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The relation between competition and innovation: Empirical results and implementation into WorldScan [1]

We analyse the theoretical and empirical relation between changes in competition levels and innovation efforts. Using OECD panel data we find a positive and significant elasticity of 1.8 between competition (measured as one minus the Lerner index) and innovation (measured as R&D intensity). This result is similar to other studies that find a monotonic relation between both variables. However, we do not find and inverted-U relationship as in the influential paper by Aghion et al. (2005). Using the theoretical insights and our own empirical results we include this relationship into WorldScan –CPB's multicountry recursive dynamic CGE model. Although the impact of competition changes on R&D expenditures can be significant at the sectoral level, our simulations using WorldScan do not result in significant macroeconomic changes when the link between competition and innovation is present.

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Contents

1 Introduction

Competition can have important effects on productivity and economic growth through different channels. One of these channels is the effect that increased competition has on the incentives to innovate. The relation between competition and innovation, however, can be complex. Innovation may allow firms to escape increased competition from rival firms, but at the same time, firms need rents to finance costly R&D expenditures, and these rents in turn are associated with current competition levels. The relation is also influenced by market-specific characteristics and strategic interactions between competing firms.

In this respect, the existing theoretical papers point to different and sometimes contradictory influences of competition on innovation (c.f. Aghion et al., 2001, 2005; Boone, 2001). Following Aghion et al. (2005) we can briefly summarise both conflicting influences as follows. If markets are not very competitive, such that profits for firms of comparable technology are relatively high, an increase in competition will reduce these profits, and consequently increase incentives to innovate, and become the market leader (the *escape competition effect*). On the other hand, in highly competitive markets, laggard firms are discouraged in innovating when competition increases yet further, since even after a successful innovation profits remain low (the *creative destruction* or *Schumpeter* effect). These simple arguments make clear that there are reasons to believe that the influence of competition on innovation efforts can have both a positive and a negative direction. Whether such arguments remain valid or relevant in real-life economies, and if so, in which regime (high or low competition) most firms are, is an empirical question.

The policy implications are most relevant. If innovation efforts depend positively on competition, then it appears to be straightforward that the usual thought of "the more competition the better" is correct. However, if more competition leads to less innovation and hence less growth, there is a trade-off between growth and the allocation of resources, and it is not a priori clear what economic policy is preferable: a focus on the near future and aim through increased competition for a better allocation of resources, or a focus on long term growth through innovation, for which a somewhat lower level of competition could be conducive.

The purpose of this paper is twofold. First, we want to know what is the empirical relation between competition and innovation in European Union countries. Thus, we survey the theoretical and empirical relation between competition and innovation and we conduct our own panel-data estimations using OECD data to assess the effect of competition on innovation.

Second, using these empirical results, we upgrade our WorldScan CGE model to include this link between competition and innovation. Previous versions of WorldScan did not account for interactions between competition levels and innovation. Using this upgraded version of WorldScan we can assess the effects of changes in competition induced by EU policies, for example through the Lisbon strategy, which contains a range of measures to improve the functioning of the EU internal market and enhance competition.

We use panel data from the OECD STAN database to define competition and innovation measures for 52 4-digit industries in 23 OECD countries for the period 1987-2007. We find a positive and significant elasticity of 1.8 between competition (measured as one minus the Lerner index) and innovation (measured as R&D intensity). This result is similar to other studies that find a monotonic relation between both variables. However, we do not find an inverted-U relationship as in the influential paper by Aghion et al. (2005).

Using the theoretical insights of the literature, together with our own estimations of the elasticity between competition and R&D intensity, we create a new version of WorldScan that incorporates this relationship into the CGE model. Using different counterfactual simulations, we find that competition changes have a significant impact on R&D expenditures at the sectoral level. At the aggregated macroeconomic level, however, the changes are not big compared to simulations where the competition-innovation link is not present.

This paper is organized as follows. Section 2 provides some theoretical background and working definitions of competition and innovation. In Section 2.2 we review the recent literature on the relation between competition and innovation. There appears to be considerable variety in the theoretical models, while there are not so many empirical studies. Motivated by this, we give our own contribution to the empirical results in Section 3, where we analyse OECD panel data of competition and R&D expenditure by industries in different EU countries. Section 4 outlines the theoretical underpinnings used to create the link between competition and innovation in WorldScan and we present the results of our counterfactual simulations.

2 Theoretical background and literature survey

Competition and innovation are two concepts that are ubiquitously used in economics, and both play a role of paramount importance in the way economies function and grow. We briefly summarize some of the roles these concepts play in economic thinking and modelling, and discuss the possible interaction between competition and innovation. We then review both the theoretical and empirical literature that deal with this relationship.

2.1 Competition, innovation and their relationship

Competition is one of the most fundamental concepts in economics. Theoretical economical models typically invoke agents that interact with each other, and compete over scarce resources, market share, employees, etc. Competition is usually assumed to be quite high and indeed in many, perhaps most, economic models, the assumption of perfect competition is considered to be a reasonable idealization of reality.

A high level of competition is usually considered to be beneficial to society. One reason economists consider competition a good thing is that it leads to a better allocation of resources. If one firm can produce a certain product at lower costs than another, then in absence of competition both can co-exist, but competition leads to the demise of the less effective firm. High competition implies low prices and more choices for consumers, who are courted by many firms. Even if there are examples where competition may have led to undesired consequences (competition is likely to have played a considerable role in the current financial crisis, where banks accepted increasing amounts of risk in order to remain competitive), competition is by most economists considered to be of vital importance for economies to function well.

Somewhat paradoxically, regulation and government intervention are necessary to provide the necessary requirements for markets to be competitive. In fact, a substantial part of economic policy is directed in keeping up a high level of competition. The European Union has a high profile commissioner responsible for competition in the EU. Many countries have their own national institutions with tasks such as preventing the formation of cartels and monopolies. Without such intervention, strong players try to co-operate strategically; as a result prices becomes unnecessarily high, and consumers have less choice.

