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Competition and Innovation. Evidence in Support of the Non-linear Relationship

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Abstract: This paper empirically investigates the relationship between product market competition and innovation in seven European countries for the period 1987-2006. To approximate change in competition level three measures are considered: mark-up level, import penetration and the number of firms on the market. Innovation is measured as R&D intensity. The analysis shows that effect of product market competition on R&D intensity can be described with a non-linear function. Non-linearity signifies that when competition level is low, an increase in competition rises R&D intensity, while with higher degree of competition on the market an upsurge of competition leads to lower R&D intensity.

Key words: Innovation, R&D, competition

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1. Introduction

Innovation has long been a heatedly debated issue both among policy-makers and academic researchers. The analysis of innovation has departed from treating innovation as a "black box" to a more detailed examination of factors behind it. While the benefits of innovation are no longer questioned, determinants of innovation are still in the focus of theoretical and empirical research. A number of factors on micro-, meso- and macro-levels are believed to influence innovative performance of firms.

One of the market-level characteristics being analyzed in relation to innovation is competition. Economic theory usually treats competition as a favourable phenomenon. Microeconomics states that in general competition is associated with a decrease in prices on the market and an increase in the number of firms. As it is suggested by economic theory, when competition becomes more intensified, firms experience lower profits and prices of goods go down. Competition improves resource reallocation. As a consequence, social welfare is higher, when goods are produced by a number of competing firms, than if the market is operated by a monopolist. Such indicators of higher competition as easier entry and exit barriers, larger amount of firms and lower prices for goods are perceived as the desirable characteristics of a market. However, competition entails optimal resource reallocation only under certain theoretical assumptions. As shown by Arrow (1962), the theoretical grounds that turn competition into a desirable market outcome do not hold when a production process involves uncertainty, implying that under certain circumstances a monopoly may lead to higher social welfare. Innovation is understood as a source of uncertainty.

In fact, the discussion on the influence competition has on innovation was initiated by Schumpeter (1942), who suggested that monopoly has more incentives to innovate, as well as has better access to resources. The negative effect of competition on innovation proposed by Schumpeter inspired a broad economic debate. Since then, economic literature has offered evidence both for and against this proposition. The earlier empirical studies tested linear cross-sectional dependence between competition and innovation, typically providing a support for Schumpeter's argument. At the same time, some models proposed the opposite relationship (e.g. Arrow 1962), and also found the supporting evidence. The pioneering view on the topic was presented by Scherer (1967) who suggested the non-linear relationship between competition and innovation and found some empirical support for this view in a cross-sectional analysis. Nevertheless, since then empirical studies has to a greater extent focused on linear specifications. Only in 2005 the seminal paper by

Aghion et al. (2005) revived the non-linear model. Aghion et al. (2005) suggested a theoretical framework that explained existence of the U-inverted relationship between competition and innovation. The paper also provided empirical support for the hypothesis using the panel data on the UK firms. The non-linearity proposition inspired further research on the topic, which still reports mixed results.

This paper aims to investigate greater in detail how the level of product market competition influences innovation activity across European manufacturing industries. In particular, this paper tests the hypothesis about the non-linear U-inverted relationship between R&D intensity and competition for several European countries. As the previous research has neglected a group of Scandinavian countries, this paper intends to add Denmark, Finland, Norway and Sweden to the sample. Unifying methodological approaches taken from the previous studies and using a broad dataset, this study aims to contribute to understanding of the relationship between product market competition and innovation. To a larger extent aims of the study are motivated by the previous literature, therefore, the aims are discussed greater in detail after the literature review.

The paper is organized as follows: Section 1 reviews theoretical and empirical literature on the topic and formulates purposes of the study, Section 2 discusses methodological approach and data. Some limitations of the study are also discussed. The econometric analysis with a brief description of the results is presented in Section 3. Section 4 provides the discussion of the results. Section 5 concludes the paper.

1.1. Theoretical and empirical background

The debate on innovation and competition was initiated by Schumpeter (1942). Schumpeter argues that commonly asserted beneficial effect of competition may not be the case when it comes to innovation. On a competitive market threat of imitation exists. Innovation developed by a competitive firm can be imitated by rivals immediately after it was presented to the market. According to Schumpeter, the threat of imitation makes incentives of a competitive firm weaker, than those of a monopolist. By innovating a monopolist prevents entrance of new players and, thus, imitation. Moreover, firms with greater market power on more concentrated markets tend to innovate more due to easier access to resources. All in all, Schumpeter implies that innovation may increase when competition is low ("Schumpeterian effect"). In contrast, Arrow (1962) argues that a monopolist may be reluctant to innovate. Arrow adds the concept of intellectual property rights to the analysis. When protected by intellectual property rights, a monopolist exploits the protected technology to seek profits. With no threat of competition profit maximization is possible without developing the new technology. The model also shows that firms on a competitive market have higher returns on process innovation, than do dominant firms on concentrated markets.

Following Arrow's propositions Chen and Schwartz (2013) develop a model describing profits of a monopolist. Distinguishing between radical and incremental innovation and between process and product innovation, the authors conclude that a monopolist has more incentives to invest in incremental product innovation than a competitive firm on a non-concentrated market. When the monopolist's position on the market is not threatened by new entries, innovation is considered as a way to renovate the old product so as to establish new pricing strategies and gain higher post-innovation profits. However, when a monopolist expects a certain threat from new entries, incentives to preempt competition increase (Gilbert & Newbery 1982). In attempt to preserve the market share, a monopolist may invest in innovation.

Similarly, Greenstein and Garey (1998) argue that a secured monopolist has the same incentives to invest in incremental product innovation as a firm under competition pressure, however, a monopolist threatened by entry of new firms have greater innovation incentives. Moreover, the model predicts that social welfare may be greater when incremental innovation is being developed on a monopolistic, rather than on a competitive market. In an attempt to innovate, all the competitive firms invest in R&D, while on a monopolistic market it is only a monopolist who invests. Thus, to develop one technology the competitive firms incur greater costs, than a monopolist. A monopolist may produce valuable innovation at lower costs. The main proposition of the paper is that, despite the common belief, in high-tech industries where gains from innovating are significant, monopolies may be more socially preferred than intense rivalry.

The empirical support of Schumpeterian effect is found in the study by Scherer (1967). Scherer tests the hypothesis that innovation effort is negatively related to competition using cross-section data on US manufacturing companies. Innovative effort is measured by three indicators of R&D-related employment (namely employment of scientists and engineers in firms). Competition is approximated by concentration ratios. The analysis demonstrates that dominant firms on more concentrated markets have higher rates of innovation activity. Furthermore, Scherer adds squared concentration ratio to the model and finds a weak support for non-linearity. The author argues that there exists a threshold effect: after a certain level of concentration is reached, rise of market concentration loses its significance as an economic impetus.

An attempt to test for a non-linear relationship can also be found in Scott (1984). The paper provides the empirical support for the inverted U-shaped relationship between market concentration and innovation expenditure for a cross-section of US companies. However, the significance disappears when industry and firms effects are included into the model. At the same time, using survey-based data Levin et al. (1985) provide evidence for the U-inverted relationship between market concentration and innovation, where innovation is measured as a ratio of company-financed R&D expenditure to sales. Even though these studies presented at least some empirical support for the non-linearity hypothesis, further studies focused on linear models. As a matter of fact, the idea of non-linearity found a weak empirical support and did not have a theoretical model behind it. Thus, the early research to a greater extent focused on linear models.

Geroski (1990) summarizes ways in which a monopoly affects innovative activity. On the one hand, stronger incentives of a monopoly to raise entry barriers and preempt competition, as well as better access to resources are expected to result in a positive influence on innovative activity (so-called "positive effect" of a monopoly). On the other hand, managers may become lazy when there is no threat of entry, thus postponing innovation-related decisions ("negative effect"). In line with Arrow's argument Geroski claims that a monopolist has weak incentives to innovate. The author unifies both effects in the theoretical model and tests the model on a cross-section of UK firm-level data. The analysis shows that the "negative effect" prevails. In particular, the data provides evidence against the inverse relationship between innovation activity and competition. The author underlines that on competitive markets there are more actors searching for technological improvements, and therefore, there is a higher probability of finding innovative solutions, than if only a monopolist develops new ideas.

It should be noted that the majority of early empirical studies, as well as some of the more recent ones employ cross-sectional data. Reliance on the cross-sectional analysis can be misleading when a study aims to detect causal relationship. Furthermore, inability to control for several observable and unobservable factors may distort the estimation results (Griffith et al. 2010). To deal with this challenge, panel data should be used. For instance, fixed effects model can be used to control for unobserved effects that are constant over the period of interest. Another methodological difficulty of the early research is the endogeneity problem. Presumably, the reverse causality may take place, implying that not only competition affects innovation, but also innovative performance has an impact on the character of competition on the market. The cross-sectional data can hardly tackle this problem. Whereas panel data takes into account change in time and can capture exogenous variation (reforms, institutional changes, etc.)

These methodological issues are dealt with in the study by Nickell (1996). The author uses the UK firm-level panel data to analyze whether higher competition leads to a higher rate of technological progress. Technological progress is measured as growth in total factor productivity. Apart from competition measures and control variables, the author also includes lagged productivity in the model, justifying that a firm may have a delayed response to an exogenous change. The analysis reveals that higher number of firms and lower profits on the market each lead to higher productivity of firms. Firms operating on more concentrated markets are found to be less productive. Thus, in contrast to Schumpeterian's view, competition is interpreted as an unambiguously favourable market phenomenon, at least in relation to technological progress. The same view is expressed in the study by Blundell et al. (1999). Using the UK firm-level panel data the authors find the negative effect of market concentration on innovative activity. Innovative activity is approximated by patent count indicators. Competition is measured by a concentration ratio. Treating market as an industry, the authors add that industries with high concentration ratio demonstrate lower levels of innovation activity, implying the direct causal relationship between market concentration and innovation. However, it is also found that within industries dominant firms innovate more. This result is interpreted as pointing to higher incentives of dominant firms to prevent competition.

