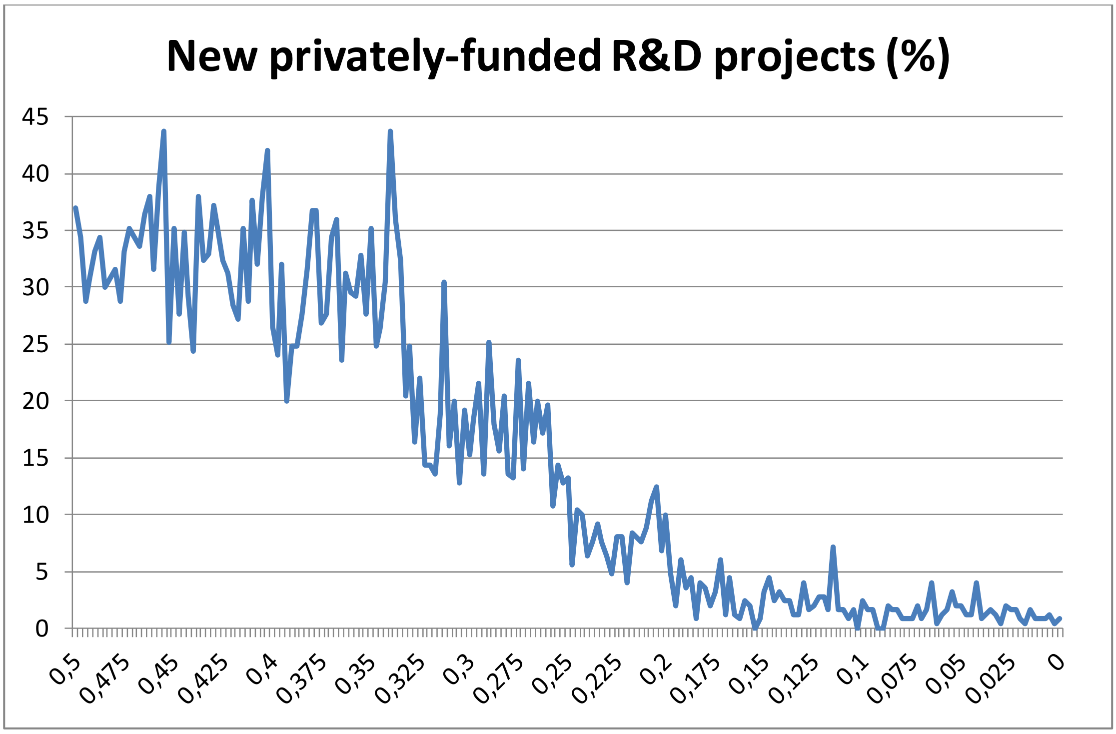


Legend:
Loop 1: Successful firms that qualify for public funding
Loop 2: Successful firms that do not qualify for public funding
Loop 3: Unsuccessful firms doing privately funded R&D and cooperation

Figure 2: Effects of an increase in the cooperation propensity (X-axis) on the six industry-level outcome variables (Y-axis).



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0,325
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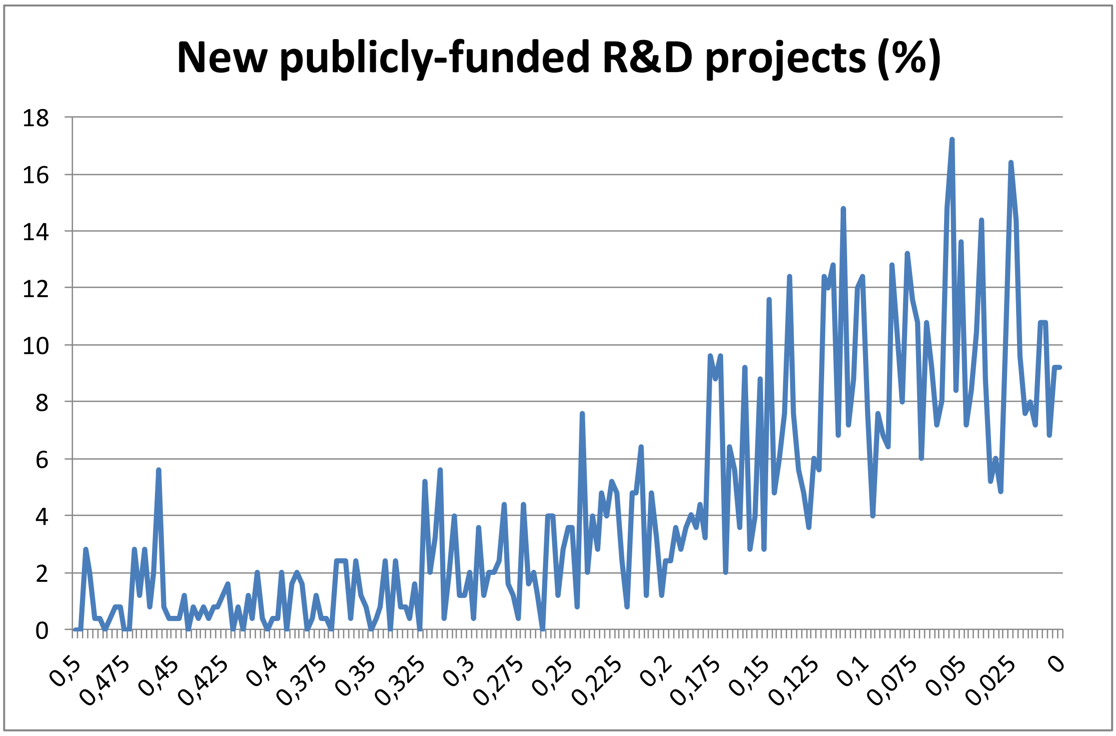