Like competition, innovation is considered to be of great importance for economic welfare. Innovation is one of the key drivers of total factor productivity (TFP) and economic growth. For example, in the context of the Solow model growth per capita is driven completely by TFP. In the absence of innovation, it is hard to imagine sustained TFP growth. Other variables, such as education and trade also play a part in economic growth. However, broadly speaking innovation leading to improving technology is a prerequisite for economic growth. This is not to say that innovation expenditure should always be as high as possible; there is a trade-off between innovation and other welfare increasing factors, such as investment or consumption.

As in the case of competition, governments see an important role for themselves in actively stimulating innovation. Given the important link between innovation and growth this is not surprising. In addition, the results of innovation are often a new idea or invention that, unlike capital or human resources, can easily be copied: the products of innovation are *non-rival* (the use of an idea by one firm does not limit the use of the same idea by another firm; the marginal costs of such products are essentially zero), and they are *non-excludable* (a firm that owns a non-excludable good cannot prevent another firm from using it). Both non-rival and non-excludable goods will not be produced by firms in a fully competitive market economy. Governments intervene by the institution and enforcement of a patent system; by directly stimulating innovation through universities and other research centres; or by indirect support of innovation in the private sector through R&D subsidies. In addition, an attractive aspect of innovation is that there are considerable (national and international) spillovers from R&D investments (e.g. Coe and Helpman, 1995; Coe et al., 2009).

Several interesting conclusions can be drawn from our brief description of the roles of competition and innovation in the functioning of economies. First, both are considered to be highly important for economic welfare. Second, competition is mostly associated with short term welfare (better allocation of resources, optimisation of welfare with the means as they currently are), while innovation is associated more with the long term evolution of economies: innovation is a vital ingredient for long term economic growth. Third, there may be a trade-off in the aspiration of governments for more competition and more economic growth. This is perhaps most clearly illustrated by the patent system, the purpose of which is to grant innovating firms a monopoly on their invention: a blatant assault on competition. At the same time, once a patent system is in place, more competition can also result in more innovation. There are arguments for either dependence a positive or negative relationship between both variables. In Section 2.2 we outline the main theoretical and empirical results from the current literature.

2.2 Literature survey

In this section we review the literature that studies the relation between competition and innovation. First, we discuss in some detail the most influential paper in the literature: Aghion et al. (2005). Their empirical results show an inverted-U pattern between competition and innovation. Then we focus on the theoretical papers, which are not conclusive about the type of relationship between both variables. Finally, we end with a short summary on other empirical papers, which find a positive relation between competition and innovation.

The model by Aghion et al. (2005) is very straightforward and intuitive, and we briefly outline its main components here. Consider two firms that may have different levels of technology, the maximal lag in technology being one, such that the sector is either leveled or unleveled, and in the latter case only the laggard has the option of innovating. Innovation can happen without investment, with a hazard rate h, but this rate can be increased to $h+n$ if the firm invests $n^2/2$. If the industry is unleveled, the laggard makes zero profit π, while the leader makes a profit equal to $1-\gamma^{-1}$, where γ measures the technological level:

$$\pi_{-1} = 0; \quad \pi_1 = 1-\gamma^{-1} \tag{2.1}$$

In leveled industries, the firms collude to some extent, and competition is modelled as the inverse of the level of collusion. Collusion implies that they divide a fraction profits of the maximal profits among themselves, such that:

$$\pi_0 = \varepsilon\pi_1; \quad 0 \leq \varepsilon \leq 1/2. \tag{2.2}$$

Given this very simple set-up, Aghion et al. (2005) first show that if the industry is leveled, then the equilibrium research intensity n_0 is an increasing function of market competition. The intuition for this result is that the higher the competition, the lower the profits given a leveled situation; as a result, the pay-off of a successful innovation becomes larger. The incentives for the firms to obtain a monopoly position are thus larger when there is a lot of competition than when there is very little (in that case they make good profits to begin with, and have less reason to run the risk of being unsuccessful at innovating).

In contrast, equilibrium research efforts n_{-1} (of laggards) for an unleveled industry can be shown to be decreasing as a function of market competition: if there is very little competition, laggards (who do not make any profits in this situation) have the prospect of sharing profits after a successful innovation. But the higher the level of competition, the smaller those profits become. In the extreme case of perfect competition, profits remain zero even after a successful innovation, and the laggard then only has the costs of R&D efforts without hope to reap any of the benefits.

If there is very little competition, this implies that in a leveled situation, firms do not innovate much, while in an unleveled situation, the laggard typically catches up quickly. As a result, at any moment the situation is likely to be leveled, and research efforts are an increasing function of competition.

Vice versa, if there is a much competition, there is much innovation in the leveled configuration and little when it is unleveled, and at any time the firms are usually unleveled; consequently, at high levels of competition, research efforts are a decreasing function of competition.

Combining these results, research efforts are, in this model, a non-monotonic function of competition, first increasing and then decreasing, a conclusion that is reached through the following reasoning:

$$\text{Competition low} \rightarrow \text{leveled industries} \rightarrow I(C) \text{ increasing;} \tag{2.3}$$

$$\text{Competition high} \rightarrow \text{unleveled industries} \rightarrow I(C) \text{ decreasing;} \tag{2.4}$$

Even if the economic arguments in this highly simplified model provide the correct intuition, it does not necessarily imply that both regimes are of importance for realistic levels of competition. However, Aghion et al. (2005) performed an empirical analysis in which they consider the relation between competition and innovation and indeed find an "inverted-U" shape: firms populate both the low competition regime where there is a positive relation between competition and innovation, and the high competition regime where there is a negative relation. The analysis was performed for firms listed on the London Stock Exchange in the period 1973-1994. Competition was measured by 1 minus the Lerner index (see equation 3.2), and innovation was measured by citation weighted patents. Their conclusion is thus that a non-monotonic relation between competition and innovation is not only theoretically plausible, but that there is in fact empirical evidence for the presence of both regimes. Moreover, Aghion et al. (2005) use instrumental variables (the Thatcher era privatizations, the EU Single Market Programme, and the Monopoly and Merger Commission investigations) to argue that the relation is causal: the level of innovation activities *depends* on the level of competition.