Aghion et al. (2005) claim that competition has a non-linear effect on innovation. The authors construct a theoretical model that explains non-linearity. In brief, the model proposes that non-linearity arises due to the fact that some markets respond to higher competition pressure by increasing innovative activity, while other markets reduce innovation. The more detailed description of the model follows. First of all, the model suggests that at any point of time there are two types of industries in the economy: "neck-and-neck" and "leader-follower".[1] The model proposes that firms innovate to reduce their costs or, to put it differently, to improve their technological level. Firms in "neck-and-neck" industries perform on similar technological levels and have similar production costs. Other things being equal, firms in "neck-and-neck" industries have no incentives to innovate. However, in case they innovate, they may considerably reduce their costs, thus they may outperform the competitors and change the state of the industry. The state of an industry, where a difference in production costs among firms is significant is called "leader-follower". "Leaders" have low costs and high post-innovation profits, therefore, they have no incentives to innovate. Whereas laggard firms ("followers") have low profits. Other things being equal, they have strong incentives to innovate so as to reduce costs and catch-up with leading firms. If "followers" successfully innovate they catch-up with "leaders", gap in production costs disappears, and industry turns into a "neck-and-neck" state.

[1] As it is common in empirical research on competition, industries are considered as product markets. Thus, describing changes in competition within an industry, Aghion et al. (2005) imply changes in competition on a particular product market. In other words, terms "market" and "industry" are used interchangeably.

Secondly, two states reveal different response to an increase in competition. In general, a rise of competition pressure reduces profits. To avoid a decrease in profits firms in “neck-and-neck” industries, which initially have medium profits, invest in innovation (“escape-competition-effect”). By innovating these firms may turn into “leaders” and, thus, earn high profits. Hence, these firms increase investment in innovation, when competition rises. On the contrary, an increase in competition in “leader-follower” industries leads to a decrease in innovation. By assumption “leaders” do not innovate, as they have high profits. At the same time, followers become less willing to innovate, as under higher competition the reward for catching up with leaders diminishes. Consequently, under higher competition pressure, firms in “leader-follower” industries invest less in innovation.

Finally, the U-inverted curve arises because each of two states corresponds to a certain degree of competition. In particular, “neck-and-neck” industries are associated with low level of competition and high competition is associated with “leader-follower” industries. In other words, when competition is low in the industry, the model suggests that this industry is likely to be “neck-and-neck” industry. Whereas, when competition is high in the industry, this industry is more likely to represent the “leader-follower” type. The model explains these associations in the following way. When competition is initially very low, firms in “neck-and-neck” industries earn similar profits and have no incentives to invest in innovation. As these firms do not innovate, the industry state does not change into “leader-follower”. At the same time, if competition is initially very low in “leader-follower” industries, laggard firms can innovate in order to catch-up with leaders. If they succeed in innovating, they turn industry into “neck-and-neck”. In other words, when competition pressure is low, it is likely that industry turns from “leader-follower” into “neck-and-neck”, however, it’s unlikely that “neck-and-neck” industry changes it state into “leader-follower”. Thus, low level of competition is associated with “neck-and-neck” industries. The opposite becomes apparent for higher degrees of competition. If competition is initially high in “neck-and-neck” industries, the firms innovate in order to escape competition, therefore, they turn an industry into “leader-follower” state. Whereas under high competition followers in “leader-follower” industries are unlikely to innovate, as the reward from catching up with leaders falls. Moreover, leaders do not innovate, as they are already on higher technological levels than their rivals. Consequently, under high competition, it is likely, that an industry turns into “leader-follower” state. Thus, high level of competition is associated with “leader-follower” industries.

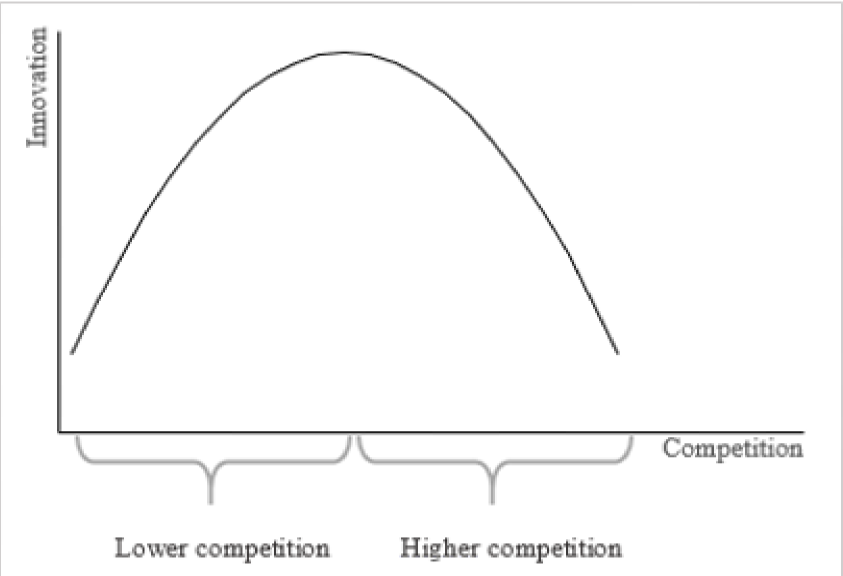
These correspondence between states of industries and competition degrees engenders the U-inverted relationship between innovation and competition. Figure 1 illustrates the essence of the non-linear relationship. The left tail of the curve is represented by “neck-and-neck” industries. For these industries “escape-competition-effect” becomes apparent, thus, with initially low level of competition a rise in competition pressure leads to an upsurge of innovation activity. The right tail is represented by “leader-follower” industries. When competition is initially high “Schumpeterian effect” takes place, in particular, a rise of competition entails lower level of innovation activity.

In general, the model predicts a non-monotonic U-inverted relationship between competition and innovation. The advantage of this model is that it combines two conflicting approaches to explaining the causality between competition and innovation.

Using the panel data on firms listed on the London Stock Exchange, Aghion et al. (2005) provide empirical support for the model predictions. Non-linearity is captured by the Poisson regression, where dependent variable is constructed using a patent count data. Competition is measured through the approximation of Lerner index. To tackle endogeneity problem, market regulations are taken into consideration.

Several studies continue testing the hypothesis about the U-inverted relationship. The study by Du and Chen (2010) considers a wide range of competition indicators and implements five of them to estimate the influence of competition on innovative activity of Chinese firms. The authors use three types of dependent variables. They estimate innovation inputs, outputs and innovation efficiency. Innovation input is calculated as a ratio of R&D expenditure to total sales. Innovation output is estimated as a ratio of new product sales to total sales. It should be mentioned that such a measure captures both innovation and imitation, as new product sales reflect products new to the firms and not to the market. Finally, efficiency of innovation is represented by a ratio of new

Figure 1. U-inverted relationship between innovation and competition



Source: after Aghion et al. (2005)

product sales to R&D expenditure. The analysis provides an empirical support for non-linear relationship between competition and innovation when Lerner index and concentration ratios are considered. Tingvall and Poldahl (2006) test Aghion's proposition using the sample of Swedish firms for the period of time from 1990 to 2000. Using two measurements of firm-level competition, the authors find dissimilar patterns in the relationship. Estimation of the relationship between Herfindahl-Hirshman index and R&D expenditure provides empirical evidence supporting the non-linearity hypothesis. However, it is found that price cost margin negatively affects R&D expenditure. Thus, estimation based on the price cost margin indicator does not support the proposition. The authors relate such an effect to endogeneity of price cost margin. Polder and Veldhuizen (2010) provide empirical evidence in support of the U-inverted relationship while examining both manufacturing and non-manufacturing sectors in the Netherlands. The authors use two indicators of competition: price cost margin and profit elasticity. Profit elasticity measures a decrease in profits that appears due to a rise in marginal costs. The idea behind the measure is that profits of firms fall when costs rise, but when competition is high this loss in profits is even larger. Firms on more competitive markets are thought to be "punished" for being less efficient. When the analysis is conducted on industry-level the non-linearity hypothesis is supported for profit elasticity. Whereas firm-level analysis reveals non-linear relationship for both measures.

However, some studies question the U-inverted relationship. Hashmi (2010) criticizes the empirical approach used by Aghion et al. (2005). He mentions that the data used in the study does not satisfy the assumptions of a method (Poisson regression). The author replicates the analysis for both the US and UK firms using the negative binomial model. The regression results for the UK companies support the non-monotonic relationship between competition and innovation, while the results based on the US firms do not. In general, the U.S. data reveals the inverse relationship between competition and innovation, thus supporting Schumpeterian hypothesis. To comment the differences in the results from two countries the author proposes two explanations. Firstly, two datasets obviously differ. Secondly, the differences in characters of economic conditions on the markets of two countries may influence the results. In particular, the author describes UK markets as more "neck-and-neck" than those in the US. Another study that questions the non-linearity hypothesis is a paper by Askenazy et al. (2008). Using a sample of French firms and survey-based measures of innovation, the authors find the non-linear relationship. However, non-linearity holds only for the largest firms. When the whole sample is considered, only the linear positive effect of competition on innovation is found to be significant. Another result is that with higher costs the relationship between competition and innovation becomes flatter. Thus, the estimation points out that small firms and firms with high production costs are not as sensitive to competition pressure, as large firms with lower costs.