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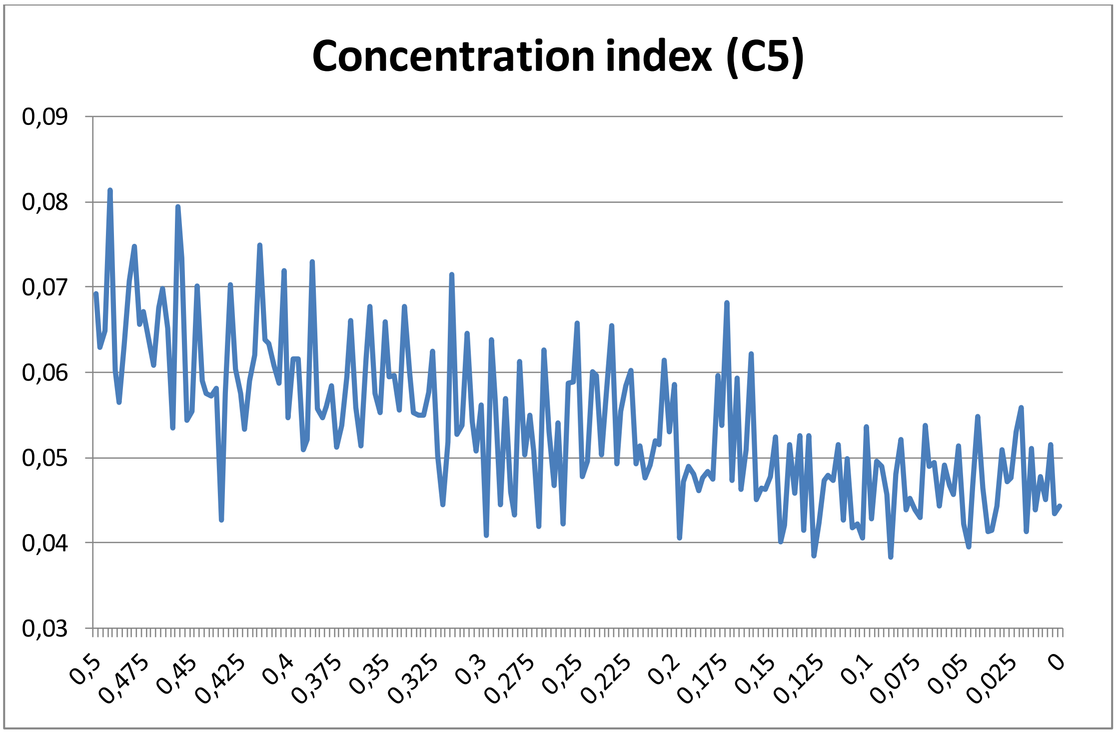
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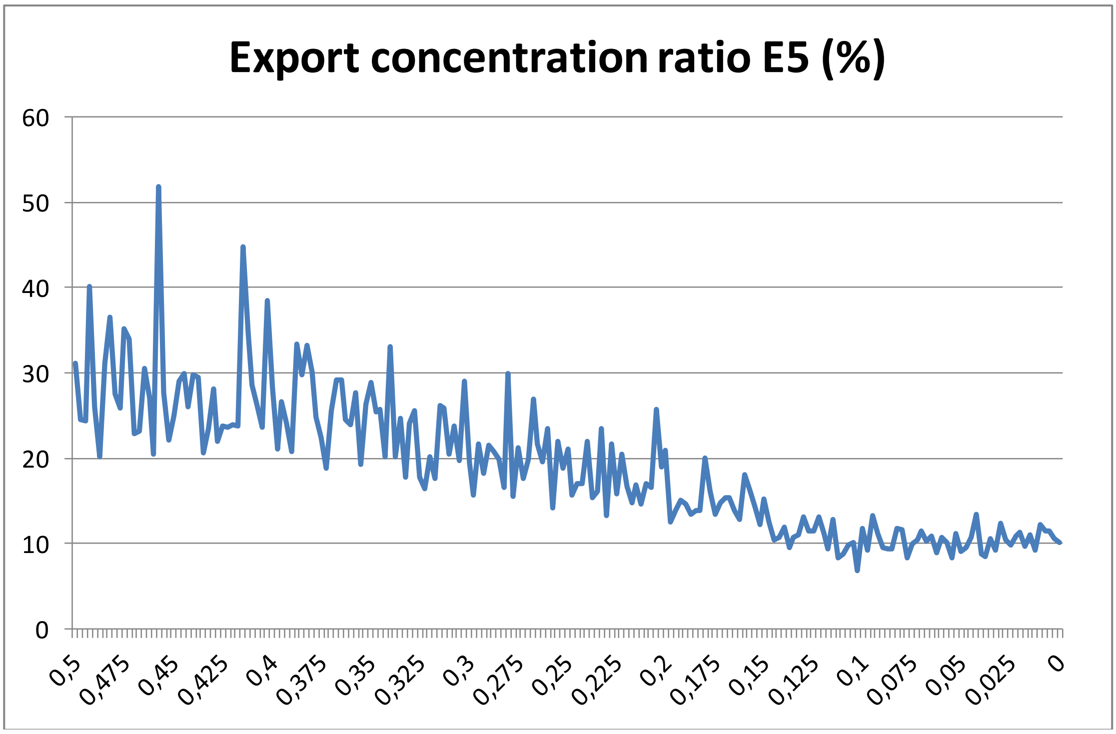
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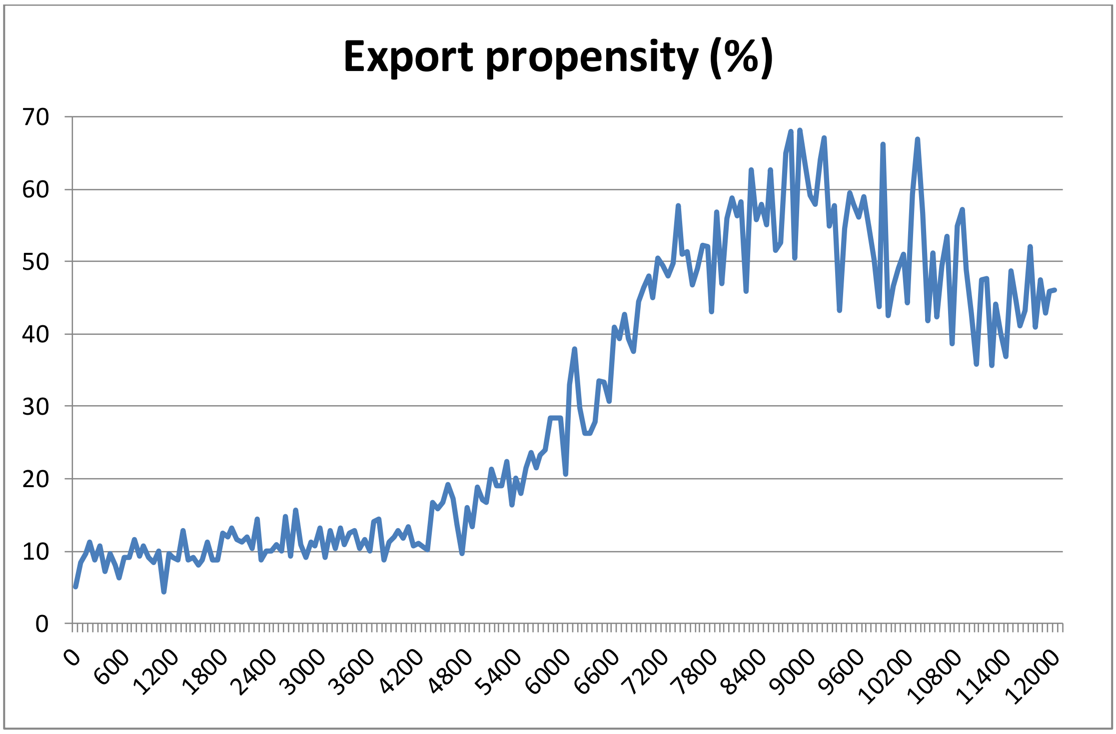
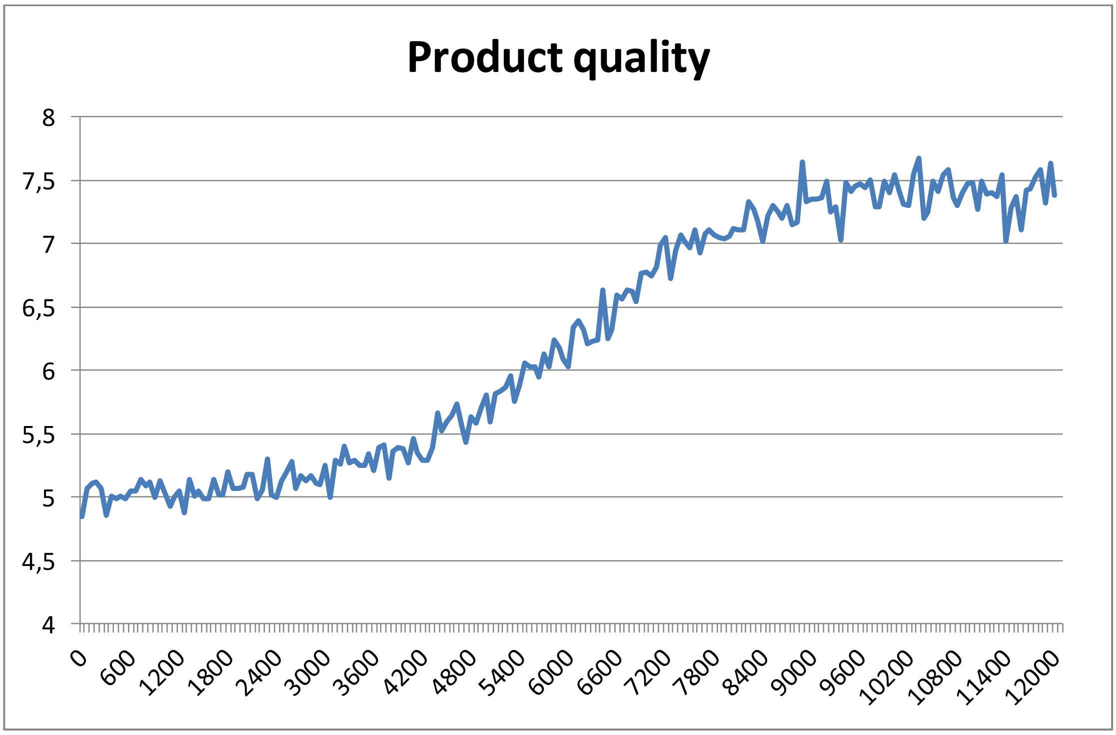
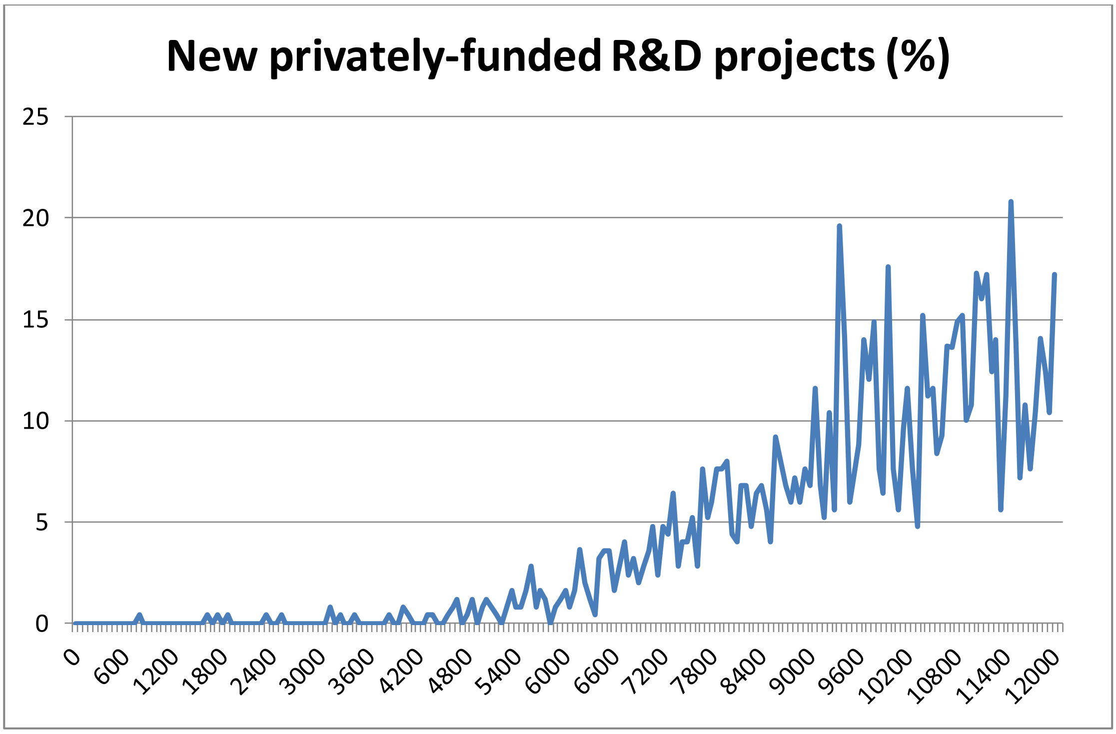
Figure 3: Effects of an increase in the success threshold (X-axis) on the six industry-level outcome variables (Y-axis).