The Aghion et al. (2005) model described above is a special case of a much more general scheme studied in Aghion et al. (2001). One important assumption that was relaxed in Aghion et al. (2001) is that the technological gap can be larger than unity, i.e., in unleveled markets not only the laggard, but also the leader can innovate; in Aghion et al. (2005) it was assumed that whenever the gap becomes larger than unit the laggard immediately imitates at zero costs until it is one step behind, so that the leader never had an incentive to innovate. The qualitative behaviour of innovation as a function of competition then depends on the size of the technological gap, and on the size each innovation. In addition to the level of competition, they also vary the level of imitation. At each moment there is a probability that a laggard firm imitates the technology of the leading firm without any efforts. For very low levels of imitation this turns out to be conducive to innovation, since it increases the number of neck-and-neck firms, which will then innovate due to the escape-competition effect (see previous section). However, for more realistic levels of ease of imitation, imitation is bad for innovation due to the usual Schumpeterian effect.

Aghion et al. (2001) find that competition is under almost all circumstances conducive to innovation. The inverted-U relation advocated in Aghion et al. (2005) is shown to be a special case that exists only for a restricted part of parameter space. In particular, it is only possible if all individual innovations are very large, and even then only under special conditions. Generally it is argued that the positive relation between competition and innovation is a sound theoretical prediction, whereas the possibility of a negative relation for very high levels of competition is uncertain.

From a historical perspective this conclusion is remarkable, since the Schumpeterian argument predicts a negative relation, and this is also what was found in the early literature. However, it is in accordance with more recent empirical findings. Both Nickell (1996) and Blundell et al. (1999) find a positive relation between competition and innovation, and so do Aghion et al. (2005) if they fit a linear relation. A study by Creusen et al. (2006) on the relation between competition and innovation in the Dutch retail sector also finds a positive relation, with no evidence for the existence of an inverted-U. Our own results, presented in Section 3, also show proof of a positive relation.

A different theoretical scheme is considered by Boone (2001), who derives several general results based on four axioms that an index of competition should fulfil. It is interesting to note that these conclusions are in conflict with those derived by Aghion et al. (2001) and Aghion et al. (2005), in particular Boone (2001) finds that in highly competitive industries, the most advanced firms innovate, and vice versa in weakly competitive industries. The difference can be traced to the third postulate, "*if the leader is far enough ahead, he gains as competition becomes more intense* ". In Aghion et al. (2005), the leader has a monopoly position and his profit is independent of the level of competition. Furthermore, in Aghion et al. (2005) innovation is a step-by-step process, and the leader can never be leap-frogged in one step. This implies that the leader does not have an incentive to invest in R&D, while in Boone (2001) it is the leader who does all the innovation in highly competitive industries: at any moment the leader risks to be overtaken by a laggard competitor firm, and it turns out that under the assumptions made by Boone (2001) the leader benefits more by averting this possibility than the laggard gains by realizing it.

The competition postulates proposed by Boone (2001) are very general. Only with further assumptions can a relation between the amount of innovation expenditure and competition be derived. However, it is clear that this relation need not be an inverted-U shape and Boone (2001) proposes that the relationship can indeed be U-shaped. Similar conclusions about the ambiguity of the relation between competition and innovation are reached by Schmutzler (2010), who argues that "an inverse U-shaped relation between competition and innovation is not necessarily more likely than a U-shaped relation".

In conclusion, theoretical models such as those by Aghion et al. (2005) and Boone (2001) provide a useful way of discussing the various mechanisms that could play a role in the interaction between competition and innovation, but their predictions are highly dependent on the details of the models such as the question whether innovation is step-by-step or leapfrogging is allowed, or whether firms are myopic or not. As a result, these models yield very little predictive power, and there is an important role for further empirical research to discern what the relevant economical mechanisms are.

Firm entry is closely related to the concept of competition. The ease of starting a new firm, entry costs, and openness of a market to the entry of foreign firms are all aspects of what is usually associated with competition. The decision whether to innovate or not therefore depends on the threat of entry in a similar way as it depends on the level of competition.

In Aghion et al. (2009) the effect of entry on (incumbent) innovation and productivity is considered as a function of distance from the technological frontier (as measured by a labour productivity index relating incumbent industries to their US equivalent). An increase of the threat of entry stimulates firms that are close to the technological frontier to innovate more in order to escape entry (this is analogous to the escape-competition effect discussed earlier). Firms close to the frontier face an increasing risk of being overtaken by foreign greenfield firms if the threat of entry increases, and thus of decreasing profits. However, since they are close to the frontier they may succeed in escaping this threat by improving their own technology. On the other hand, an increasing threat of entry has a discouraging effect on innovation efforts by incumbent firms that are far away from the technological frontier: while they may be able to compete in technology with local firms, they will likely fail to close the technological gap with foreign firms, and hence any R&D expenditure will usually be wasted. Empirical analysis by Aghion et al. (2009) on micro-data of UK firms indeed confirms that an increasing threat of entry is conducive to innovation efforts for firms close to the frontier, but leads to less innovation for firms that are far away from the frontier.

Aghion et al. (2009) use patents as a measure of innovation, which is, along with R&D expenditure, the most common measure. A novel approach is made in Amiti and Khandelwal (2009), who attempt to measure the "quality" of products that are exported to the US, and use that as a proxy for innovation. The quality of a product is an index that depends, among other things, on its price and market share (see Khandelwal, 2009, for more details). As a measure for competition they use import tariffs in the country where the products are produced. Their analysis makes use of 10,000 products that are exported to the US from 56 countries. They fit the following relation between changes in quality (ΔQ) and proximity to frontier (PF) and import tariffs:

$$\begin{aligned}\Delta\text{Quality}_{c,h,t} = {} & \alpha_{h,t} + \alpha_{c,t} + \beta_1 PF_{c,h,t-5} + \beta_2 \text{Tariff}_{c,h,t-5} \\ & + \beta_3 PF_{c,h,t-5}\text{Tariff}_{c,h,t-5} + \varepsilon_{c,h,t},\end{aligned} \tag{2.5}$$

where c is a country index, h a product index, and t the time in years.