Following the line of reasoning developed in Aghion's model, Griffith et al. (2010) take into account change in profits to estimate the link between competition and innovation. The study examines manufacturing industries in thirteen EU member states. The authors exclude Sweden, Denmark and Finland due to the differing industrial composition. The analysis is focused on the outcomes of the Single Market Programme. One of the aims of the programme was to promote product market competition in the EU member states. Taking the reform into account provides analysis with the exogenous variation. The outcomes of the reform are quantified as an index variable. More specifically, the instrumental variable approach is used. On the first stage, the effect of the SMP reform on market profits is estimated. On the second stage, the effect of profits on innovation is analyzed. It is found that the reform decreased market profits implying an increase in competition. Competition in turn increased investment in R&D. The model predicts the linear positive relationship between competition and innovation.

To summarize, even after Aghion et al. (2005) suggested a theoretical model that is able to unify two contradictory views on the relationship between competition and innovation, empirical literature still provides mixed results. All in all, several features of research design of more recent studies should be underlined. First of all, the studies largely focus on panel data, thus better dealing with unobserved factors, than in the early studies where cross-section data was used. Secondly, the analysis of previous research reveals that results of estimation are sensitive to the choice of competition measures, suggesting that a wider choice of variables should be considered to provide robust estimates. Moreover, the sample construction affects the results. Polder and Veldhuizen (2010) emphasize that even if the theoretical model is correct, the non-linearity hypothesis may not be supported if the sample is not heterogeneous enough. For instance, if markets under consideration are all "neck-and-neck", the data reveals the positive relationship between product market competition and innovation. Polder and Veldhuizen (2010) underline that the U-relationship can be identified only when sample includes industries with both high and low levels of competition. In fact, the degree of competition can be influenced by institutions of a particular country. Thus, it makes sense to have a broader set of observations and not to limit analysis to a single country. Finally, the studies that acknowledge possibility of endogeneity in competition either use policy instruments or data transformation so as not to distort estimation results. All this features of research design should be taken into account in the empirical investigation.

1.2. Aim and scope of the study

This paper aims to improve understanding of the relationship between innovation and competition by examining the effects of the product market competition on innovation across several European countries. The contribution of this paper is fourfold. *Firstly,* this study intends to throw some light on determinants of innovation by testing Aghion's proposition of non-linearity between innovation and competition. *Secondly,* the study intends to test the non-linearity hypothesis for a broader set of countries. Existing studies to a greater extent focus on a single country. Since the theoretical model predicts that effect of competition depends on the industry characteristics, a variety in observations is needed to provide reliable estimates. Therefore, to ensure greater variety, seven countries with different pace of economic development are considered. *Thirdly,* Scandinavian countries are included in the analysis. In fact, the previous empirical examination to a greater extent is limited to the USA, UK and Western Europe with minor attention to Scandinavian countries. For instance, while concentrating on Europe, Griffith et al. (2010) ignore Nordic countries due to higher innovation performance. Current study aims to take into account innovative performance of Scandinavian countries. *Finally*, the study intends to control for endogeneity in competition by using data on the policy reform. In addition, with the aim to add robustness to the estimation results three different measures of competition are used for the analysis and several model specifications are examined.

2. Methodological approach

This section describes the methodological approach to the empirical analysis. Firstly, the econometric model is described and expected estimation results are outlined. Next, the data is discussed in greater detail.

2.1. Econometric model

As mentioned in the previous section, the choice of the model was motivated by the conclusions made in the study by Aghion et al. (2005). The goal is to test the non-linearity proposition. In Aghion's paper patent count data is examined by means of Poisson regression. This study uses a continuous measure of innovation, therefore, non-linearity is modelled by means of a polynomial function. In particular, the quadratic function is considered.

Variation in innovation activity across industries is likely to be influenced not only by competition, but also by other meso-level factors. Characteristics of goods produced in an industry may directly or indirectly affect innovative performance. Product durability, target customers, sensitivity of demand, threat of substitution are among many factors that determine features of innovative activities for a particular industry. Hence, to account for differences among industries it is important to control for industry effects when constructing a model. Similarly, characteristics of a particular country are likely to have an impact on innovative performance of firms. Regulation, openness to international cooperation, tax burden and efficiency of institutions are among the potential determinants of innovation. Therefore, country effects should also be taken into account. Furthermore, to account for macroeconomic changes, year effects should be included into the model.

Apart from country and industry effects, control variables should be incorporated into the model. Country-level characteristics may explain a considerable share of variation in innovation activity across countries (Furman et al. 2002). In fact, there is no united opinion on the set of variables that should be included in the models that predict innovative activity. Obviously, all the observed and unobserved factors can hardly be included in the model. Having at least some control variables in the model (even if they are not significant) decreases the omitted variable bias. In addition, the problem of omitted variable bias is partly lessened by the error term and the fixed effects approach. (Verbeek 2004, p.344). Stock market capitalization in relation to a country's GDP, as well as GDP per capita are usually taken into account. Following Furman et al. (2002) spending on tertiary education as a share of GDP is also included into the model.

To capture a possible non-linear U-inverted relationship the model was constructed in the following way:

$$y_{ict} = \alpha + \beta_1 comp_{ict} + \beta_2 comp_{ict}^2 + \sum_i \gamma_c dc_{itc} + \sum_i \delta_t dt_{itc} + \sum_i \mu_i di_{itc} + \theta X_{ict} + \upsilon_{ict} \qquad \text{(I)}$$

Index i denotes industries[2], c - countries and t - years. The dependent variable y_{ict} stands for innovation activity and is measured by R&D intensity, defined as R&D expenditure over value added. The key independent variable $comp_{ict}$ is an approximation of competition. The choice of variables is clarified in the next subsection. The variable dc_{itc} denotes dummy variables for countries. Dummy variables for time are denoted by dt_{itc}. Dummy variables controlling for industry effects are denoted by di_{itc}[3]. The variable X_{ict} represents the vector of control variables (GDP per capita, spending on tertiary education as a percentage of GDP and stock market capitalization). Error term is denoted as υ_{ict}.

[2] Unit of observation is an industry in a particular country. So that, for instance, Food industry in Denmark and Food industry in Germany are denoted by different values of index *i*.

[3] This dummy variable is included to capture industry characteristics. It distinguishes only between industries, so that, for instance, Food industry in Denmark and Food industry in Germany have the same value of this dummy variable.

When $comp_{ict}$ represents a direct measure of competition, a positive coefficient β_1 and a negative β_2 are thought to provide a support for the U-inverted relationship. Polder and Veldhuizen (2010) underline, that apart from signs of coefficients, it is important to calculate whether the turning point of the inverted U-curve lies in the range of data. By definition, the turning point of quadratic function is calculated as the ratio of coefficients $-\beta_1/2\beta_2$. Additionally, the marginal effect in a specific point is usually considered for a non-linear function. By definition, marginal effect is calculated as following $\frac{\partial y}{\partial comp} = \beta_1 + 2\beta_2 comp_i$. The marginal effect is commonly estimated for mean or median value of a variable.

Additionally, a second model was developed. Model II incorporates lagged R&D intensity (y_{ict-1}). Consideration of lagged variable is motivated by the idea that firms do not always immediately respond to a change in economic conditions. Firms may need some time to take certain strategic decisions (Nickell 2006) All in all, the purpose of testing a dynamic model is to provide robustness to the analysis. In particular, the purpose is to investigate whether non-linearity holds when lagged R&D intensity is included into the model.

$$y_{ict} = \alpha + \mu y_{ict-1} + \beta_1 comp_{ict} + \beta_2 comp_{ict}^2 + \sum_i \gamma_c dc_{itc} + \sum_i \delta_t dt_{itc} + \sum_i \mu_i di_{itc} + \theta X_{ict} + \upsilon_{ict} \quad \text{(II)}$$

To avoid correlation of the lagged variable and the error term, the model was transformed and estimated in the first differences.

$$\Delta y_{ict} = \mu \Delta y_{ict-1} + \beta_{1\Delta} comp_{ict} + \beta_2 \Delta comp_{ict}^2 + \sum_i \gamma_c \Delta dc_{itc} + \sum_i \delta_t \Delta dt_{itc} + \sum_i \mu_i \Delta di_{itc} + \theta \Delta X_{ict} + + \Delta \upsilon_{ict} \quad \text{(III)}$$

Again, a positive coefficient β_1 and a negative β_2 are thought to provide a support for the U-inverted relationship between competition and innovation.

2.2. Data description

2.2.1. Measurement of competition

Competition is quite an extensive and abstract concept. Microeconomic theory interprets an increase in competition as an increase in the number of firms on the market. The result of intensified competition is lower prices and lower average profit. In more complex models an increase in competition can be treated as lowering of entry barriers, a rise of product substitutability on the market, a change from Cournot to Bertrand model of competition, etc. (Boone 2000). Type of goods produced, age of companies, life-cycle stage of a market, dependence on suppliers, openness to international trade are among the factors that affect the character of competition between economic actors.

With numerous factors involved, quantification of competition becomes a challenging task. Boone (2000) generalizes that there are three ways by which higher competition in markets occurs. The first way is a decrease in entry costs which results in the increased number of firms on the market. The second is more intensified aggressiveness of interactions between firms, which, for instance, becomes apparent when competitors start producing closer substitutes. Thirdly, competition becomes more intense when competitors have lower production costs. Lower production costs imply higher efficiency of a firm. Cost-efficient firms are able to reduce production prices, thus making it harder for the opponents to compete. These three scenarios provide a basis for parameterization of competition. The first scenario can be parameterized either by entry costs or by the amount of firms on the market. The second can be approximated by some firm-level characteristics, for instance, by the degree of product substitutability. Finally, to parameterize the third one costs of firms can be considered.