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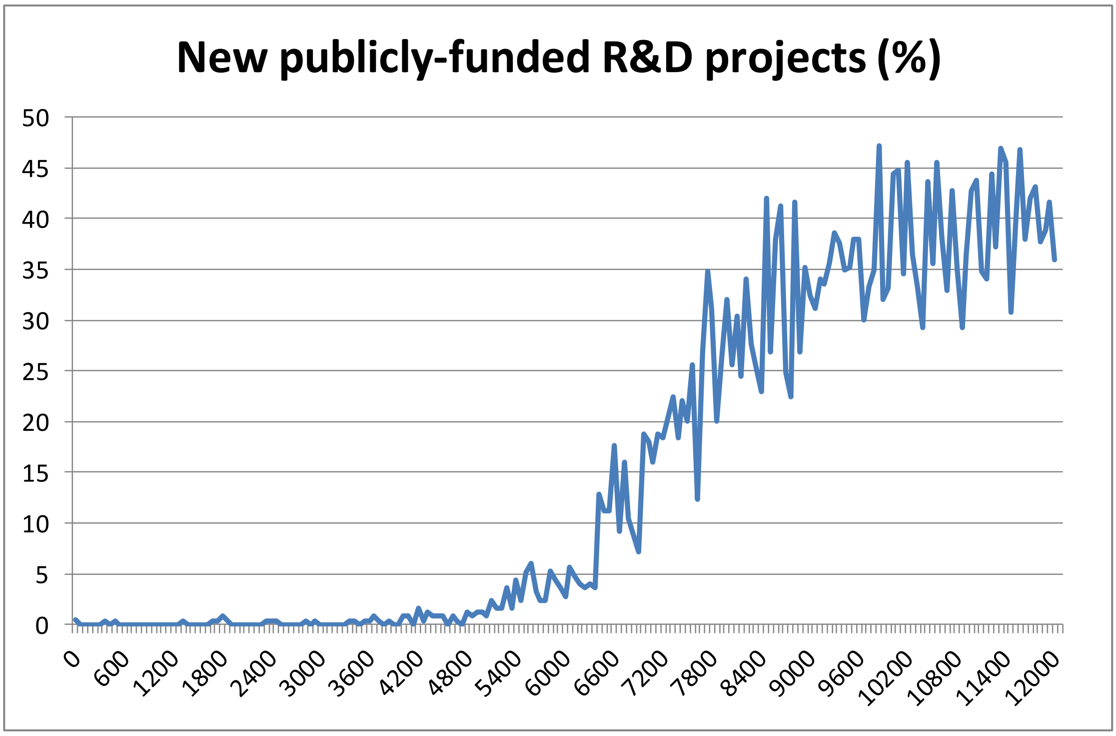
New publicly-funded R&D projects (%)
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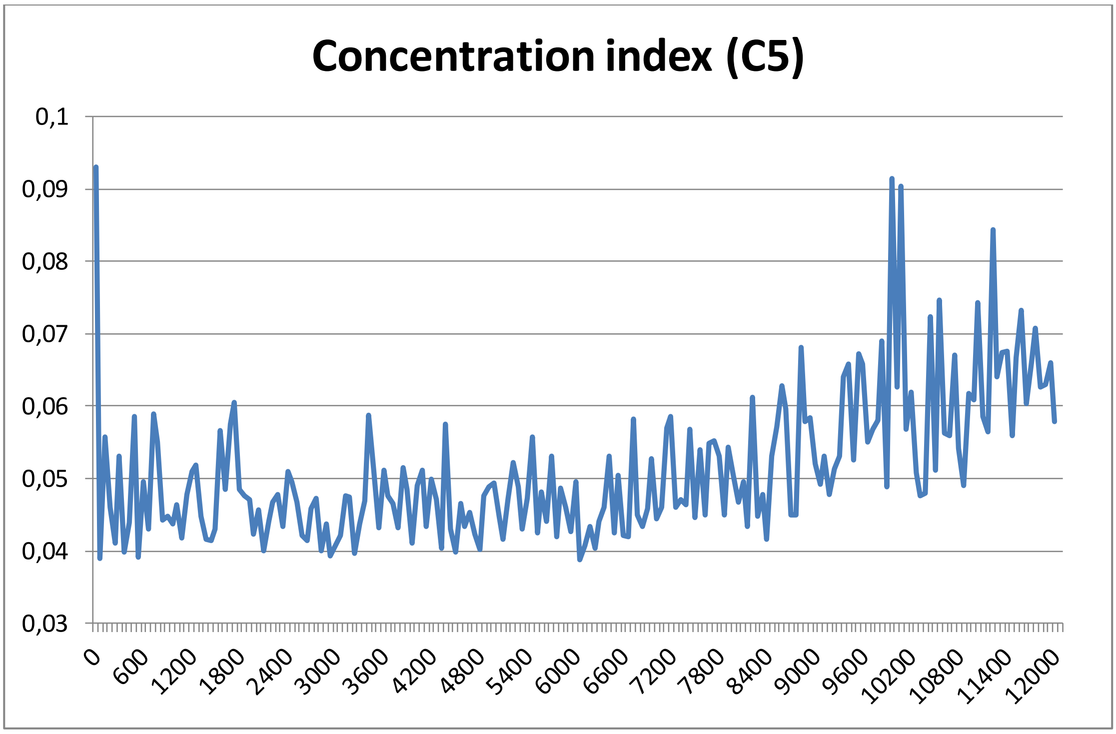
Concentration index (C5)
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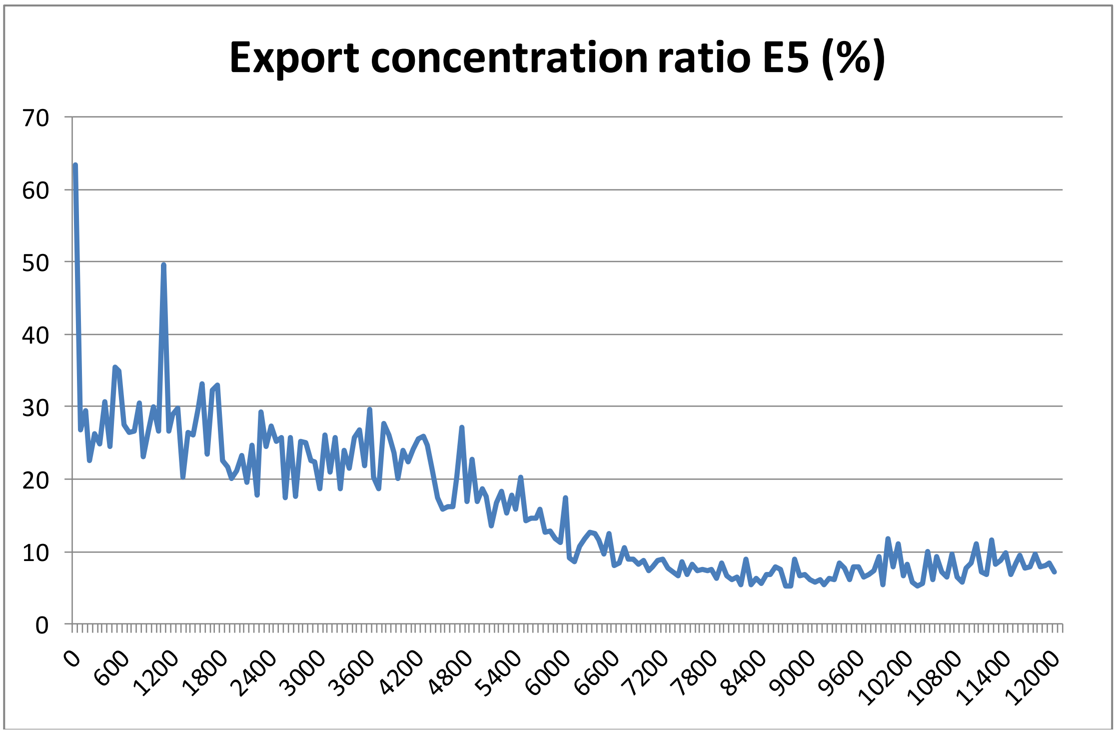
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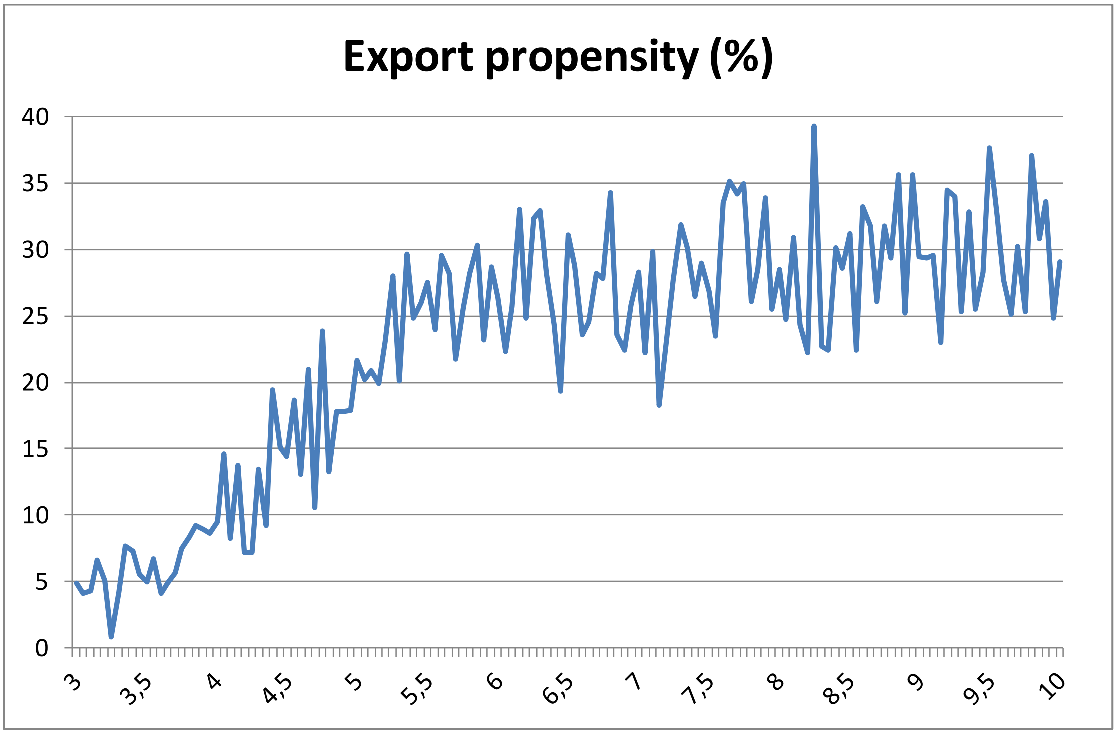
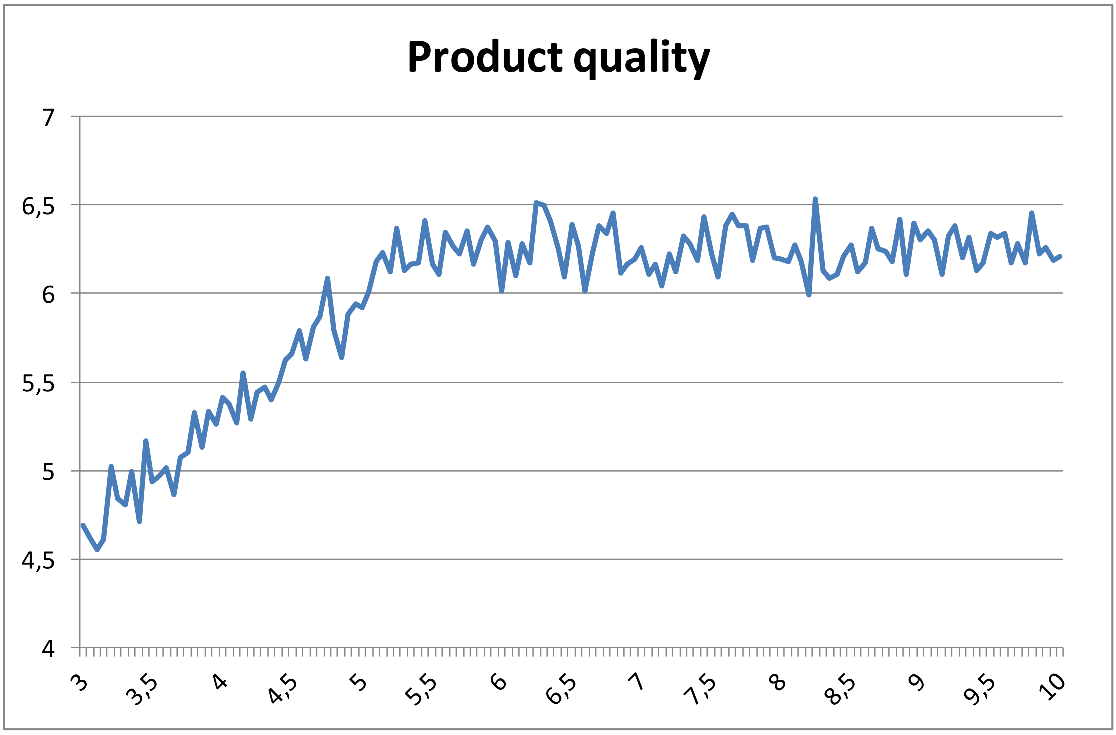
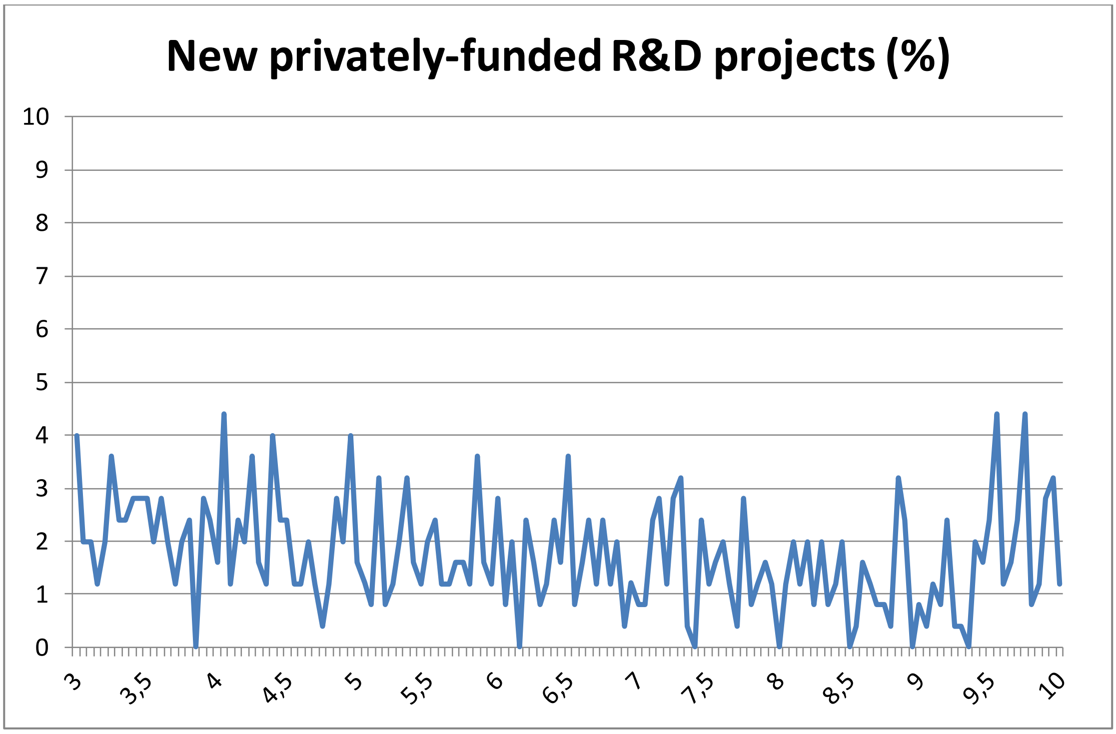
Figure 4: Effects of an increase in the product quality threshold (public funding requirement I, X-axis) on the six industry-level outcome variables (Y-axis).