From their regression, we highlight the following aspects. First, $\beta_2 > 0$, implying a negative relation between competition (i.e., tariffs; note that competition is inversely related to tariffs) and innovation (i.e., quality). However, $\beta_3 < 0$: if the proximity to the frontier PF is small, then this term does not make a difference, but if $PF \approx 1$, this term becomes large and can reverse the effect of competition on innovation. Finally, they find that $\beta_1 < 0$, implying convergence in quality.

An interesting aspect of the analysis is that the effect is more pronounced for OECD countries than for non-OECD countries; the authors conjecture that the difference is caused by the fact that for the economic mechanisms to operate there need to be good institutions. The different consequences of increased competition between countries, dependent on whether they are close to the technological frontier or far away from it, are also stressed by Acemoglu et al. (2006). Countries far away from the frontier adopt an investment-based strategy in their model, while more advanced countries switch to an innovation-based strategy.

3 Empirical results for OECD countries

From the literature review of the relation between competition and innovation it can be concluded that there is usually a positive relation between the two, with possibly a negative relation for very high levels of competition, although the inverted-U shape is not confirmed by all studies (see e.g. Creusen et al., 2006; van der Wiel et al., 2008).

In order to calibrate WorldScan, we have performed our own empirical analysis. The regression gives us quantitative results for the relation between competition and innovation measures that are close to the WorldScan model (for example, Aghion et al., 2005, use citation weighted patents as a measure of innovation, which are harder to interpret in terms of WorldScan than R&D intensity).

We use panel data from the OECD STAN database to define competition and innovation measures for 52 4-digit industries in 23 countries (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Sweden, South Korea, Spain, United Kingdom, United States) in the period 1987-2007.

3.1 Working definitions of competition and innovation

In spite of the importance of competition and its ubiquitous use in economic analysis, economists do not always agree on what exactly is meant by competition, or simply avoid a precise definition. Competition is associated with good information, low tariffs, low profits, large numbers of firms with equally divided market shares, lots of choice for consumers, etc. In theoretical work, competition is usually a rather abstract concept related to how much profits are shared among firms, while the mechanism leading to these profits is not always specified. In empirics, it is necessary to define an index that captures as well as possible the many different aspects of competition. Several of such measures are used in the literature. The index we consider here are motivated by the idea that competition reduces profits. Other measures of competition focus on other aspects of competition, for example the Herfindahl index measures the number of firms in an industry and their concentration. The *Lerner index* can be defined as [1]:

$$L = \frac{\text{Gross operating surplus} - \text{Financial costs}}{\text{Output}} \tag{3.1}$$

The motivation for this definition is that it is a (scaled) measure of the profits of firms. When the gross operating surplus is large (net of financial costs) compared to turnover, this can be seen as

[1] An alternative definition used in theoretical models is $L = (P - MC)/P$ with P the price and MC the marginal costs of a given product. This measure is not so useful in empirical analysis since the marginal costs cannot be observed.

an indication that there is little competition for a firm (or industry/sector), for if there were a lot of competition, firms would lower their prices in turn for a larger market share, which would increase their profits. Since larger Lerner indices imply higher profit and hence less competition, we define the related competition index as:

$$C = 1 - L \tag{3.2}$$

Closely related to the Lerner index is the *markup* and its corresponding competition measure, which we define following Griffith et al. (2006) as:

$$\mu = \frac{\text{Value added}}{\text{Labour costs} + \text{Capital costs}} \tag{3.3}$$

There are many possible interpretations of innovation and as a result many different indices that are used. We can divide such indices in those that try to measure input, typically through R&D efforts of firms, and those that measure output, for which changes in the quality of products can be used (Amiti and Khandelwal, 2009), or the number of patents that have been granted in a certain industry.

The measure we use in our empirical analysis for measuring innovation is the R&D intensity, defined as R&D expenditure divided by value added:

$$I = \frac{\text{R\&D expenditure}}{\text{value added}} \tag{3.4}$$

For the purpose of illustration, we plot the time series of averaged R&D intensity $\langle I \rangle$ and Lerner indices $\langle L \rangle$ in Figure 3.1. The average is done over all industries and countries, without weight. It seems indicative of a decreasing competition in the late eighties and early nineties, then followed by a more or less stable period. R&D intensity appears to have decreased considerably in the period studied.

In Figure 3.2 we show a scatter plot of $\ln\langle I \rangle$ versus $\ln\langle C \rangle$. There appears to be a positive relation between competition and innovation.

To summarize, as a our measure of innovation we use R&D intensity, as measured by R&D expenditure divided by value added (see also, e.g., Griffith et al., 2006). Our competition index is 1 minus the Lerner index, see equation 3.2. We calculate the financial costs using the perpetual inventory method, with a depreciation rate of 10% and we assume a constant interest rate of 8%.

3.2 Empirical results

We first consider a monotonic dependence of innovation on competition using industry-country fixed effects, specified by:

$$I_{ict} = \alpha_1 C_{ict} + \alpha_2 \delta_{ic} + \varepsilon_{ict}, \tag{3.5}$$

Figure 3.1 Mean R&D intensity (solid) and Lerner index (dashed) as a function of time.