Even though there exist several types of measures that are based on the above mentioned approaches to parameterization, a proper way of quantifying competition pressure is still an open question. In general, in empirical research, three types of competition measures are considered. Firstly, some studies, especially in the earlier literature, focus on market-related effects of competition. In particular, such market structure indicators as concentration ratio and the number of firms are often considered. Higher concentration ratio means that larger share of output is produced by a smaller amount of firms. Thus higher concentration ratio is associated with the higher market power among the dominant firms. Commonly in the empirical studies concentration ratios are calculated for the top four dominant firms. However, concentration ratios do not account for either the distribution among the dominant firms or among the rest (Du & Chen 2010). At the same time, such an indicator as the number of firms on the market is criticized for ignoring market shares of companies (Gilbert 2008).

The second type of indicators are price-related measures. In fact, monopoly pricing has long been a focus of the literature on competition. Prices established above marginal costs are commonly associated with higher market power. Mathematically this idea is expressed by Lerner index ((P-MC)/P, where P stands for price of a product and MC denotes marginal costs). However, in practice, the index is hard to obtain due to limited information on marginal costs of economic agents.

Thirdly, competition can be approximated by profit-related indicators. Changes in profits may reflect changes in number of customers, number of competitors, trade barriers and market conditions on the whole. Comparison of measures based on profits is a way of assessing firms' relative performance. Advantage of profit-based measures of competition is that they do not rely on the definition of market. Therefore, they capture pressure from both domestic and international firms (Aghion et al. 2005). In addition, profit-related measures are believed to discern more intensified aggressiveness of interactions between firms. Boone (2000) claims that profit-related indicators are more robust estimates of competition than market-related, as they reflect all three scenarios of increased competition (change in number of firms, in aggressiveness of interaction and in production costs).

Results of empirical estimation can be sensitive to the choice of measures. Therefore, it is reasonable to use several types of measurements in the analysis. This paper considers three measures of competition: the mark-up measure, import penetration and the number of firms on the market. The mark-up measure is a profit-related indicator, import penetration and the number of firms are market-related measures. More detailed description of the variables follows.

The first measure is an approximation of firm profitability – the mark-up measure. The basic idea of constructing the mark-up measure is to obtain a ratio of firm's revenues and costs. By definition, mark-ups are thought to be inversely related to competition. More specifically, higher mark-ups of firms are believed to reflect lower competition pressure. For instance, other things being equal, monopolistic mark-ups are higher than those of firms on a competitive market. Thus an increase in average mark-ups implies low competition, whereas a decrease in mark-ups is associated with the rise of competition.

Boone (2000) claims that such a type of competition measure is theoretically robust. Griffith et al. (2010) mention that a mark-up measure is an increasing function of the Lerner index and, therefore, should be considered as preferable measure of competition on the industry-level. Following Griffith et al. (2010) the industry-level mark-ups (m) are calculated as the ratio of value added to the sum of labour and capital costs:

$$m = \frac{Value\ Added}{Labour\ Costs + Capital\ Costs}$$

The data for a ratio was collected in nominal prices in local currencies due to the absence of the data in real prices. Nominal values are usually transformed into real values to eliminate the effects of changes in price level. Since the variable of interest is a result of division, the effect from a change in price level is eliminated simply by calculation.

The data on Value Added and Labour Costs was collected from the OECD STAN Database. To have a measure of capital costs additional calculations were conducted. Capital costs is a product of capital stock and cost of capital (Müller 2010). The conventional way of estimating capital stock is to use perpetual inventory method (Du & Chen 2010; Aghion et al. 2005; Griffith et al. 2010).

The essence of the perpetual inventory method is that it estimates the capital stock by summarizing the previous purchases of assets over the period of its service lives (Measuring Capital: OECD Manual 2001). Thus, capital stock K_t for the period *t* is calculated in the following way:

$$K_t = (1 - \delta)K_{t-1} + I_t$$

where δ is the rate of depreciation and I_t is investment. Investment is measured as the amount of gross fixed capital formation.

Following (Müller 2010) the initial capital stock was estimated as an average investment of the industry over the period under consideration. Data on gross fixed capital formation and investment was obtained from OECD STAN Database. The depreciation rate of 5% is considered (e.g. Müller 2010).

To obtain cost of capital either a constant or long-term interest rate can be considered. Following Griffith et al. (2010) the data on the US long-term interest rate was used to estimate the cost of capital. The calculations imply the assumption that there is a free capital movement across the markets and all the countries can borrow at the world's interest rate. Data on the US interest rate was collected from the OECD Interest rates statistics. Thus, the perpetual inventory method provides the final component (capital costs).for calculating the variable of interest (mark-ups).

It should be noted that this methodological approach relies on estimations. However realistic the assumptions may be, estimation results may still differ from the reality. Yet, as regards the estimation of capital costs, the measurement errors are not expected to bias the results of the analysis due to the following reasons. Firstly, capital costs are considerably lower than labour costs, thus they have lower impact on the target variable (see summary statistics for the variables used to calculate the mark-up measure in the Appendix, Table 3). Secondly, since essentially the analysis is focused on changes of variables over time, rather than on their absolute values, measurement inaccuracies in the capital costs estimation are not expected to significantly distort the results.

As regards the variable of interest, mark-ups can entail certain difficulties in interpretation of the results due to the fact they are inversely related to competition. Polder and Veldhuizen (2006) suggest using linear transformation to turn the inverse measures of competition into direct measures. In particular, the target indicator can be constructed by subtracting each mark-up value from the maximum value. The transformation was executed in order to make the measure comparable to the other indicators of competition. Thus, the derived measure implies that its higher values are associated with higher degree of competition. Throughout the paper, this measure is called “the mark-up measure”).

The second measure of competition is import penetration. As an approximation of competition the measure is used in the papers by Nickell (1996), Blundell et al. (1999). Import penetration reflects the significance of imports on domestic markets. The indicator is calculated as a ratio between the value of imports and total domestic demand. Import penetration is an approximation of international market pressure. Import penetration is perceived as a direct measure of competition. Higher share of import in domestic demand implies higher competition pressure on domestic producers. However, high reliance on foreign products may reflect better competence of international producers and lack of expertise among local firms. Import penetration is a crude approximation of competition degree, since some markets can experience tough inner competition with no pressure from international firms. However, the measure is worth taking into account.

Finally, the number of firms is also considered among competition indicators. The measure does not capture change in aggressiveness of interaction between firms. Nevertheless, an increase in the number of firms is commonly associated with higher degree of competition (Boone 2000). As a matter of fact, on the example of Chinese firms Du and Chen (2010) show that the number of firms is strongly correlated with measures of market concentration and Lerner index, while displaying insignificant correlation with size inequality measures (such as market share). However naive the measure is, it may be a proper approximation of competition for “neck-and-neck” industries (Du & Chen 2010).

All three measures significantly differ from each other, as each measure focuses on different aspects of market performance. Table 1 shows pairwise correlations between the measures. It can be seen that the mark-up measure is only slightly correlated with the rest two measures.

Table 1. Correlations between competition measures

	Mark-up	Import penetration	Number of firms
Mark-up	1.000		
Import penetration	0.1603*	1.000	
Number of firms	0.0448*	0.0025	1.000

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Usage of firm-level data would allow having a broader range of competition variables. For instance, based on extensive firm-level dataset Lerner index can be calculated. However, due to the data limitations implementation of firm-level measures is out of scope of this study.

2.2.2. Measurement of innovation

It is commonly asserted that innovation is hard to quantify properly. Since innovation comprises importance of ideas, skills, creativity and learning process, it is difficult to choose a suitable numeric approximation for it. This study is based on R&D intensity as a measure of innovation. In the framework of this paper R&D intensity is defined as R&D expenditure divided by value added. R&D intensity is a common measure of innovation activity in the economic research. The data on R&D intensity has been published for a long time spans and is comparable across countries. The major disadvantage is that R&D component represents inputs of innovation and not outputs. Despite its theoretical drawbacks, R&D intensity is broadly used in empirical literature on innovation. Data on the R&D intensity was collected form OECD STAN Database. The R&D intensity was obtained on industry-level for manufacturing industries classified in accordance with ISIC Rev.3 (International Standard Industrial Classification of All Economic Activities, Rev.3).

Alternatively, the data on outputs could be obtained from the Community Innovation Survey (CIS). Apart from being able to approximate innovation output, the CIS data has a plenty of other advantages (covers process innovation, captures type of improvements, etc.). However, the CIS data does not exist for the period under consideration and, therefore, cannot be used. Another commonly used approximation of innovation output is patent count. The main drawback of using patent-based indicators is that patents approximate inventions, rather than innovation. Secondly, the role of patents across industries considerably differs. Thirdly, in some cases registration of a new patent may be more of a formal character and may not imply the further realization of innovator's idea. Usage of patent-based indicators is out of scope of this study.

2.2.3. Control variables

As for the control variables, following Furman et al. (2002) and Levin et al. (1985) GDP per capita, spending on education as a percentage of GDP and stock market capitalization as a percentage of GDP. The data was obtained from the World Development Indicators Database.