New privately-funded R&D projects (%)
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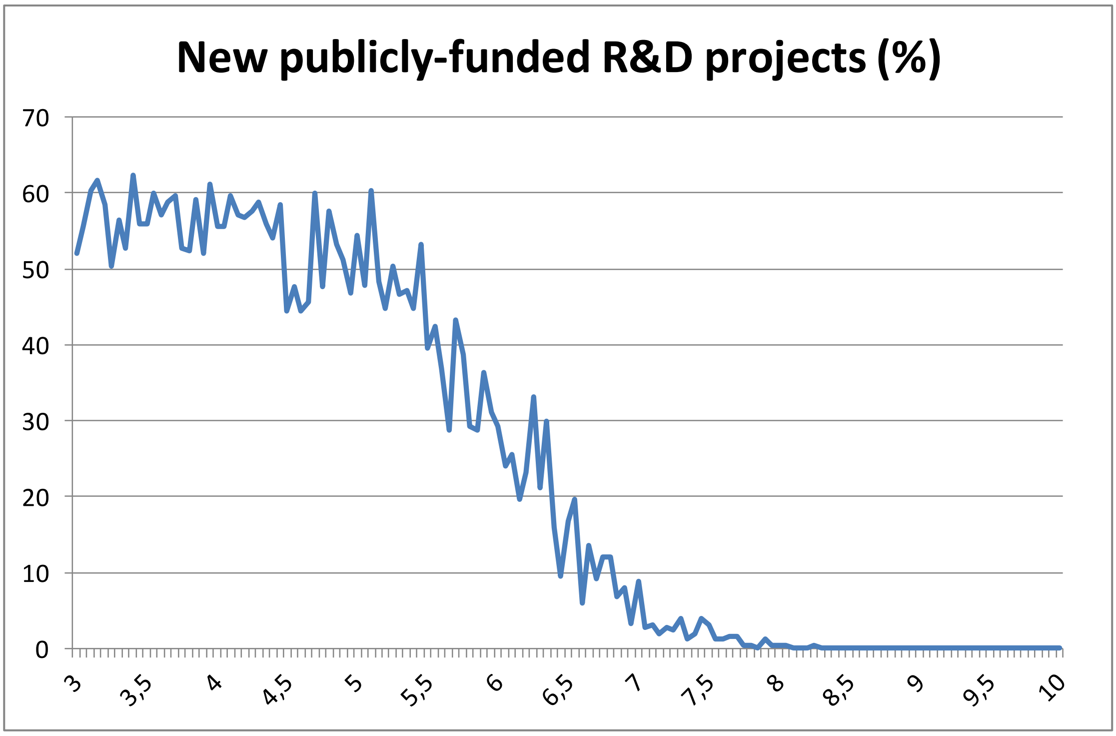
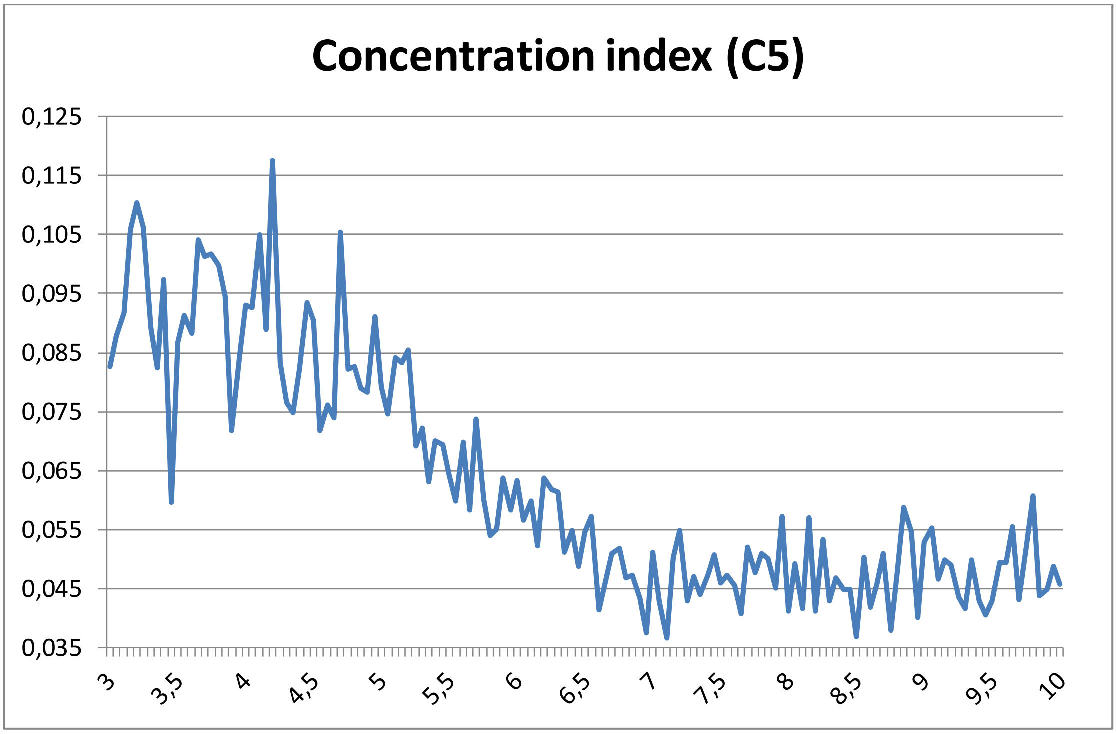
1
0
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10