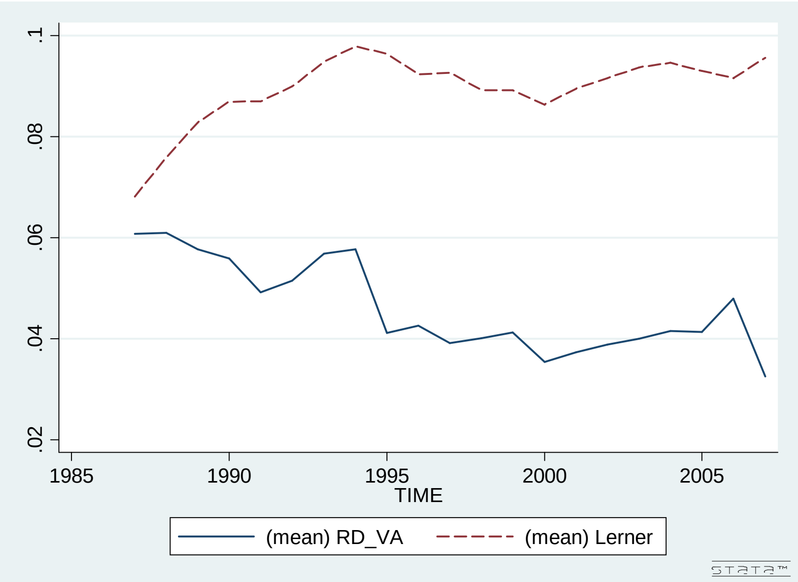
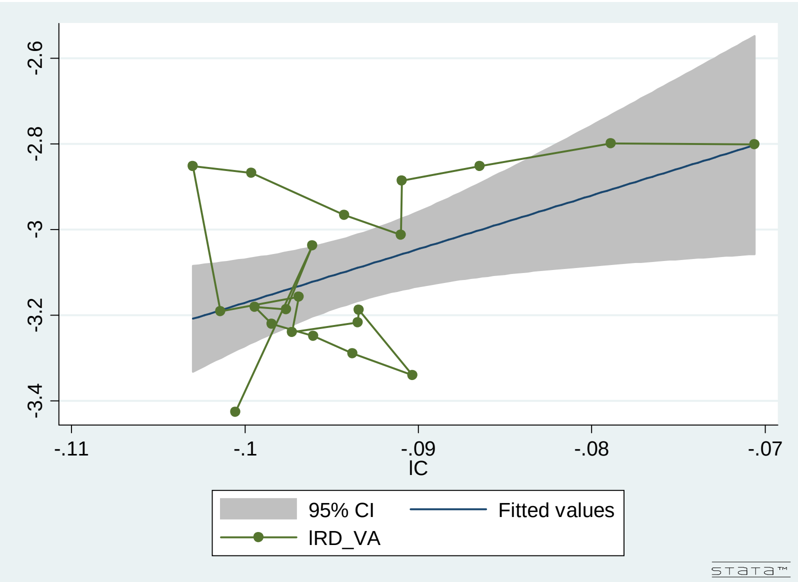


Figure 3.2 Scatter plot of $\ln I$ **versus** $\ln C$**, for the period 1987-2007. The series starts in the right upper corner.**



where I is our innovation measure of R&D divided by value added (equation 3.4), C is the competition measure, defined as one minus the Lerner index (equation 3.2), δ_{ic} are industry-country dummies, and i indexes industries, c countries and t years.

We also consider a quadratic relation to test for the inverted-U shape proposed by Aghion et al. (2005). The panel data results using industry-country dummies are shown in columns (1) and (2) in Table 3.1.

Table 3.1 Panel data regressions using industry-country fixed effects

Dependent:	Independent:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
RD_VA	Comp	6.733***	2.191					
		[1.801]	[10.144]					
	Comp^2		2.499					
			[5.721]					
Log_RD_VA	Log_Comp			1.823***	1.864***			
				[0.331]	[0.431]			
	Log_Comp^2				0.152			
					[1.370]			
	Log_Comp_Lag1					1.139***		0.976***
						[0.366]		[0.314]
	Log_Comp_Lag2						0.696**	0.275
							[0.350]	[0.296]
Observations		10934	10934	10551	10551	9375	8588	8394
R-squared		0.014	0.014	0.015	0.015	0.006	0.002	0.006

Notes: Innovation (RD_VA) measured by R&D intensity (i.e. R&D/value-added). Competition (Comp) measured as one minus the Lerner index. The data are weighed by the output of the industry. Robust standard errors in brackets. Significance levels are coded as: *** significance at 1% level, ** at 5% level, and * at 10% level.
Source: OECD STAN database and own estimations.

We find that there is a positive and monotonic relation between competition and innovation (as defined by the indices we employ here), which is significant at the 5% level. The sign of this result is in agreement with the recent literature (e.g. Nickell, 1996; Blundell et al., 1999; Aghion et al., 2005; Griffith et al., 2006). We do not find a significant quadratic relationship as in Aghion et al. (2005).

However, we are more interested in the relation between the logarithm of innovation with respect to the logarithm of competition (closely related to the elasticity), for which we estimate:

$$\ln(I_{ict}) = \beta_1 \ln(C_{ict}) + \beta_2 \delta_{ic} + \varepsilon_{ict}, \qquad (3.6)$$

The results are shown in columns (3) and (4) of Table 3.1. The relation is again monotonic and positive, and highly significant. A change of 1 percentage point in the level of competition, leads to a change of 1.8 percentage points in the level of R&D intensity.

In order to evaluate the magnitude of the relation between competition and innovation, we compare to Griffith et al. (2006). They consider the relation between R&D expenditure and markup μ (equation 3.3) to find that $\ln(\text{R\&D}) \approx -4\mu$. In comparison, we find $\ln(\text{R\&D}) \approx -2.3L$. Although the Lerner index and the markup cannot be directly compared, our value for the proportionality coefficient between competition and innovation appears to be of a similar order of magnitude.

3.3 Endogeneity and robustness tests

So far we have not addressed in our empirical analysis the question of whether competition is *causing* innovation or merely correlated with innovation. The theory discussed in the literature (see Section 2.2) suggests that there is a causal effect that goes in the direction of competition driving innovation. Furthermore, by using R&D intensity, we consider the *input* for innovation as our innovation index. It seems not very likely, however, that R&D expenditure affects the competition level within the same year; consequently, it is plausible that the relation we find is indeed causal, in the sense that a higher level of competition, as measured by one minus the Lerner index, leads to higher R&D expenditure.