2.2.4. Definition of the market

Discussion if the relationship between competition and innovation encompasses a concept of the market on which firms innovate and on which changes in competition intensity occur. In fact, market is a rather abstract and complex concept. As a result of data limitation in the empirical studies the market is usually defined as an industry, where industry borders are determined in accordance with an industry classification (e.g. ISIC Rev. 3). The drawback of such an aggregation is that industry classifications are quite formal definitions and do not reflect real market boundaries. In reality, the number of markets may not correspond to the classified number of industries. In addition, firms operating in the same industry may compete on different markets. Such an aggregation assumes that all the firms in the industry are exposed to the same degree of competition. Nevertheless, potentially firms may be more heterogeneous and, thus, experience different levels of the competition pressure. All in all, despite the fact that treating industry as a market is subject to some inaccuracy, such definition is a common way of dealing with the market-level indicators. Terms "market" and "industry" are used interchangeably in the rest of the paper.

2.2.5. Endogeneity problem

Previous literature emphasizes that the endogeneity problem may arise when the relationship between competition and innovation is examined. Presumably, the reverse causality may take place, implying that innovative performance of firms has an influence on the degree of competition on the market. For instance, profits used for constructing the mark-up measure may have reflected changes in innovative activity of firms.

To control for endogeneity a policy reform is considered as a robustness check. More specifically, the study takes into account the actual market policy that affected competition rates in the European Union. In particular, the Single Market Programme (SMP) is considered. The SMP was launched in 1992[4]. The programme aimed, inter alia, to promote competition within the European Union and to boost economic growth. More specifically, the programme was launched in order to decrease existing trade barriers for the Member States and promote the cross-border procurement. These initiatives aimed to reduce market power of dominant firms, facilitate new market entries, bring down barriers to capital and labour movement. The favourable effect of the SMP on the competition across European industries has been documented in several studies (e.g. Allen et al. 1998; Bottasso & Sembenelli 2001; Badinger 2007). It has been shown that intensity of the cross-border trade considerably intensified and the price dispersion decreased after the programme was put in force. Since the SMP affected the average level of the product market competition, the study treats the SMP as an exogenous shock.

The expected macroeconomic outcomes of the integration within European countries were evaluated in so-called Cecchini Report. To estimate the implications of the programme three

[4] In the paper time of launching is understood as a time when the reform came into force (http://ec.europa.eu/internal_market/top_layer/historical_overview/background_en.htm)

measures were compared across sectors of the Member States. These measures included the degree of non-tariff barriers in the industry, price dispersion for identical goods and the intensity of trade with other Member States. Based on these three indicators about 40 three-digit sectors (according to NACE classification) were labelled as expected to be sensitive to the programme effects. The set of sensitive sectors was adjusted for the Member States based on the differences in the industrial structure and pace of economic development. In particular, several more sectors were added for Southern European countries.

The study by Buigues et al. (1990) assesses the structural adjustment of Member States to the SMP. The study scrutinizes the impact the reform had on sectors across the Member States. Based on the estimates provided by the report, the affected industries can be distinguished. In the report the affected industries are defined according to NACE classification codes. To make the data comparable it was converted into ISIC Rev.3. This information was used to construct a dummy variable for the reform effects. The variable equals one for affected sector in the Member State during the years when the SMP was taking place. The list of the industries can be found in the Appendix, Table 1. Table 2 in the Appendix contains the list of industries affected by the SMP.

2.2.6. Sample

The period under consideration is from 1987 to 2006. The data was obtained for manufacturing industries of seven European countries: Belgium, Denmark, Germany, Spain, Sweden, Finland and Norway. Industry classification ISIC Rev.3 was used for data collection. The list of industries can be found in the Appendix, Table 1. The sample represents a certain degree of variety since the countries under consideration demonstrated dissimilar patterns of economic development over the period. Unit of observation is an industry in a particular country[5]. The sample is unbalanced due to a number of missing observations in the data source. A few observations were eliminated from the sample as outliers[6]. Descriptive statistics are shown in the Table 2.

Table 2. Descriptive statistics

	Number of observations	Mean	Standard Deviation	Min	Max
R&D intensity	2389	0.065	0.081	0	0.395
Mark-up	2023	1.333	0.49	0.02	7.419
Import penetration	2080	45.059	24.793	4.016	99.795
Number of firms	1466	3032	6065	1	44928
GDP per capita	2389	34062.5	11058.6	16547.51	67804.6
Education spending	1807	5.874	1.423	3.03	8.438
Stock MC	2107	59.425	38.462	11.45	246.05

[5] For instance, the first observation is Food Industry in Denmark in 1987, the second observation is Food Industry in Germany in 1987

[6] Observations with R&D intensity > 0.4 were considered as outliers, following Du and Chen (2010)

Apart from the drawbacks of empirical estimation mentioned above, some more limitations should be acknowledged. First of all, the paper explores a quadratic function to test the non-linearity proposition, while theory does not suggest that the relationship between competition and innovation is namely quadratic. Non-linearity can also be modelled by means of other non-monotonic specifications. Secondly, data limitations affect definition of the market and quantification of the key variables. Finally, data aggregation neglects firm-level unobserved characteristics, which potentially can explain more about innovation performance of firms.

3. Results

This section presents the results of econometric estimation. Firstly, the static model (I) is discussed and, secondly, estimation of the dynamic model (III) is presented. Then a few more specifications are explored. On the whole, the analysis provides empirical evidence in support of the non-linear relationship between innovation and competition. The hypothesis is supported for the mark-up measure. The analysis demonstrates, that when initially competition is low, a rise in competition positively affects innovation. While under higher competition pressure, an upsurge of competition has a negative effect on R&D intensity. This result is perceived as supporting the hypothesis of the U-inverted non-linear relationship between competition and innovation. The estimation results for import penetration do not correspond to the non-linearity proposition. The analysis of the number of firms does not support non-linearity either.

3.1. Static model

Firstly, the method of estimation is outlined. Then, the model estimation is described for the mark-up measure. Next, estimation results for import penetration and the number of firms are discussed.

3.1.1. Approach to estimation

In assumption that there is no correlation between explanatory variable m_{ict} and the error term, pooled OLS model provides consistent estimates. However, estimates of random effects model are by definition more efficient. In addition, Breusch-Pagan Lagrange multiplier point to the preference of the random effects model over OLS estimation. However, in assumption that explanatory variable m_{ict} and the error term are correlated, neither OLS, nor random effects estimates are consistent. It may be assumed that the error term (υ_{ict}) is presented in the following way:

$$\upsilon_{ict} = \eta_j + \varphi_c + \varepsilon_{ict},$$

where industry effects are captured by variable η_j, country effects by φ_c and ε_{ict} denotes the error term. Further, it may be assumed, that correlation between explanatory variable m_{ict} and the error term appears, because the explanatory variable m_{ict} is correlated with two components of υ_{ict}, namely with industry effects η_j and country effects φ_c. The assumption that m_{ict} is correlated with η_i and φ_c, and is not correlated with ε_{ict} fits the fixed effects model. The fixed effects approach removes the impact of time-invariant individual characteristics which are assumed to be correlated with the dependent variable. As for the model under consideration, F-test indicates that fixed effects model is preferable as compared to a pooled OLS regression.

3.1.2. Mark-up measure

Several tests were conducted to diagnose the model where the mark-up measure is used to approximate competition. Modified Wald test for group-wise heteroscedasticity detected the presence of heteroscedasticity. Wooldridge test for autocorrelation indicated that there is autocorrelation in the data. To remedy autocorrelation and heteroscedasticity, data transformation suggested by Baltagi and Wu (1999) was carried out. The transformation deals with both heteroscedasticity and autocorrelation problems, thus providing efficient and consistent estimates. Hausman test showed that for specification with the mark-up measure random effects model is preferred over fixed effects. The results are presented for both types of models (Table 3).

Table 3. Estimation results of model (I). The mark-up measure.

VARIABLES	(1) Fixed Effects	(2) Random Effects	(3) Fixed Effects	(4) Random Effects	(5) Fixed Effects	(6) Random Effects
Competition	0.041***	0.063***	0.080***	0.071***	0.086***	0.076***
	(0.006)	(0.005)	(0.007)	(0.006)	(0.009)	(0.009)
Competition^2	-0.002*	-0.006***	-0.007***	-0.006***	-0.009***	-0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
GDP per capita			0.000***	-0.000*	0.000	-0.000
			(0.000)	(0.000)	(0.000)	(0.000)
Education spending			0.000	0.000	-0.001	0.001
			(0.002)	(0.002)	(0.002)	(0.002)
Stock MC					0.000	0.000
					(0.000)	(0.000)
Constant	0.120***	0.138***	-0.026***	0.133***	-0.012***	0.143***
	(0.002)	(0.009)	(0.003)	(0.029)	(0.004)	(0.039)
Observations	1,892	2,023	1,468	1,599	1,388	1,519
Number of groups	130	131	130	131	130	131
Country FE	YES	NO	YES	YES	YES	YES
Industry FE	YES	NO	YES	YES	YES	YES
Year FE	NO	NO	YES	YES	YES	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Columns (1) and (2) of Table 3 demonstrate the basic models with only competition and competition squared as explanatory variables. The other specifications include control variables and dummy variables for years. The random effects specifications presented in columns (4) and (6) also include dummy variables for industry and country effects.

It can be seen, that the competition and squared competition variables are highly significant for all the specifications. A positive sign of the linear term and a negative of the quadratic term correspond to the U-inverted relationship between mark-ups and R&D intensity, as it was expected. The U-inverted relationship implies that when the level of competition is low, a rise in competition rises R&D intensity. While with higher degree of competition on the market an upsurge of competition is associated with lower R&D intensity. The prediction plot can be found in the Appendix, Figure 1.

Since Hausman test points that random effects model is preferred over fixed effects, the model displayed in Column (6) is used for interpretation. First of all, the marginal effect can be interpreted. For the mean value of the mark-up measure (the mean value equals 1,34) the marginal effect is positive and equals 0.054. This effect signifies that one unit change when competition increases by one unit, for an industry that experiences a mean value of mark-ups, R&D intensity increases by 0.054.