New publicly-funded R&D projects (%)
70
60
50
40
30
20
10
0
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10


Concentration index (C5)
0,125
0,115
0,105
0,095
0,085
0,075
0,065
0,055
0,045
0,035
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10

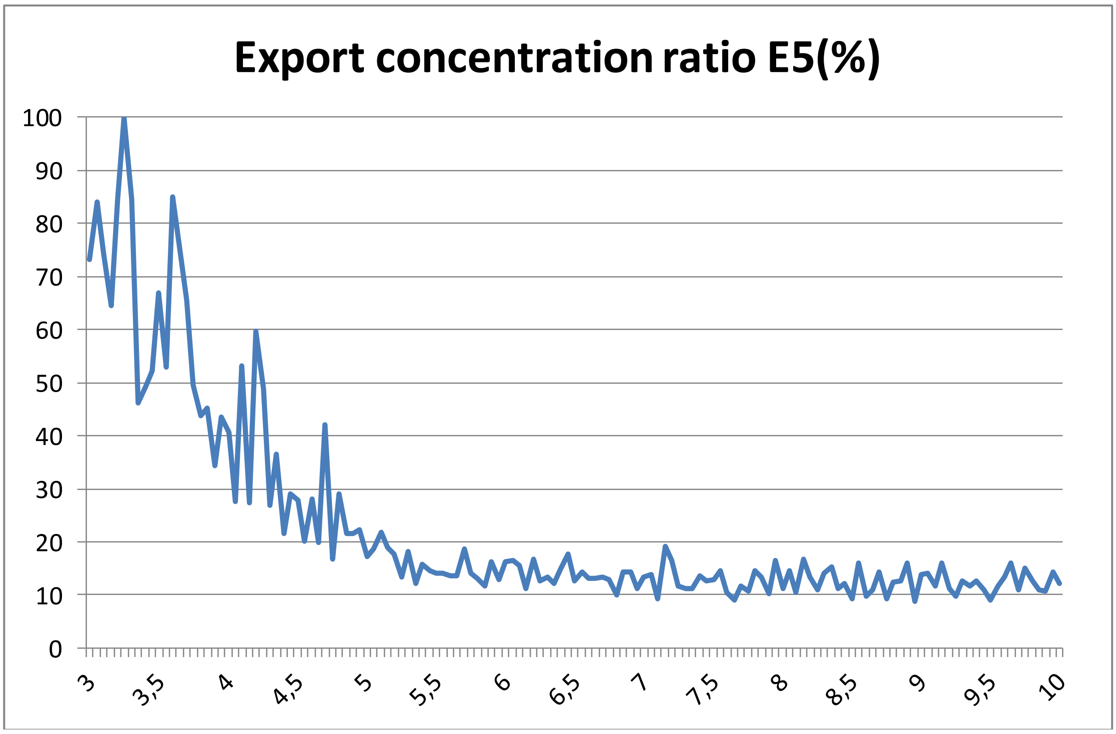
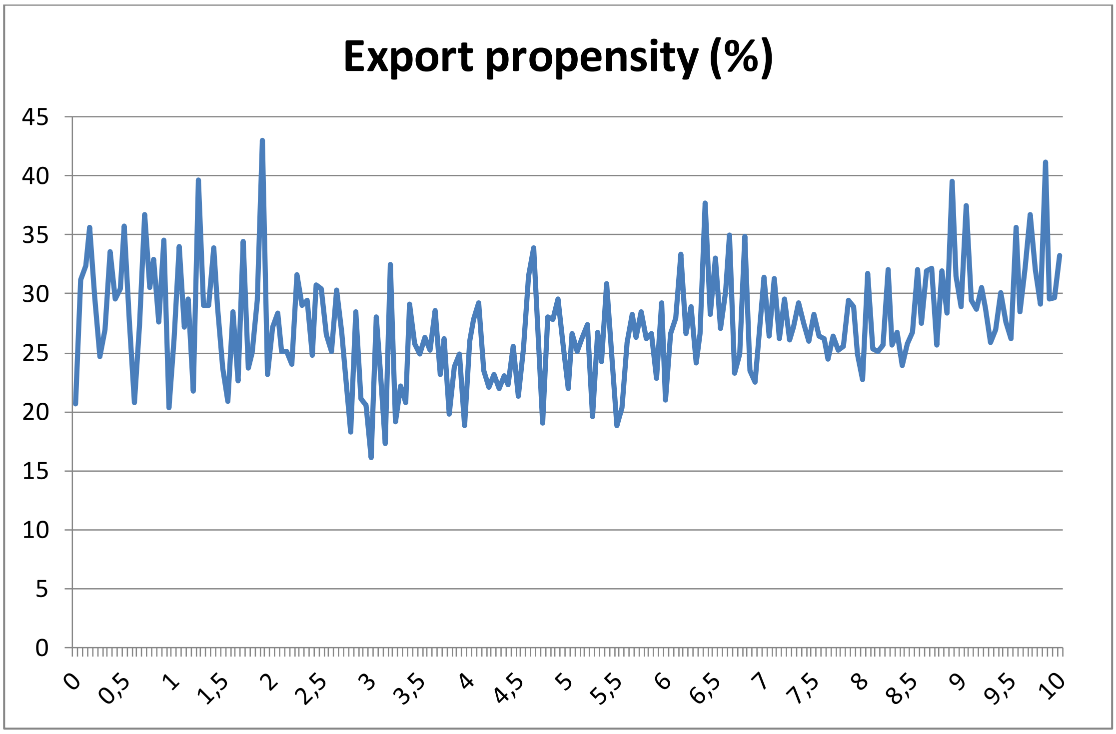
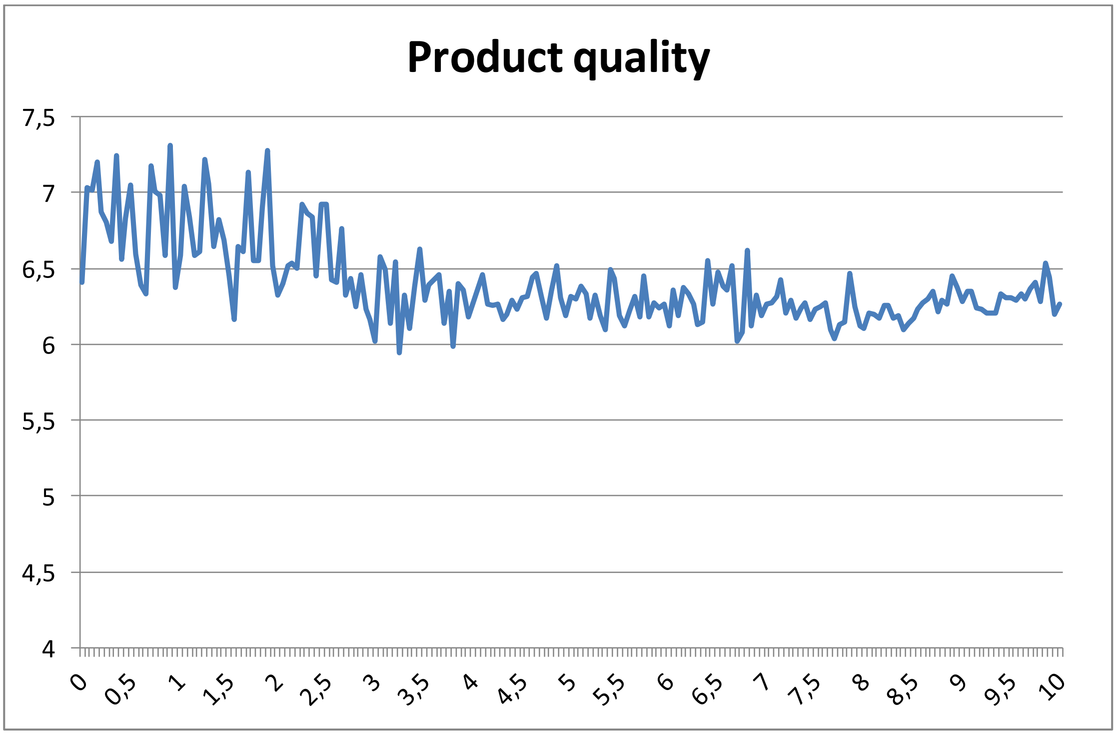
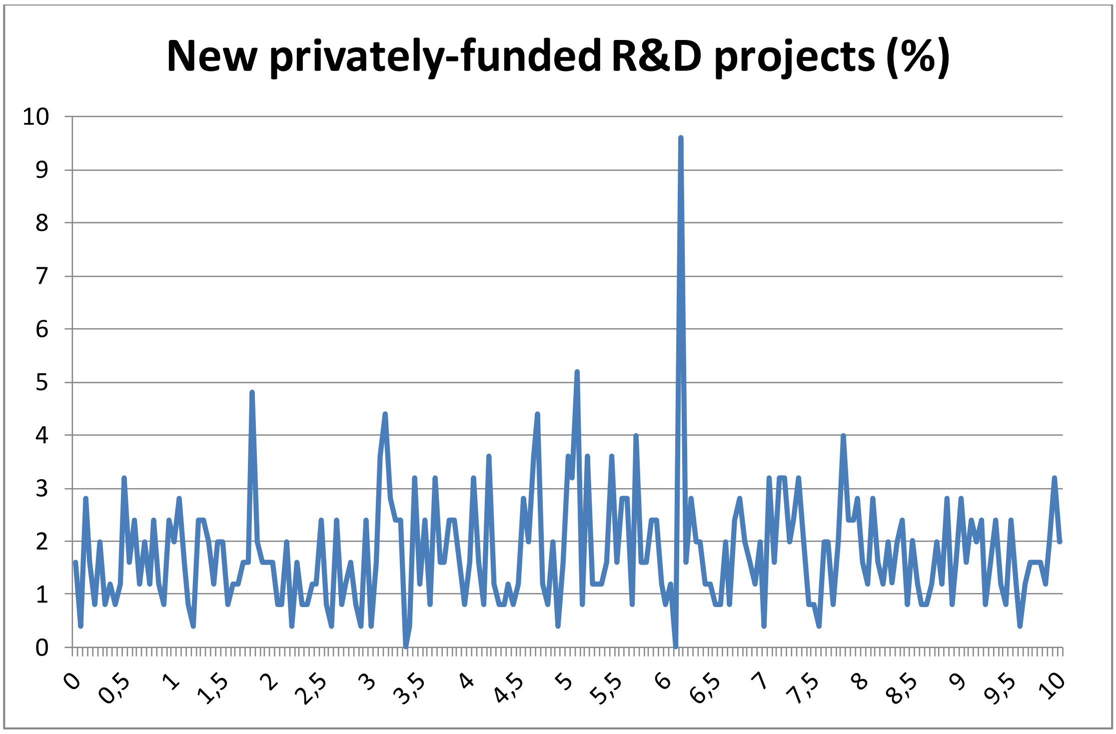
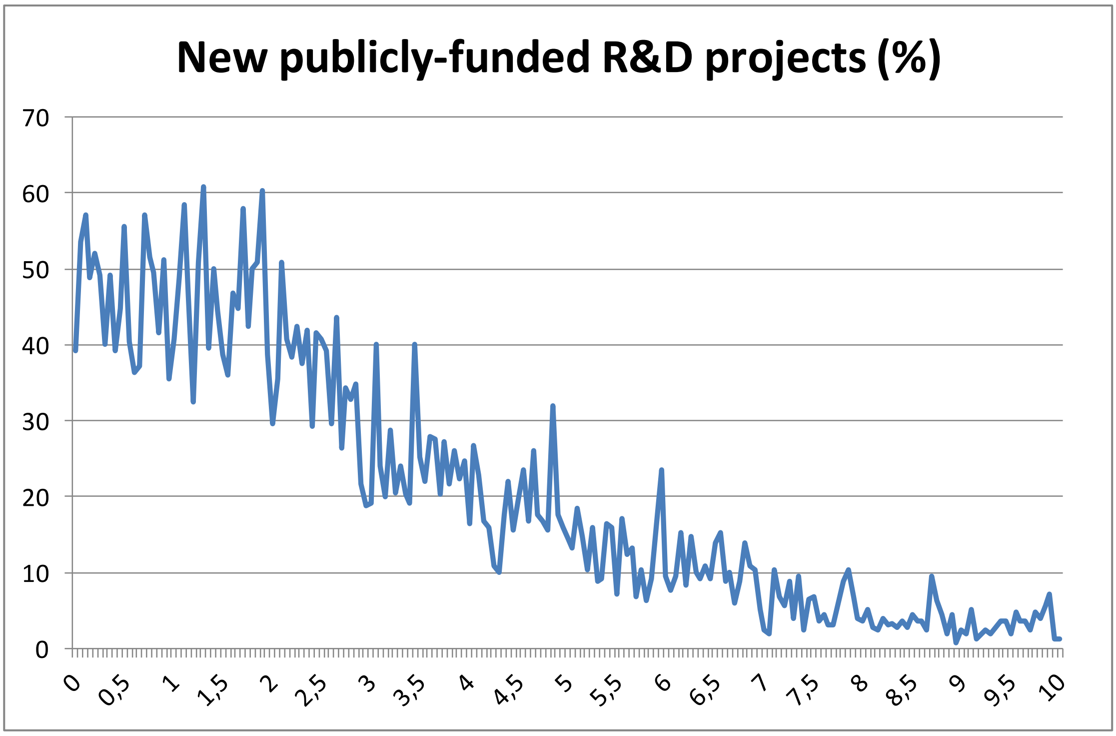

Export concentration ratio E5(%)
100
90
80
70
60
50
40
30
20
10
0
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10

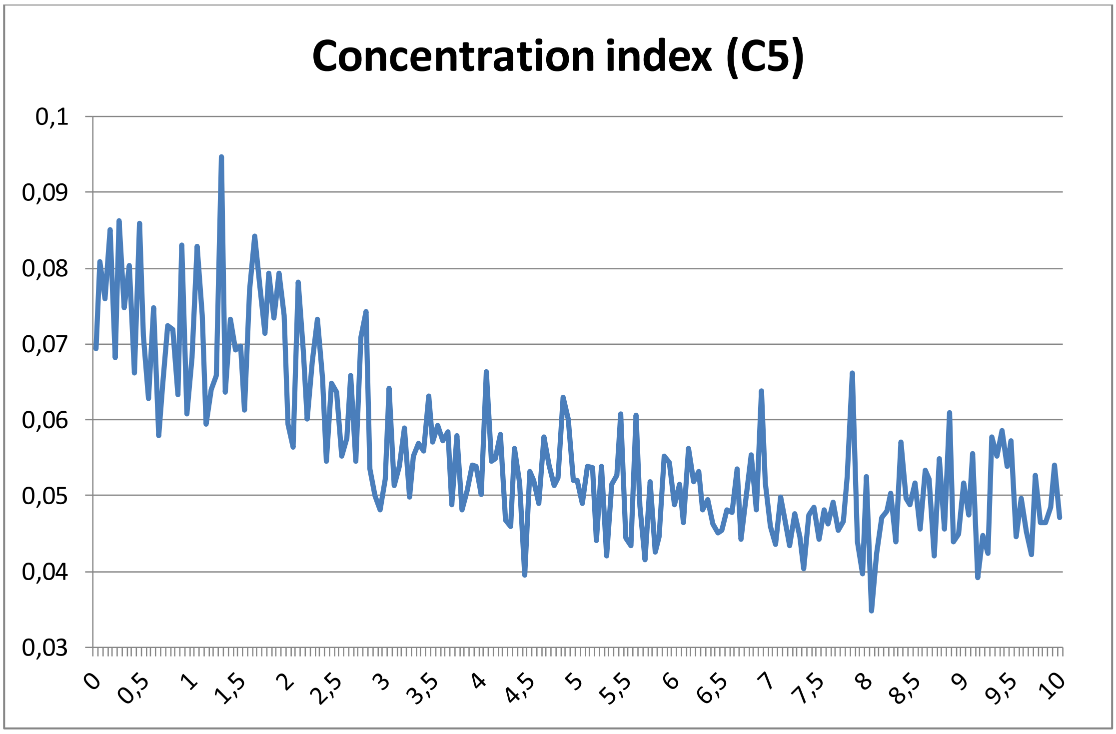
Figure 5: Effects of an increase in the competence breadth threshold (public funding requirement II, X-axis) on the six industry-level outcome variables (Y-axis).