To address the question of endogeneity econometrically, regress R&D intensity against lagged competition. The results of these regressions are presented in columns (5) to (7) in Table 3.1. We find that competition with one year lagged and even with a two-year lag still has a positive and significant influence on R&D intensity. From an economic point of view, it is highly unlikely that current R&D expenditures have an influence on competition changes one or two years ago. Therefore, we are reassured that the causal relation from competition to innovation is positive and that it is not a result of an endogeneity bias.

As additional tests for endogeneity we use (lagged) competition differences as instrumental variables. We denote $c_{ict} \equiv \ln(C_{ict}) \equiv \ln(1 - L_{ict})$. Our set of instruments is $\Delta c_t = c_t - c_{t-1}$; $\Delta c_{t-1} = c_{t-1} - c_{t-2}$; and $\Delta c_{t-2} = c_{t-2} - c_{t-3}$. We then use two stage least squares, first projecting competition on the set of instruments, such that:

$$\hat{c}_{ict} = \beta_0 \Delta c_t + \beta_1 \Delta c_{t-1} + \beta_2 \Delta c_{t-2} + \delta_{ic} + \eta_{ict}, \tag{3.7}$$

where δ_{ic} are industry-country dummies, and η_{ict} is the error term. From the regression we find $(\beta_0, \beta_1, \beta_2) = (0.66, 0.47, 0.31)$, all significant at the 95% confidence level. We then regress:

$$\ln(I_{ict}) = \alpha^{\text{IV}} \hat{c}_{ict} + \delta_{ic} + \varepsilon^{\text{IV}}_{ict}, \tag{3.8}$$

The IV result again yields a positive relation between competition and innovation that is significant at the 95% level. The coefficient is slightly smaller than the direct OLS result (equation 3.6).

A Sargan test which regresses the error terms $\varepsilon_{ict}^{\text{IV}}$ on the instruments fails to reject the null hypothesis that the instruments are exogenous ($P_{\text{Sargan}} = 0.88$), such that the instruments are valid. The Kaufman test rejects the null hypothesis that competition is exogenous ($P_{\text{Kaufman}} = 0.0097$).

We also apply Arellano-Bond regression, where we perform IV regression with the same instruments $(\Delta c_0, \Delta c_1, \Delta c_2)$ on the dynamic equation:

$$\ln(I_{ict}) = \gamma \ln(I_{i,c,t-1}) + \alpha^{\text{AB}} \ln(C_{ict}) + \delta_{ic} + \varepsilon_{ict}, \tag{3.9}$$

Alternatively, we also regressed equation 3.9 without additional instruments. The results of these regressions are presented in Table 3.2.

We considered a number of alternative specifications in order to test how sensitive our result is to the assumptions we made. Since our method to calculate the financial costs is rather convoluted, we repeated the analysis with an alternative Lerner index where we set the financial costs to zero; this slightly reduced the proportionality coefficient, but did not lead to a significantly different result.

Table 3.2 Endogeneity and robustness tests

Dependent variable	independent	coefficient	standard error	Comments
ln (I)	ln (1 - L)	1.58 ***	(0.26)	IV: Two lags (equation 3.8)
ln (I)	ln (1 - L)	1.56 ***	(0.23)	Arellano-Bond with IV: Two lags (equation 3.9)
ln (I)	ln (1 - L)	1.72 ***	(0.47)	Arellano-Bond without IV: Two lags (equation 3.9)
ln (I)	ln (1 - L)	2.50 ***	(0.36)	Using an alternative Lerner index

Notes: Innovation (I) measured by R&D intensity (i.e. R&D/value-added). Competition measured as one minus the Lerner index. The alternative Lerner index is calculated without the substraction of financial costs. The data are weighed by industry output. Significance levels are coded as: *** significance at 1% level, ** at 5% level, and * at 10% level.
Source: OECD STAN database and own estimations.

Finally, we also considered an industry-specific relations between competition and innovation. These regressions are presented in the Appendix. However, in our final analysis we use one overall coefficient: we did not have data for all industries in WorldScan, many of the results were not significant, and the ones that were all of comparable magnitude.

To summarise, we find that the use of instrumental variables maintains a significant positive relation between competition and innovation, as measured by our indices. The elasticity does change, but only slightly, from $\alpha = 1.8$ for regression without instruments, to $\alpha = 1.56$ for Arellano-Bond regression with instruments. As we argued in the beginning of this section that endogeneity is unlikely to play a role of importance, we use the result in equation 3.6 ($\alpha = 1.8$) as our parameter in WorldScan.

4 Modelling imperfect competition and innovation in WorldScan

4.1 Current version of WorldScan with imperfect competition

We first present how imperfect competition is currently modelled in WorldScan. Based on de Bruijn (2006), these are the main features of imperfect competition that are present in the previous version of WorldScan (WS):

- Dixit-Stiglitz and Armington specifications for love-of-variety effects, both in the supply and the demand side.
- Distinction between the love-of-variety and ease of substitution.
- Monopolistic competition (free entry and exit of firms) with endogenous number of firms, but no strategic interaction.
- Variety scaling: all firms are symmetric and there are no scale effects in the model.

The equations that define the Dixit-Stiglitz and Armington specifications for love-of-variety effects are well specified in de Bruijn (2006). Here we focus on the equations that deal with monopolistic competition and define mark-up prices, fixed costs and number of firms

4.1.1 Fixed costs, mark-ups and number of firms

Raw output X^0_{fir} is produced under CRS using a composite of intermediate inputs and factors with unit cost P^0_{ir}, where f indexes firms (or varieties/brands), i indexes sectors and r regions. Part of this raw output is used as setup-costs or fixed costs of production, such that:

$$X^0_{fir} = X_{fir} + F_{fir} \tag{4.1}$$

where X_{fir} is output sold by firm f and F_{fir} are the fixed costs by firm. In addition, $X_{fir} > 0$ only if $F_{fir} < X^0_{fir}$, otherwise the firm does not produce and $X_{fir} = 0$. Output sold is less than raw output in terms of quantity, but not in terms of value, since the fixed costs are covered by the mark-up μ.