Next, the U-inverted curve reaches its peak (the turning point) when the mark-up value equals 4.75. An important observation here is that the mark-up value of 4,75 lies in the range of the dataset, consequently, the point at which the effect of competition turns from positive into negative is within the range of the dataset. It should be noted that the peak value is higher than mean and median value. In fact, the peak value is closer to the third quartile of the mark-up value. Thus, industries are not equally distributed along the curve, but rather are shifted to the left tail. More specifically, about 75% of industries lie on the left tail of the inverted U-curve, revealing that on average these 75% of industries demonstrate lower competition levels, and increase in competition for these industries leads to an increase in R&D intensity. In terms used by Aghion et al. (2005) the majority of industries in the sample are “neck-and-neck” industries, where technological advancement of firms is similar and an increase in competition promotes innovative activity. At the same time about 25% of the sample are “leader-follower” industries, where some firms have lower production costs, than their followers, and in response to higher competition pressure these industries reduce investment in innovation. The obtained distribution of industries differs from the results in Aghion et al. (2005), where the turning point of the inverted U-curve corresponds to the median value of competition, implying that industries in the sample of the UK firms are evenly spread along the curve. At the same time the derived results are in line with the results discussed in the study by Polder and Veldhuizen (2010), where the majority of industries in the sample (about 75% of industries in the Netherlands) are "neck-and-neck", while the rest are closer to "leader-follower" industries. Thus, the study demonstrates that in the Netherlands the majority of industries experience increase in innovation activity when competition degree becomes stronger. This discrepancy in results points to the difference in the industrial mix across different countries.

An important remark here is that the estimation results may noticeably differ from sample to sample. When the sample to a greater extent is represented by industries of one type, it is more likely to detect a linear relationship between competition and innovation. In fact, using the same mark-up measure as approximation of competition, Griffith et al. (2010) find a positive linear dependence between competition and innovation. Sample construction is presumably among the reasons of the dissimilarity in the results. In particular, insignificance of a non-linear relationship described by Griffith et al. (2010) may have arisen due to the prevalence of "neck-and-neck" industries in the sample.

3.1.3. Import penetration

As regards import penetration, the diagnostic tests detected heteroscedasticity and autocorrelation, which were tackled in a similar way as for the mark-up measure. The estimation results do not offer support for the U-inverted relationship (Table 4, Columns (7)-(10)). Specifications demonstrated in Columns (7) and (8) represent a linear model. Estimation provides evidence for the positive influence on R&D intensity. Specifications displayed in Columns (9) and (10) test the non-linearity hypothesis. It can be seen, that analysis does not support the non-linear relationship. Consequently, interpretation is done only for the linear specification. Hausman test suggests that the fixed effects model describes data better than random effects. Therefore, interpretation of the linear model is based on the specification demonstrated in Column (7). Other things being equal, with one unit growth in share of imports in total domestic demand average R&D intensity of industries rises by 0.001.

Thus, when competition is measured as import penetration, analysis shows that an increase in import penetration leads to higher R&D expenditure, implying a positive linkage between competition and innovation. In fact, the positive relationship between import penetration and innovation activity is in line with the results described in earlier studies (Nickell 1996; Blundell et al. 1999). Increase in import penetration occurs either due to an upsurge of imports or due to a decrease in the domestic demand. The former corresponds well to the stronger competition pressure, while the latter is not associated with higher competition. Growth in imports promotes rivalry among firms on the market. Blundell et al. (1999) suppose that import penetration captures only international competition pressure (so-called "trade effect"), while it does not reflect change in the degree of domestic competition. On the whole, after the SMP was launched in 1992, trade barriers across the Member States diminished and amount of imported goods enlarged (Allen et al. 1998). Therefore, it is more likely that an increase in import penetration occurred namely due to the trade effect and not due to a slump in demand.

It can be noticed that the positive relationship derived from the model with import penetration as an explanatory variable is partly in line with the results for the mark-up measure. As it was shown for the mark-up measure, the majority of industries demonstrate the positive relationship between increase in product market competition and change in R&D intensity.

Table 4. Estimation results of model (I). Import penetration and Number of firms.

	Import penetration				Number of firms			
	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
VARIABLES	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
Competition	0.001***	0.000***	-0.000	-0.000	-0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Competition^2			0.000***	0.000***			0.000	0.000
			(0.000)	(0.000)			(0.000)	(0.000)
GDP per capita	0.000***	-0.000	0.000***	-0.000*	0.000	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education spending	0.000	-0.000	-0.000	-0.001	0.003	0.002	0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.002)	(0.003)	(0.002)
Constant	-0.008***	0.009	-0.009***	0.034	-0.008	0.030	-0.008	0.030
	(0.003)	(0.027)	(0.003)	(0.027)	(0.005)	(0.052)	(0.005)	(0.052)
Observations	1,457	1,579	1,457	1,579	1,026	1,150	1,026	1,150
Number of groups	120	122	120	122	123	124	123	124
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

3.1.4. Number of firms

In a way similar to previously discussed, diagnostic tests were conducted for the specifications, where competition is approximated by the number of firms on the market, and the transformation was implemented. Columns (11)-(14) display the specifications which use the number of firms as a proxy for competition. Estimation reveals no significant relationship for all four specifications. As it was previously discussed, the number of firms is believed to be a good approximation of competition for more "neck-and-neck" markets. Although, estimation for the mark-up measure shows that the majority of industries under consideration are "neck-and-neck" industries, the number of firms is not significant. Presumably, the effect discussed in the paper by Boone (2000) may be the reason for insignificant results. More specifically, the author claims that when competition pressure arises due to higher aggressiveness of competitors, some firms may leave the market if they expect difficulties in keeping the pace of the opponents. Thus, the number of firms may diminish or stay unchanged when competition rises.

On the whole, dissimilarities in the estimation among used indicators are not surprising. As it is shown in Table 1, the indicators are not strongly correlated. Moreover, all three indicators represent very different phenomena. As it was already emphasized, as a measure of competition the number of firms neglects aggressiveness of interactions among rivals. It is also limited to a definition of market and, therefore, does not reflect an impact of international competitors. International competition is well reflected by import penetration. At the same time, import penetration does not capture the effect from domestic competition. As for the mark-up measure, it is believed to reflect the impact of both international and domestic competitors. When there is a strong pressure caused by international producers on the market, local firms are likely to experience changes in their profits and thus in mark-ups. At the same time, mark-ups are also affected when there is no international competition, but domestic rivalry is substantial. Furthermore, mark-ups are influenced by intensified aggressiveness of interaction among firms. Based on this line of reasoning, the mark-up measure can be perceived as a better approximation of competition pressure, than import penetration and the number of firms. Thus, this study treats namely the mark-up measure as more reliable.

3.1.5. Robustness check

In addition, the static model (I) was estimated for those industries that were affected by the SMP. For these industries, growth of competition degree was exogenous. The estimation results provide evidence for the U-inverted relationship (Table 5). Support for the inverted U-curve derived from the analysis of affected industries is considered as an indication of the robustness of results derived for the whole sample.

Table5. Estimation results of model (I). Industries affected by SMP

VARIABLES	(15) Fixed Effects	(16) Random Effects	(17) Fixed Effects	(18) Random Effects	(19) Fixed Effects	(20) Random Effects
Competition	0.023**	0.054***	0.050***	0.050***	0.053***	0.042***
	(0.010)	(0.010)	(0.012)	(0.012)	(0.013)	(0.012)
Competition^2	-0.001	-0.007***	-0.005**	-0.005**	-0.006**	-0.004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
GDP per capita			0.000***	0.000***	0.000	0.000
			(0.000)	(0.000)	(0.000)	(0.000)
Education spending			0.002	0.001	0.001	0.002
			(0.002)	(0.002)	(0.002)	(0.002)
Stock MC			-0.000**	-0.000	0.000	0.000
			(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.099***	0.126***	0.006**	0.054**	-0.003	0.010
	(0.003)	(0.012)	(0.003)	(0.022)	(0.004)	(0.065)
Observations	1,063	1,151	756	844	756	844
Number of id2	88	88	88	88	88	88
Country FE	YES	NO	YES	YES	YES	YES
Industry FE	YES	NO	YES	YES	YES	YES
Year FE	NO	NO	YES	YES	YES	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

3.2. Dynamic model

This subsection describes estimation results for a model with the lagged R&D intensity. The purpose is to investigate whether non-linearity holds when lagged R&D intensity is included into the model. Therefore, analysis is conducted only for the mark-up measure, which was the only measure that provided support for non-linearity in static models. The results of estimation are in line with those of the static model.

Adding lagged R&D intensity in the model (I) would provoke correlation between the lagged variable and the error term, therefore, to avoid correlation the model can be transformed into the model in differences (III). However, in the model in first differences one of the explanatory variables Δy_{ict-1} is correlated with the transformed error term $\Delta \upsilon_{ict}$. So as not to provide inconsistent estimated, Δy_{ict-1} was instrumented by y_{ict-2}. Even though this transformation leads to a small loss in the number of observations, it is a common approach to instrumenting the lagged variable, because the derived instrument is highly correlated with the variable and is not correlated with the error term.