New privately-funded R&D projects (%)
10
9
8
7
6
5
4
3
2
1
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10


New publicly-funded R&D projects (%)
70
60
50
40
30
20
10
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10


Concentration index (C5)
0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10

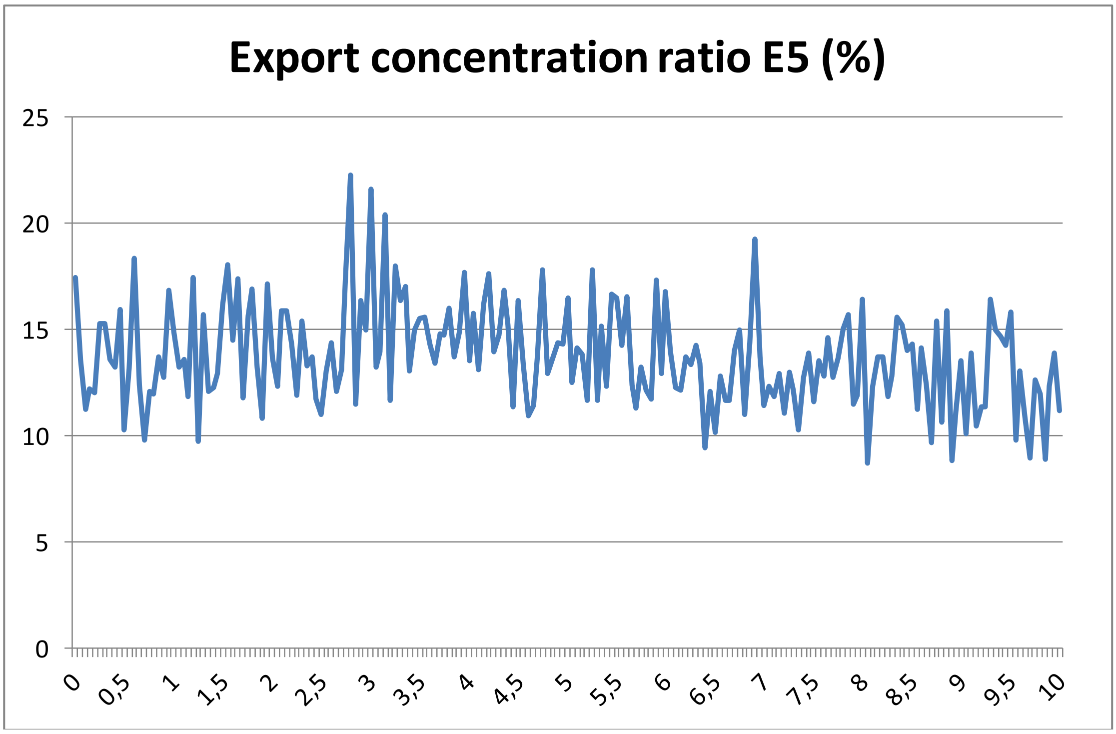
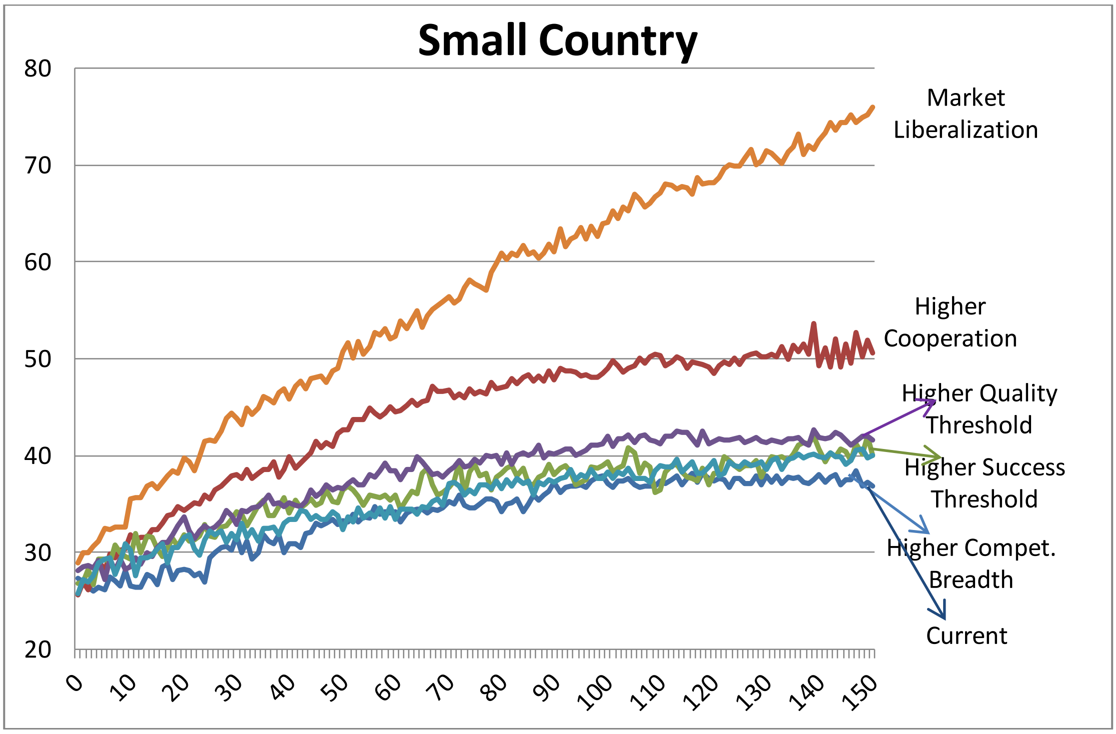
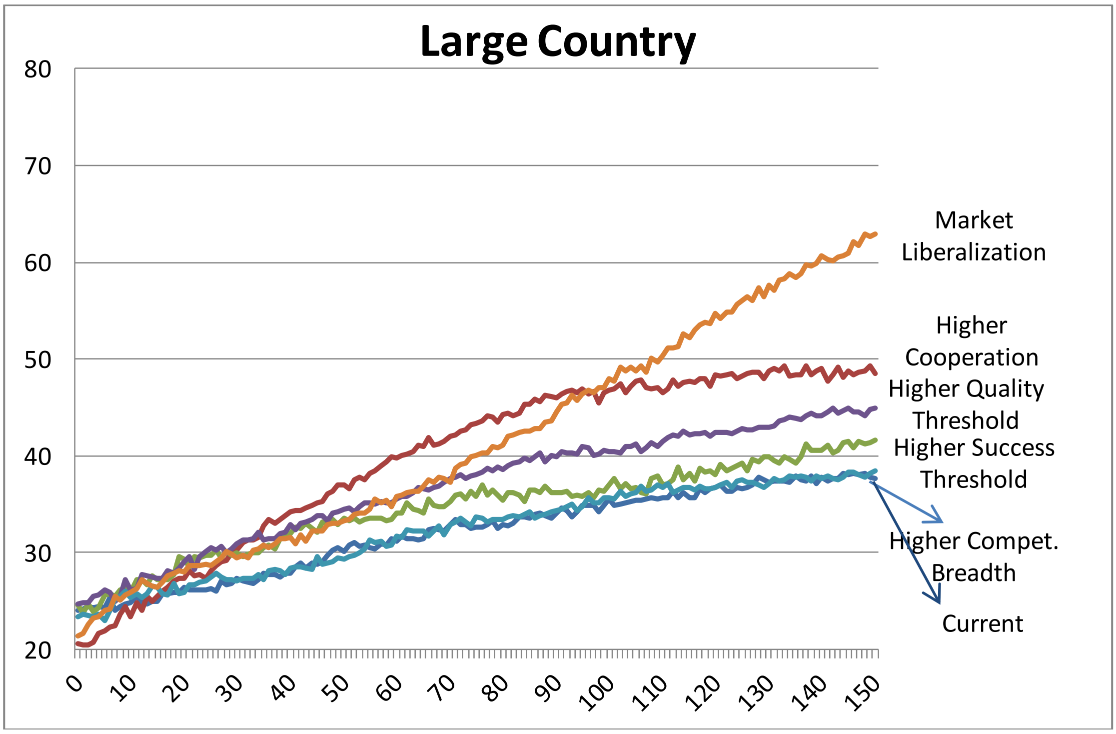

Export concentration ratio E5 (%)
25
20
15
10
5
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
5,5
6
6,5
7
7,5
8
8,5
9
9,5
10

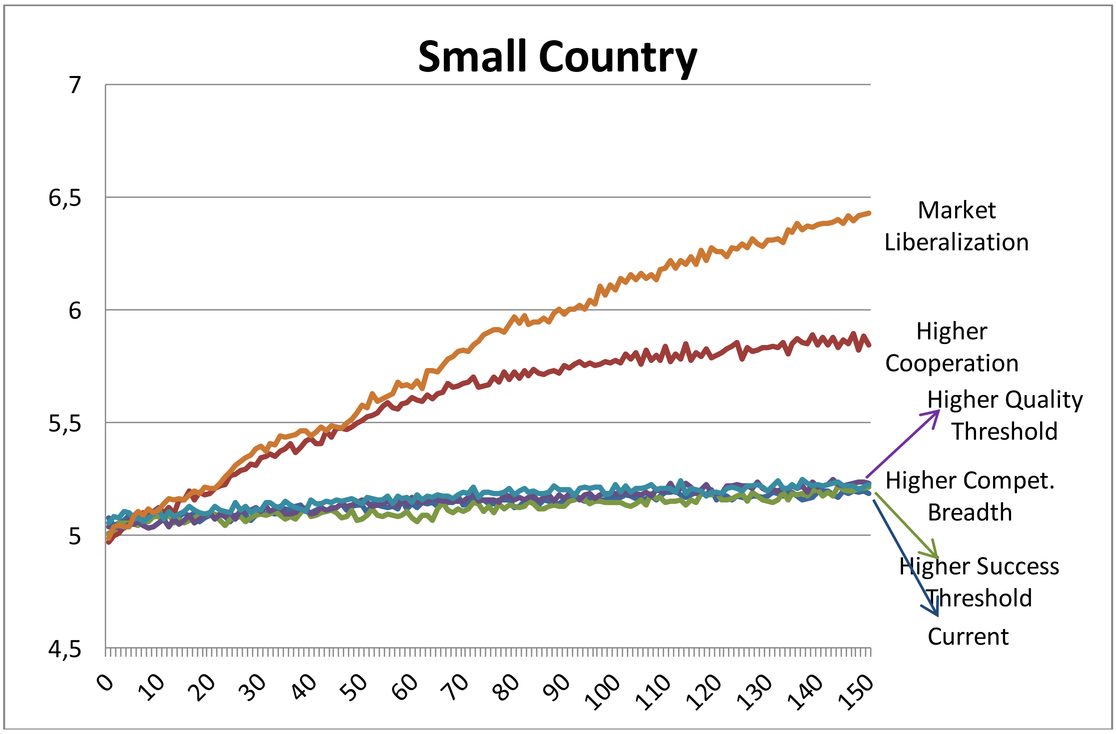
Figure 6: Simulating six different policy scenarios

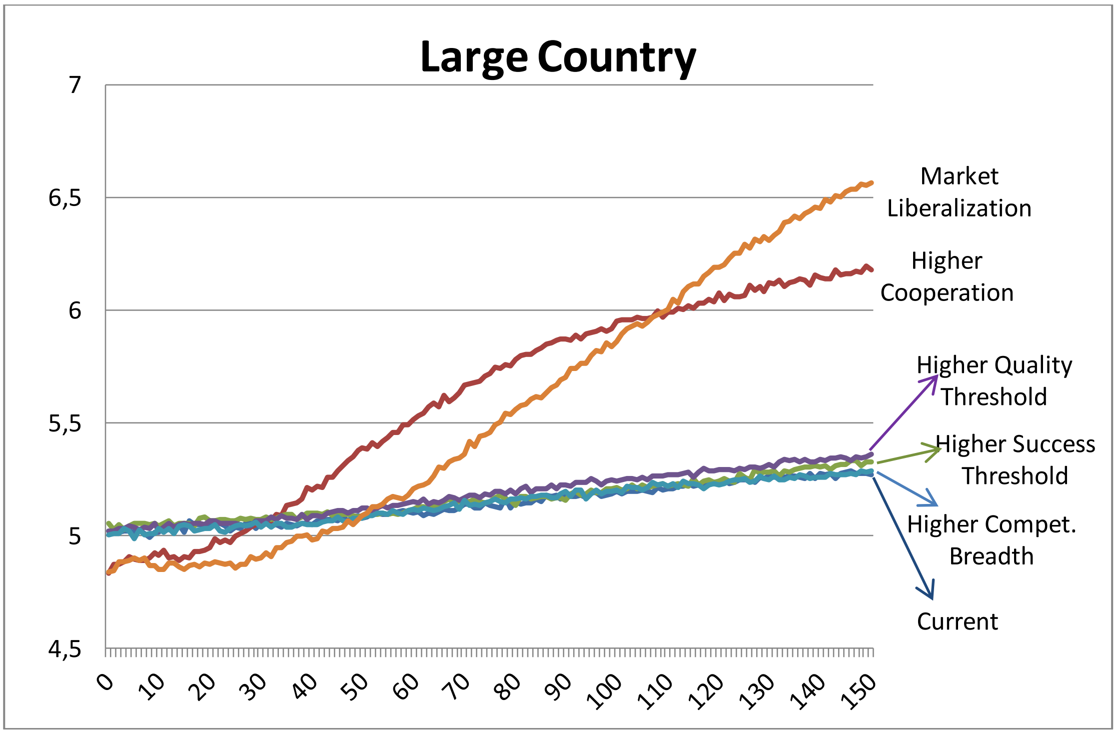
Time path of export propensity (%)