Using equation 4.1 the firm's profits are given by:

$$\pi_{fir} = P_{fir}X_{fir} - P^0_{ir}X^0_{fir} = P_{fir}X_{fir} - P^0_{ir}\left(X_{fir} + F_{fir}\right) \tag{4.2}$$

We assume a monopolistic competition setting, where there is a large number of firms and no strategic interaction among them. The profit-maximization first order condition is:

$$\frac{\partial \pi_{fir}}{\partial X_{fir}} = P_{fir} + X_{fir}\frac{\partial P_{fir}}{\partial X_{fir}} - P^0_{ir} = P_{fir}\left(1 + \frac{X_{fir}}{P_{fir}}\frac{\partial P_{fir}}{\partial X_{fir}}\right) - P^0_{ir} = 0 \tag{4.3}$$

Defining the demand elasticity ε_i using $\frac{X_{fir}}{P_{fir}} \frac{\partial P_{fir}}{\partial X_{fir}} = -\frac{1}{\varepsilon_i}$ yields:

$$P_{fir} = P^0_{ir} \left(\frac{\varepsilon_i}{\varepsilon_i - 1} \right) \tag{4.4}$$

where the price mark-up is $\mu = \frac{\varepsilon_i}{\varepsilon_i - 1} = \left(1 + \frac{1}{\varepsilon_i - 1}\right)$.

Assuming free entry and exit of firms, then prices are equal to average costs and there are zero profits. Setting equation 4.2 equal to zero we obtain:

$$P_{fir} = P^0_{ir} \left(1 + \frac{F_{fir}}{X_{fir}} \right) \tag{4.5}$$

In this equation it is clear that mark-ups are set to compensate for fixed costs: $\mu = \left(1 + \frac{F_{fir}}{X_{fir}}\right)$. This equation also provides the downward shape of the average cost curve and is the source of economies of scale. As production increases average costs decreases.

It is further assumed that all firms within a sector are symmetrical, i.e. they have the same technology (cost function), size $\left(F_{fir} = F_{ir}\right)$ and charge the same price, such that $P_{ir} = P_{fir}$. This is known as "variety scaling" in the literature (Francois and Roland-Holst, 1996). Therefore, sectoral output is given by:

$$X_{ir} = n_{ir} X_{fir}, \tag{4.6}$$

where n_{ir} is the number of firms.[2] This specification implies that sectoral production changes only with regard to the number of active firms n_{ir}, but not with respect to the production level of each firm X_{fir}. Thus, imperfect competition in this model yields variety effects, but no scale effect. Substituting equation 4.4 in 4.5 we have:

$$X_{fir} = F_{fir} \left(\varepsilon_i - 1\right). \tag{4.7}$$

Combining equation 4.6 with sectoral output quantities we obtain the number of firms active in the sector. With $n_{ir} X_{fir} = X^0_{ir} - n_{ir} F_{fir} \Rightarrow n_{ir} = \frac{X^0_{ir}}{X_{fir} + F_{fir}}$, and using equation 4.7 we get:

$$n_{ir} = \frac{X^0_{ir}}{\varepsilon_i F_{fir}}. \tag{4.8}$$

This solves the imperfect competition model. To summarize, we have two unknowns: P_{ir} and n_{ir}, two parameters: ε_i and F_{fir}, and the following two equations:

$$P_{ir} = P^0_{ir} \left(\frac{\varepsilon_i}{\varepsilon_i - 1} \right) \tag{4.9}$$

$$n_{ir} = \frac{X^0_{ir}}{\varepsilon_i F_{fir}} \tag{4.10}$$

The variety-scaling assumption, means that equation 4.7 is redundant and the scale of production of each firm is fixed at $X_{fir} = F_{fir} \left(\varepsilon_i - 1\right)$.

[2] Because of calibration issues discussed below, n_{ir} is indexed to one in the baseline. Thus, n_{ir} is interpreted as an index number rather than the absolute number of firms.

4.1.2 Calibration

The parameters are calibrated as follows:

- The love-of-variety parameter is set to one.
- $\varepsilon_i = (1+\sigma_i) * \sqrt{2}$, where σ_i is the Armington elasticity. This formulation assures that $\varepsilon_i > \sigma_i$, which is needed for the model to have a numerical solution.
- $F_{fir} = \frac{X_{ir}^{0,base}}{n_{ir}^{base}\varepsilon_i}$, where $base$ are the base year values and n_{ir}^{base} is set equal to one. [3] Note that the fixed costs are firm-specific, thus, it is implicitly assumed that the sectoral fixed costs are equal to the firm-specific fixed costs in the base year.
- Substituting the calibrated F_{fir} into equation 4.8 we get the actual equation used in WorldScan to estimate the number of firms:

$$n_{ir} = \frac{X_{ir}^0}{X_{ir}^{0,base}} \tag{4.11}$$

Therefore, fixed costs F_{fir} are not explicitly present in this version of WorldScan.

4.2 New version of WorldScan including the competition-innovation link

In this section we show how imperfect competition is now modelled in order to include the linkage between competition and innovation.

If we define the fixed costs as a set-up R&D expenditure, then an increase in the number of firms (reflecting increased competition) can only be obtained if each new firm –producing a new variety– can pay for the fixed R&D set-up costs. This mechanism provides a direct link between competition (indexed number of firms) and innovation (R&D expenditures).