Table 6. Estimation results of model (III). Mark-up

	(21)	(22)
VARIABLES		
Δ R&D intensity (t-1)	0.531***	0.577**
	(0.158)	(0.247)
Δ Competition	0.090***	0.115***
	(0.010)	(0.017)
Δ Competition^2	-0.010***	-0.012***
	(0.002)	(0.003)
Δ GDP per capita		-0.000
		(0.000)
Δ Education spending		-0.002
		(0.003)
Δ Stock MC		0.000
		(0.000)
Constant	0.000	-0.001
	(0.001)	(0.002)
Observations	1,745	1,158
Country FE	NO	YES
Industry FE	NO	YES
Year FE	NO	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

The estimation was conducted by means of 2SLS method. The dynamic model was estimated only for the mark-up measure, since it was the only measure that revealed significant non-monotonic relationship with R&D intensity. Estimation results provide support for the hypothesis of the non-linear relationship between competition and innovation (Table 6). First-stage estimation results are reported in the Appendix, Table 5.

Column (21) displays the basic specification. Control variables and dummies are included in the model shown in Column (22). Even though the impact on R&D intensity is to a greater extent caused by the lagged R&D intensity, the competition measures still have the expected signs. Thus, the derived results correspond to the estimation of the static model in particular and to the non-linearity hypothesis in general.

3.3 Additional specifications

This subsection presents a few more specifications of the model (I).

3.3.1. Scandinavian countries

The first one was considered to check whether the results hold for Scandinavian countries only. As it was mentioned in literature review, Scandinavian countries have not been extensively examined before. Moreover, the interest in constructing the sample only for Nordic countries was motivated by the following observation. In the study by Griffith et al. (2010) authors intentionally omit Scandinavian countries due to the different industrial structure.

Table 7. Estimation results of model (I). Scandinavian versus non-Scandinavian countries

	Scandinavian	non Scandinavian
	(23)	(24)
VARIABLES		
Competition	0.076***	0.039***
	(0.012)	(0.006)
Competition ^2	-0.006**	-0.003***
	(0.003)	(0.001)
GDP per capita	-0.000**	0.000**
	(0.000)	(0.000)
Education spending	-0.002	0.002
	(0.003)	(0.001)
Constant	0.179***	-0.124
	(0.060)	(0.079)
Observations	997	602
Number of groups	68	63
Country FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Estimation shows that when distinguishing between Scandinavian (Denmark, Finland, Norway, Sweden) and non-Scandinavian (Belgium, Germany, Spain), models differ in coefficients, but still provide significant coefficients in support of the non-linear relationship (Table 7). Thus, according to the conducted analysis, the results supporting non-linearity hold for Scandinavian countries. The prediction plots are illustrated in the Appendix, Figure 2.

3.3.2. High-tech versus low-tech industries

Furthermore, it seems interesting to compare high-tech and low-tech sectors in their responses to competition pressure (Table 8). To differentiate industries traditional classification suggested by OECD Science, Technology and Industry Scoreboard 1999 was used. The classification is based on average R&D intensity. Industries 24, 29, 30, 31, 32, 33, 34 and 35 were labelled as high-tech. The rest were considered as low-tech industries.

Table 8. Estimation results of model (I). High-tech versus low-tech industries

	High-tech	Low-tech
	(25)	(26)
VARIABLES		
Competition	0.124***	0.022***
	(0.022)	(0.003)
Competition ^2	-0.012**	-0.002***
	(0.006)	(0.000)
GDP per capita	-0.000	-0.000*
	(0.000)	(0.000)
Education spending	-0.001	-0.000
	(0.004)	(0.001)
Constant	0.294***	0.056***
	(0.052)	(0.010)
Observations	685	914
Number of groups	54	77
Country FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES

Dependent variable is R&D intensity
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Marginal effects were calculated for the mean value of the mark-up measure of the whole sample (mean value equals 1,34) to make the results comparable. For the mean value of the mark-up measure in high-tech industries the marginal effect is positive and equals 0.092. It indicates that when competition increases by one unit, for a high-tech industry that experiences a mean value of mark-ups, R&D intensity increases by 0.092. The marginal effect for low-tech industries is lower in absolute magnitude. It is also positive and equals 0.017, signifying that when competition rises by one unit for a low-tech industry that experiences a mean value of mark-ups, R&D intensity increases by 0.017. Thus for the mean mark-up level, the positive impact of competition pressure is more pronounced for high-tech industries. In other words, high-tech industries are on average more sensitive to changes in competition, than low-tech. The visualization of the differences between two types of sectors is presented in the Appendix, Figure 3. The result indicates that not only the absolute amount of R&D intensity is larger for high-tech sectors, but also the degree of the response is greater. The interpretation might be that by definition performance of high-tech sectors, as opposed to low-tech, depends more on innovation, therefore, namely innovative activity is an important way of responding to economic shocks. While low-tech industries may rely more on other factors of economic performance, high-tech sectors respond to changes in economic environment mostly by adjusting R&D-related activities.

4. Discussion

All in all, the analysis shows that examination of the relationship between innovation and competition is sensitive to the choice of measures. In this study the empirical investigation provides a support for non-linearity between competition and R&D intensity only when competition is approximated by the mark-up measure. Import penetration detects the linear relationship, and the number of firms does not reveal any significant relationship. However, based on the essence of the measure, namely the mark-up measure is believed to be better approximation of competition as compared to the other considered indicators. Therefore, relying on the estimation of models with the mark-up measure as an explanatory variable, it can be concluded that the analysis supports the non-linear U-inverted relationship between innovative activity and the degree of product market competition.

The derived non-linear relationship indicates that when industries initially experience low competition pressure, a change in the degree of product market competition results in a rise in R&D intensity. When industries initially face higher degree of competition, further growth of competition pressure reduces R&D intensity. Thus, when competition is low, “escape-competition-effect” takes place, while when competition is high, “Schumpeterian effect” dominates. According to the theoretical framework proposed by Aghion et al. (2005) these results can be interpreted in the following way. As it was discussed in the first section, Aghion's model proposes that low level of competition is associated with "neck-and-neck" industries. Firms in these industries earn medium profits and have no incentives to change their production technologies. When competition rises in these industries, the firms tend to invest in innovation in order to escape competition and to avoid a fall of profits. Consequently, a rise of competition leads to a rise of innovation activity. While high degree of competition is associated with "leader-follower" industries. "Leaders" do not innovate, because they are already on higher technological level then their rivals. Whereas for "leaders" further upsurge of competition implies that they experience further decrease in profits, moreover, the reward for catching up with "leaders" decreases. Hence, when the initial degree of competition is high, further increase in competition entails lower innovation activity. Thus, according to Aghion's model, the U-inverted relationship arises, because on the markets with low levels of competition firms respond to an increase in competition by investing more in innovation. Whereas on the markets with initially high competition, further increases in competition discourage firms from investing in innovation.

As estimation reveals, the industries under consideration are unevenly spread along the inverted U-curve. In particular, the majority of industries demonstrate the positive relationship between competition and R&D intensity. It indicates that "neck-and-neck" industries are prevalent in the sample. These industries are associated with lower competition and more similar level of technological advancement.

It should be also kept in mind, that estimation results can be discussed only as a support for non-linearity. As it was underlined, absolute values of competition-related variables are subject to estimation bias. Therefore, such estimates as a turning point of the inverted U-curve should not be interpreted as a numerical expression of competition degree that turns industry into "leader-follower" from "neck-and-neck".

An important implication for the research design follows from the conducted analysis. Uneven distribution of industries along the curve implies that the results of empirical examination depend on the industry mix under consideration. According to the model described by Aghion et al. (2005), the positive effect of competition is observed for "neck-and-neck" industries, whereas "leader-follower" industries reveal the negative relationship. Presumably, prevalence of one type of industries in a sample can explain the significance of the linear relationship documented by some of the previous studies. An additional remark is that when analysis aims to refute or support Aghion's proposition, a large sample should be used (preferably rich in both years and countries of observation).

Several suggestions for perspective research follow from this study. Firstly, it may be interesting to conduct analysis for non-manufacturing industries and compare with present results. Secondly, process innovation can be considered. Thirdly, firm-level indicators can be used to construct competition measures and to control for firm-level characteristics.

As for policy implications, analysis shows that industries under consideration are not homogenous. According to the estimation results, industries respond differently to changes in economic conditions. Stimulation of competition in "neck-and-neck" industries provokes innovative activity. Thus, lower entry costs and trade barriers for these industries are expected to trigger innovation output. At the same time, for "leader-follower" industries intensifying competition policies discourage innovation. Consequently, a common belief that competition improves corporate performance and economic welfare is arguable for these industries. In order to promote innovation policy makers should focus on assisting laggard firms ("followers") in catching up with dominant firms ("leaders").

5. Conclusion

The paper has examined the relationship between innovation and competition. In particular, the hypothesis about the non-linear relationship between competition and R&D intensity has been tested. This study has employed a rich dataset containing data for seven European countries for a period from 1987 to 2006, thus allowing for greater variation in data. Despite being intentionally ignored in the previous empirical studies, four Scandinavian countries have also been included in the sample. Due to the complexity of competition as economic phenomenon, the paper has considered three different measures of competition. The mark-up measure, import penetration and the number of firms have been analyzed.

The analysis conducted for the mark-up measure provides the empirical support for the non-linear relationship between mark-ups and R&D intensity. The documented relationship infers that when the initial level of competition is low, an increase in competition rises R&D intensity. While with initially higher degree of competition on the market an upsurge of competition leads to lower R&D intensity. The result is consistent with the conclusions discussed by Aghion et al. (2005), as well as with the analysis of Chinese industries by Du and Chen (2010) and the study of industries in the Netherlands by Polder and Veldhuizen (2010). The policy reform (the Single Market Programme) has also been considered to add robustness to the analysis in respect of the potential endogeneity of competition. Finally, estimation of the model with lagged R&D intensity provided evidence in support of non-linearity. Additionally, the model with the mark-up measure has been explored in a few more specifications. The results show that non-linearity holds for the sample restricted only to Scandinavian countries. Furthermore, non-linearity is found to hold for both high- and low-tech sectors. Particularly, high-tech sectors are found to be more sensitive in their response to changes in competition pressure.