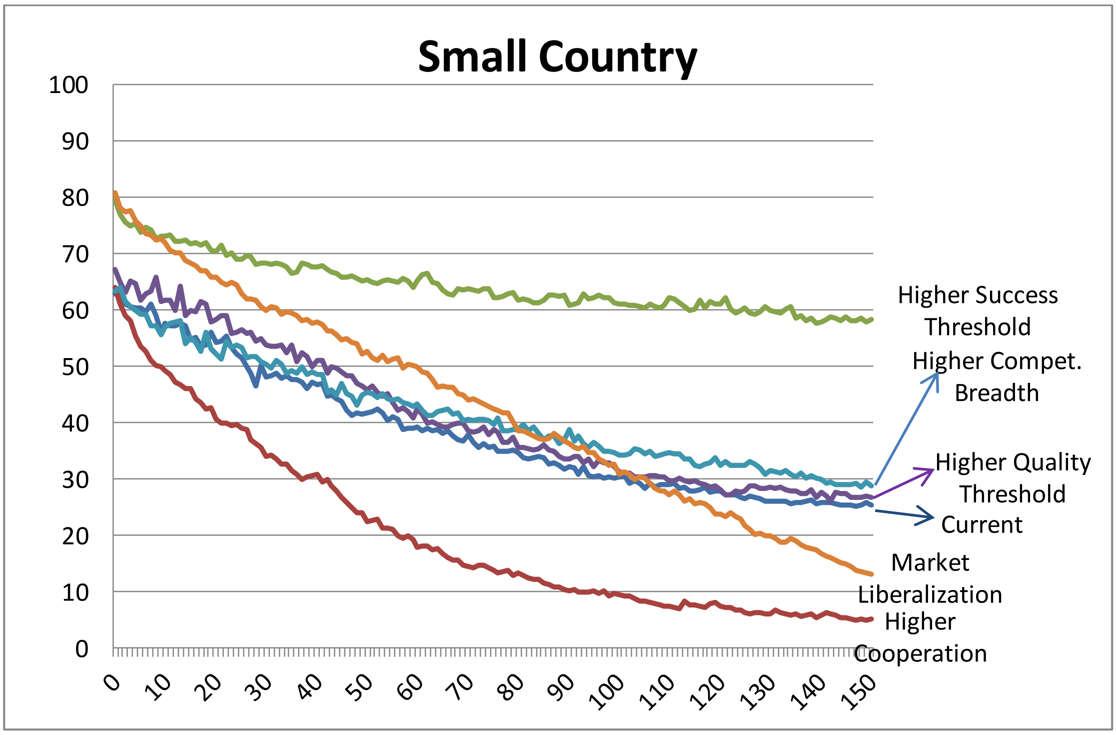


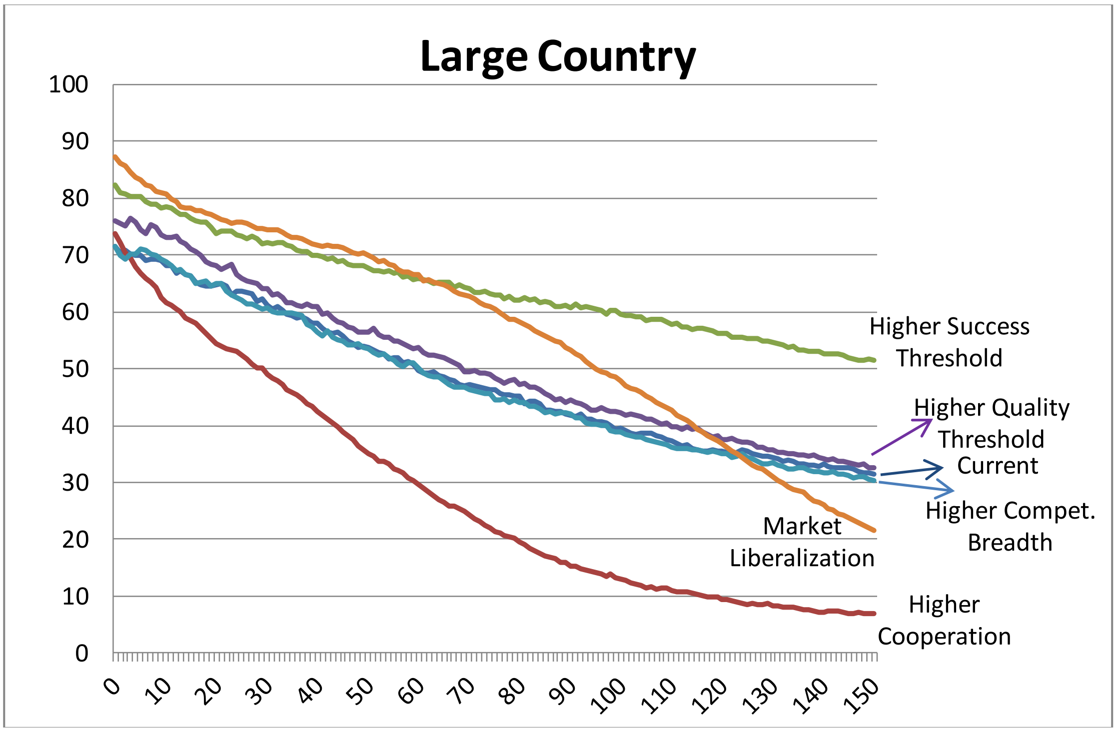
Time path of product quality



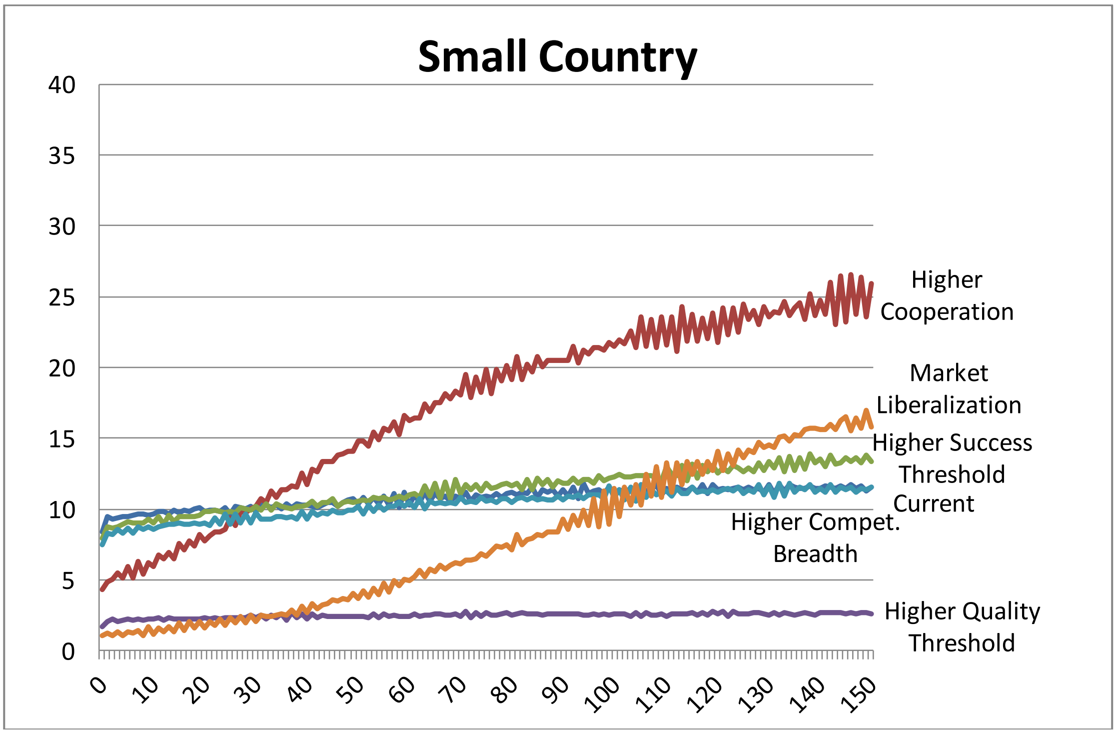


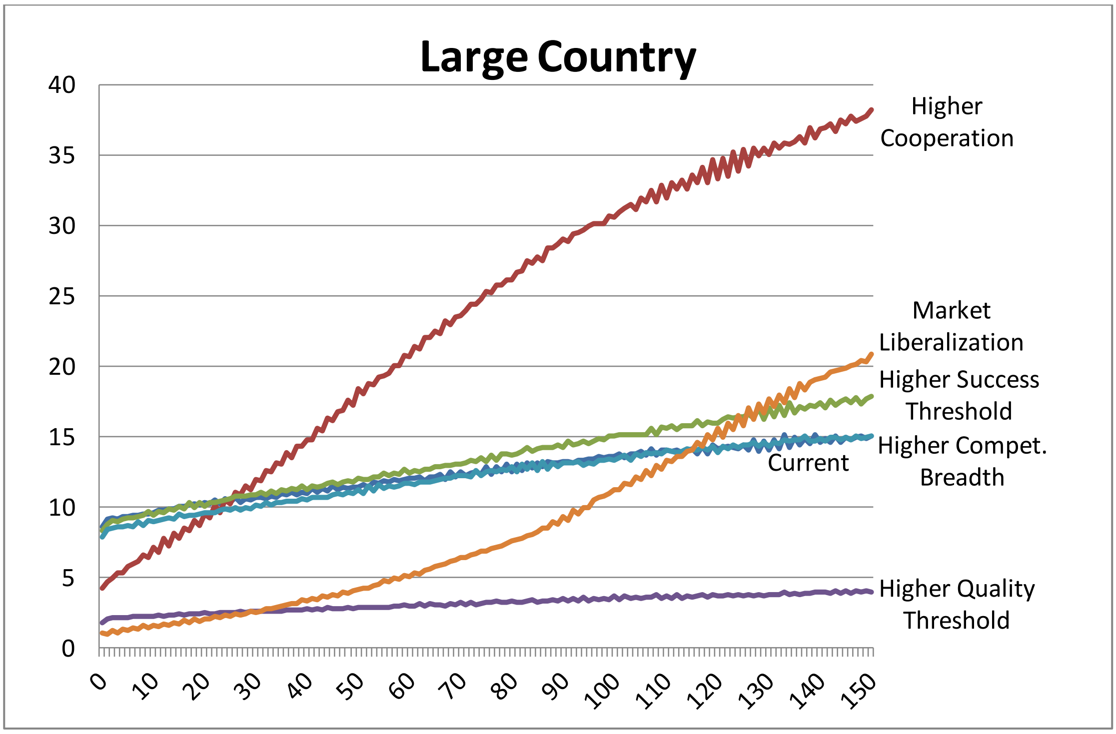
Time path of new privately-funded R&D projects (%)



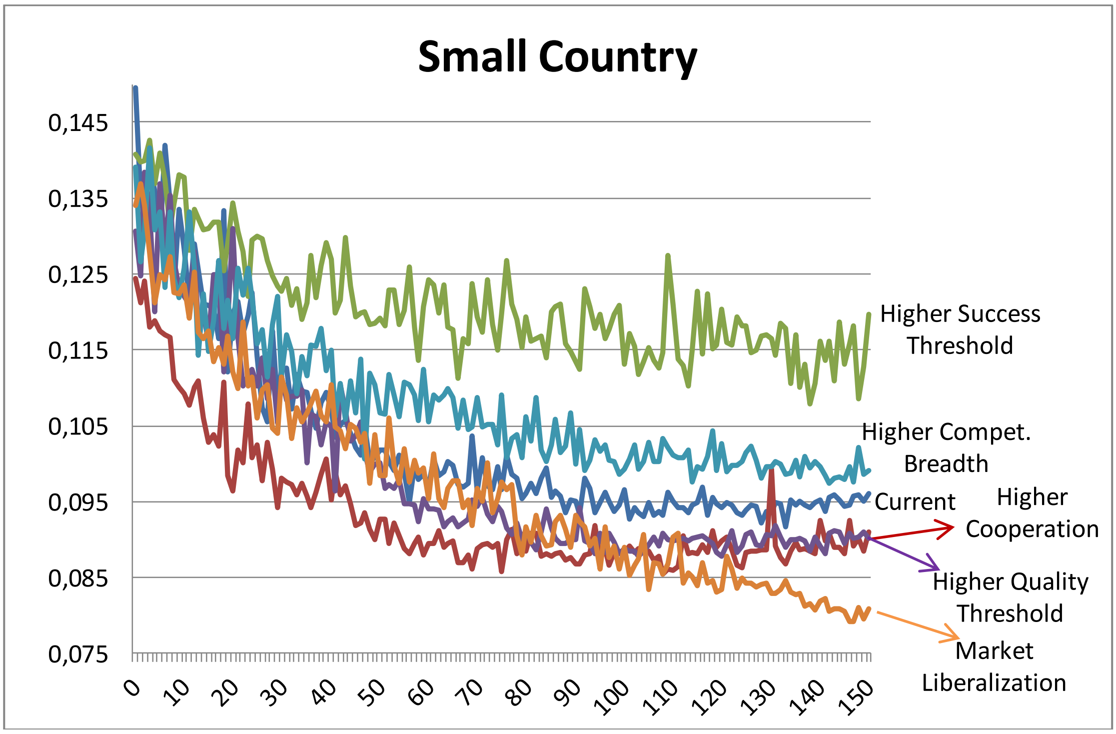


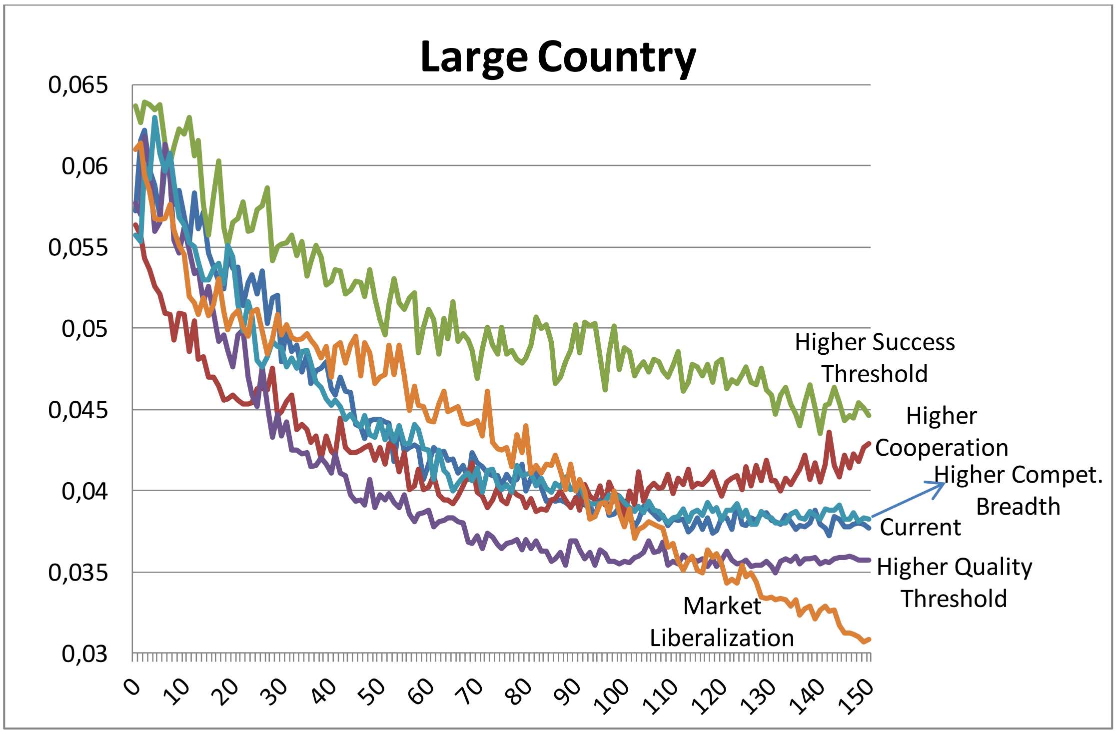
Time path of new publicly-funded R&D projects (%)



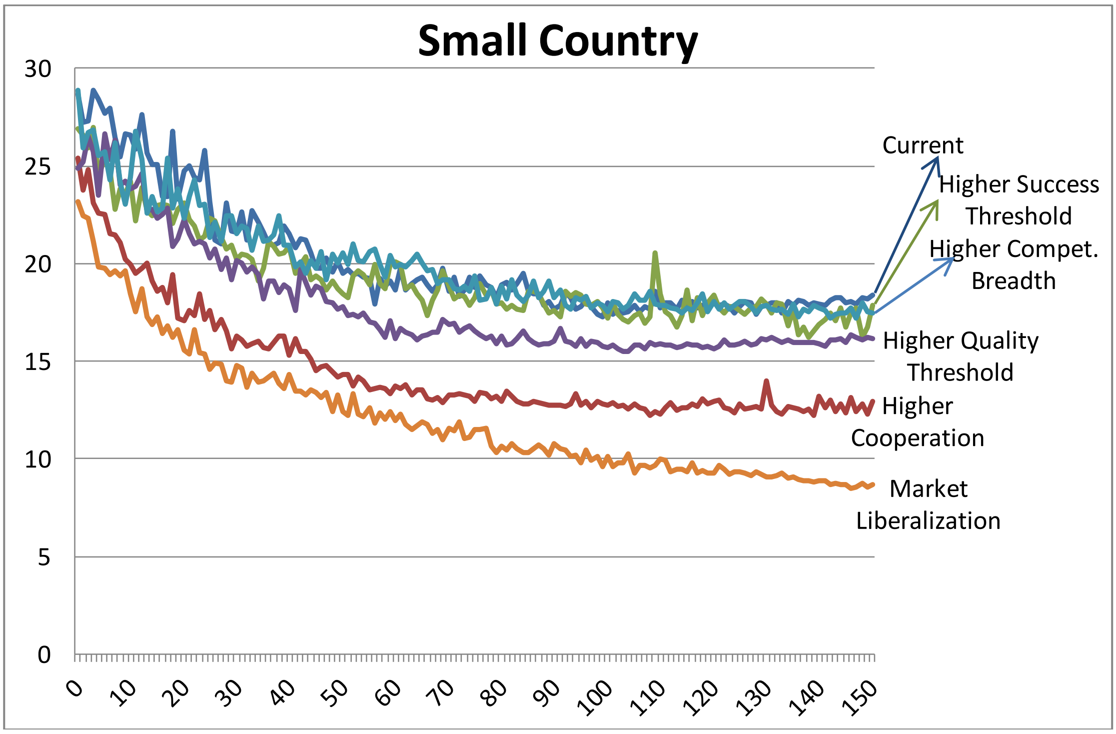


Time path of the concentration index (C5)





Time path of the export concentration ratio E5 (%)



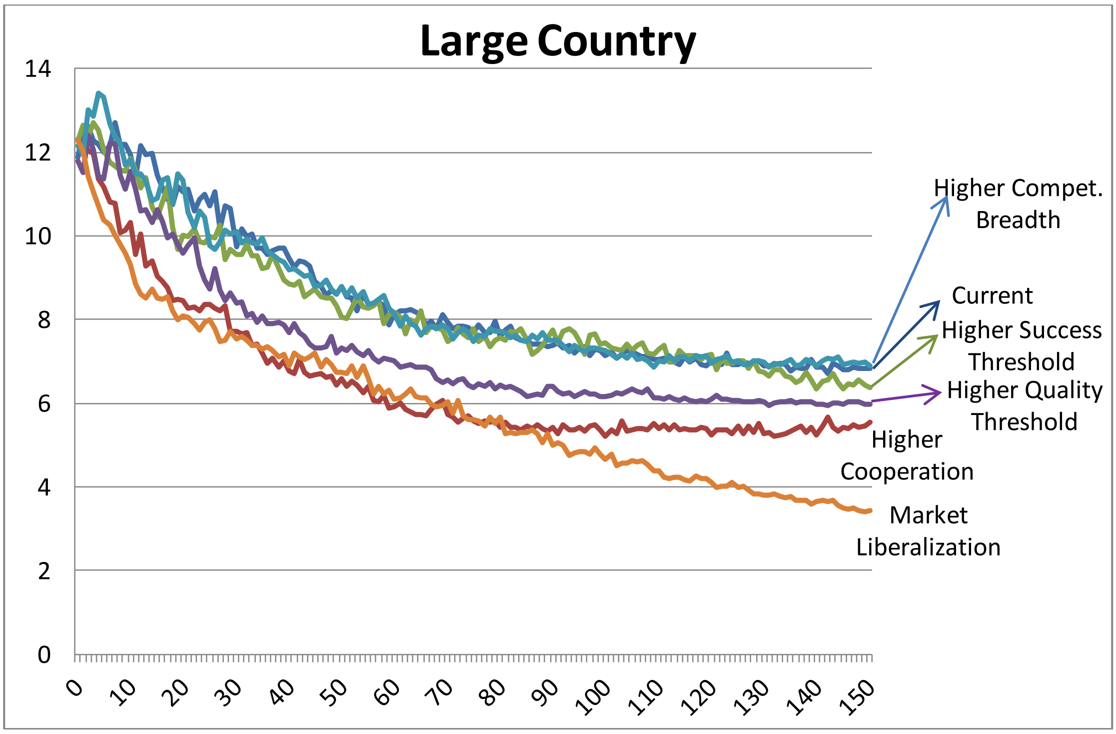


Table 1: Regression results: firms' profits and export activities as a function of their product quality (*technological depth*) and innovation hypothesis length (*competence breadth*) – Panel fixed effects estimations (FE) on the simulated firm-level dataset

	(1)	**(2)**	**(3)**	**(4)**
Scenario	*Current*	*Market liberalization*	*Current*	*Market liberalization*
Estimation method	Linear FE	Linear FE	Probit FE	Probit FE
Dependent variable	Profits	Profits	Export dummy	Export dummy
Product quality (*technological depth*)	3484.86 (21.32)***	2820.03 (38.5)***	0.9452 (20.41)***	0.8780 (53.50)***
IH length (*technological breadth*)	-1960.12 (-20.19)***	-905.45 (-20.84)***	-0.1382 (-6.60)***	-0.0346 (-4.67)***
Year	10.95 (7.88)***	-4.46 (-2.60)***	0.0055 (16.11)***	0.0023 (7.74)***
Observations	30150	30150	26130	29547

The regressions include a constant. Significance levels: ***: 1%.