At the same time, two other measures of competition do not support the non-linearity proposition. Examination of import penetration reveals its positive influence on R&D intensity, which may possibly be interpreted as a stimulating effect of international trade. Whereas, the number of firms is found insignificant as a determinant of innovative activity.

Major policy implication of the analysis follows from the finding that the industries under review respond differently to changes in the degree of competition. Thus, different policy tools should be used to boost innovative activity among these industries. Stimulation of competition in "neck-and-neck" industries is expected to trigger innovation output, while for "leader-follower" industries it is more important to assist laggard firms in catching-up with the "leaders" so as to encourage innovation.

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Appendix

Table 1. List of industries

Number of industry	Industry name	Number of observations	Mean R&D intensity
15	Food products and beverages	59	0.0089
16	Tobacco products	58	0.0129
17	Textiles	86	0.0208
18	Wearing apparel, dressing and dying of fur	83	0.0110
19	Leather, leather products and footwear	84	0.0145
20	Wood and products of wood and cork	120	0.0063
21	Pulp, paper and paper products	111	0.0184
22	Printing and publishing	111	0.0036
23	Coke, refined petroleum products and nuclear fuel	100	0.0346
24	Chemicals and chemical products	119	0.1462
25	Rubber and plastics products	139	0.0306
26	Other non-metallic mineral products	139	0.0172
27	Basic metals	139	0.0280
28	Fabricated metal products, except machinery and equipment	139	0.0159
29	Machinery and equipment, nec	139	0.0656
30	Office, accounting and computing machinery	127	0.1707
31	Electrical machinery and apparatus, nec.	139	0.0744
32	Radio, television and communication equipment	97	0.2646
33	Medical, precision and optical instruments	137	0.1378
34	Motor vehicles, trailers and semi-trailers	127	0.0901
35	Other transport equipment	136	0.1154

Table 2. Industries affected by the Single Market Programme

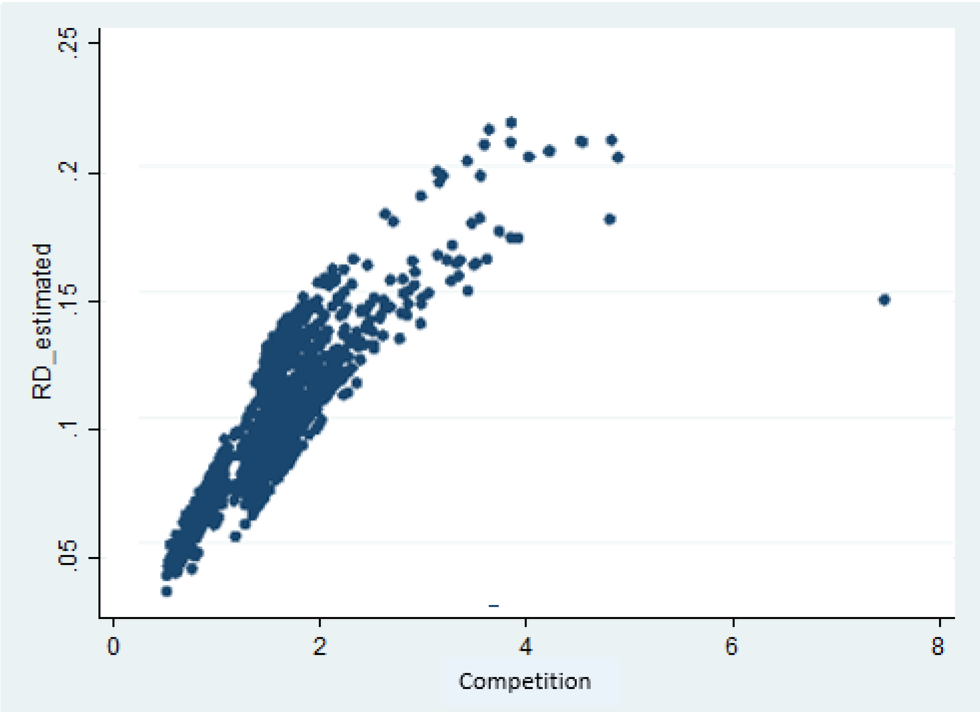
Country	*Industry number*
Belgium	15, 17, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35
Denmark	16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34
Germany	17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35
Finland*	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34
Spain	15, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35
Sweden*	15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34

*Finland and Sweden joined European Union in 1995, therefore, the effect of the SMP is accounted for only from 1995 for these countries.

Table 3. Descriptive statistics for variables used for estimation of Capital Costs

	Number of observations	Mean	Standard Deviation	Min	Max
Gross fixed capital formation, mln	2082	1402.879	2139.697	0	16654
Labour costs, mln	2227	6733.16	10564.07	13	76801
Value added, mln	2243	7225.375	10132.57	18	74600
Interest rate USA	2389	6.112378	1.501652	4.02	8.85
Depreciation rate	2389	0.05	0	0.05	0.05
Capital Costs, mln	**2082**	**514.718**	**817.29**	**0.259697**	**6612.236**

Figure 1. Quadratic prediction plot for model (I). Mark-up.



The outlying value corresponds to the mark-up measure of 7.42. The estimation results hold if the outlier is eliminated from the sample (see Table 5 below).

Table 4. Estimation results of model (I) after the outlier have been eliminated

VARIABLES	(1) Fixed Effects	(2) Random Effects	(3) Fixed Effects	(4) Random Effects	(5) Fixed Effects	(6) Random Effects
Competition	0.036***	0.072***	0.088***	0.079***	0.086***	0.076***
	(0.007)	(0.007)	(0.009)	(0.008)	(0.009)	(0.009)
Competition ^2	-0.001	-0.008***	-0.009***	-0.009***	-0.009***	-0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
GDP per capita			0.000***	-0.000*	0.000	-0.000
			(0.000)	(0.000)	(0.000)	(0.000)
Education spending			-0.000	0.000	-0.001	0.001
			(0.002)	(0.002)	(0.002)	(0.002)
Stock MC					0.000	0.000
					(0.000)	(0.000)
Constant	0.115***	0.146***	-0.026***	0.141***	-0.012***	0.143***
	(0.002)	(0.010)	(0.003)	(0.030)	(0.004)	(0.039)
Observations	1,891	2,022	1,467	1,598	1,388	1,519
Number of groups	130	131	130	131	130	131
Country FE	YES	NO	YES	YES	YES	YES
Industry FE	YES	NO	YES	YES	YES	YES
Year FE	NO	NO	YES	YES	YES	YES

Dependent variable is R&D intensity

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 5. First-stage equation for the dynamic model

VARIABLES	(1) First stage
ΔCompetition	-0.053***
	(0.009)
Δ Competition ^2	0.006***
	(0.002)
ΔGDP per capita	-0.000**
	(0.000)
ΔEducation spending	0.000
	(0.003)
ΔStock MC	-0.000
	(0.000)
R&D intensity(t-2)	-0.041***
	(0.009)
Constant	0.008***
	(0.002)
Observations	1,158

Estimation results for the first stage equation, where for the first-differences model the difference in lagged R&D intensity is instrumented with R&D intensity of a period *t-2;*
Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Figure 2. Fitted values for a sample of Scandinavian and non-Scandinavian countries

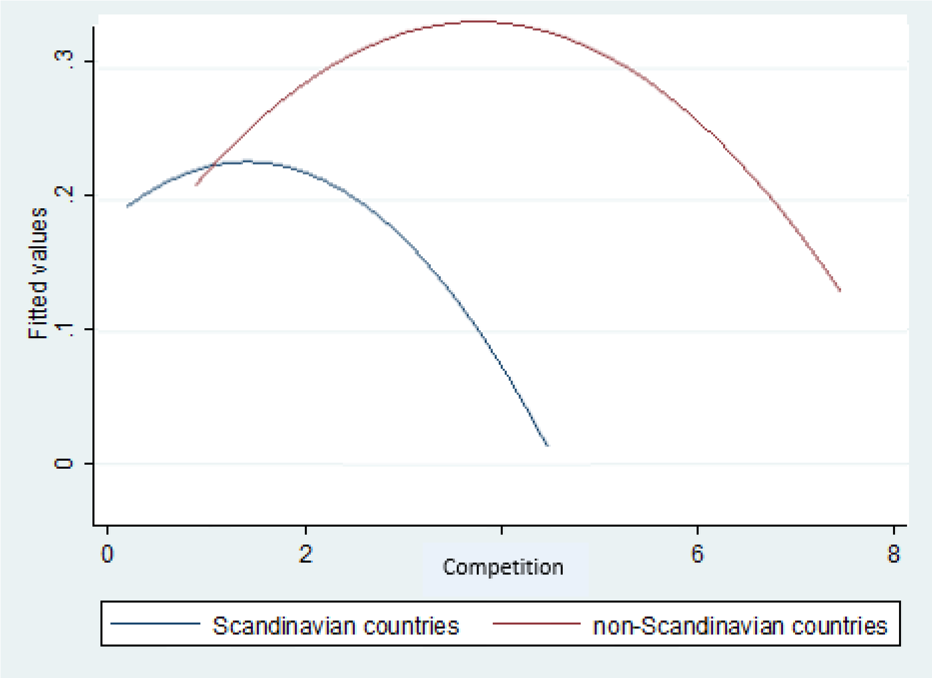


Figure 3. Fitted values for a sample of high-tech and low-tech sectors