4.2.1 New imperfect competition equations

Assuming that the fixed cost are now R&D set-up costs F_{fir}^R, equation 4.1 is now:

$$X_{fir}^0 = X_{fir} + F_{fir}^R \tag{4.12}$$

and firm's profits are now given by:

$$\pi_{fir} = P_{fir}X_{fir} - P_{ir}^0 X_{fir} - P_{fir}^R F_{fir}^R \tag{4.13}$$

[3] As an alternative to indexing the baseline number of firms to one, Herfindahl concentration indexes can be used directly to estimate n_{ir}. However, de Bruijn (2006) mentions that for a small number of sectors (as is common in CGE estimations) EUROSTAT data shows that the sectoral number of firms can be very large. This causes numerical problems in the calibration procedure, while it does not add much information at such sectoral aggregations (they where using 4 sectors and we use 9 sectors in the current version). Therefore, the index is set to one. For other applications, it can be relevant to have the full 57 GTAP sectors and check if the EUROSTAT data can be meaningfully used.

where P^R_{fir} is the cost price of R&D capital. With a large number of firms and no strategic interaction, the profit-maximization first order condition is:

$$\frac{\partial \pi_{fir}}{\partial X_{fir}} = P_{fir} + X_{fir}\frac{\partial P_{fir}}{\partial X_{fir}} - P^0_{ir} = P_{fir}\left(1 + \frac{X_{fir}}{P_{fir}}\frac{\partial P_{fir}}{\partial X_{fir}}\right) - P^0_{ir} = 0 \tag{4.14}$$

and we obtain the same pricing condition as before:

$$P_{fir} = P^0_{ir}\left(\frac{\varepsilon_i}{\varepsilon_i - 1}\right) \tag{4.15}$$

Assuming free entry and exit of firms, then prices are equal to average costs and there are zero profits. Setting the profit equation 4.13 equal to zero we obtain:

$$P_{fir} = P^0_{ir} + \frac{P^R_{fir}F^R_{fir}}{X_{fir}} \tag{4.16}$$

where the mark-ups are set to compensate for fixed costs: $\mu = \frac{P^R_{fir}F^R_{fir}}{X_{fir}}$. This equation also provides the downward shape of the average cost curve and is the source of economies of scale. As production increases average costs decrease.

We assume again variety scaling, such that: $P^R_{fir} = P^R_{ir}$ and $P_{fir} = P_{ir}$. Sectoral output is given by:

$$X_{ir} = n_{ir}X_{fir} \tag{4.17}$$

Substituting equation 4.15 in 4.16 we have: $P^0_{ir}\left(\frac{\varepsilon_i}{\varepsilon_i-1}\right) = P^0_{ir} + \frac{P^R_{ir}F^R_{fir}}{X_{fir}} \Rightarrow P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right) = \frac{P^R_{ir}F^R_{fir}}{X_{fir}} \Rightarrow$

$$X_{fir} = \frac{P^R_{ir}F^R_{fir}}{P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)} \tag{4.18}$$

From equation 4.18 we have that the scale of production is no longer fixed. If the price of R&D inputs increases more than the price of the raw output (composite inputs), then firms have to increase production in order to decrease average costs and remain able to pay the relative increase in the fixed costs value. Thus, in this setting we have both scale and variety effects.

Combining the sectoral output quantities from equation 4.17 with equation 4.12 we obtain: $X^0_{ir} = n_{ir}X_{fir} + n_{ir}F^R_{fir} \Rightarrow n_{ir} = \frac{X^0_{ir}}{X_{fir}+F^R_{fir}}$, and using equation 4.18 we get: $n_{ir} = \frac{X^0_{ir}}{\frac{P^R_{ir}F^R_{fir}}{P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)} + F^R_{ir}} \Rightarrow$

$$n_{ir} = \frac{X^0_{ir}P^0_{ir}}{F^R_{fir}\left(P^R_{ir}(\varepsilon_i - 1) + P^0_{ir}\right)} \tag{4.19}$$

Finally, we obtain the sectoral output using equation 4.17 in combination with equations 4.18 and 4.19: $X_{ir} = n_{ir}X_{fir} = \frac{P^R_{ir}F^R_{fir}}{P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)} \frac{X^0_{ir}P^0_{ir}}{F^R_{fir}\left(P^R_{ir}(\varepsilon_i-1)+P^0_{ir}\right)} \Rightarrow$

$$X_{ir} = \frac{X^0_{ir}P^R_{ir}}{\left(P^R_{ir} + P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)\right)} \tag{4.20}$$

This solves the new imperfect competition model. To sum up, we have two parameters (ε_i and F^R_{fir}), with four unknowns: P_{ir}, $X_{ir,}$ X_{fir} and n_{ir}, and the following system of equations:

$$P_{ir} = P^0_{ir}\left(\frac{\varepsilon_i}{\varepsilon_i - 1}\right) \tag{4.21}$$

$$X_{fir} = \frac{P^R_{ir}F^R_{fir}}{P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)} \tag{4.22}$$

$$n_{ir} = \frac{X^0_{ir}P^0_{ir}}{F^R_{fir}\left(P^R_{ir}\left(\varepsilon_i - 1\right) + P^0_{ir}\right)} \tag{4.23}$$

$$X_{ir} = \frac{X^0_{ir}P^R_{ir}}{\left(P^R_{ir} + P^0_{ir}\left(\frac{1}{\varepsilon_i-1}\right)\right)} \tag{4.24}$$

The calibration of ε_i is done as before, and we use equation 4.19 to calibrate F^R_{jir}. We assume that in the base year $n_{ir} = 1$, such that:

$$F^R_{fir} = \frac{X^{0,base}_{ir}P^{0,base}_{ir}}{P^{R,base}_{ir}\left(\varepsilon_i - 1\right) + P^{0,base}_{ir}} \tag{4.25}$$

Finally, we update the value of the love-of-variety parameter. In the previous version of WorldScan a value of one was used, but we now use the value of 0.56, following the empirical findings of Ardelean (2009).

4.2.2 Linkage between competition and innovation

The next step is to calibrate the increase in competition to the increase in R&D expenditures. We have that: $I^{R\_D}_{ir} = R\_D_{ir} - (1-\delta_{R\_D}) * R\_D_{ir-1}$, where I^{R_D} is the volume of investment in R&D in sector i, region r and year y; R_D_{ir} is the volume of the R&D stock and δ_{R_D} is the depreciation rate of R&D stocks. This supply of R&D stocks is equated to the demand for the R&D input $\left(D^R_{ir}\right)$, such that: $R\_D_{ir} = D^R_{ir}$.

Following the idea that new varieties can only be created if the R&D setup costs are covered, then the link between competition and innovation is given by:

$$R\_D_{ir} = D^R_{ir} + F^R_{fir}\widetilde{n}_{ir} \tag{4.26}$$

where $\widetilde{n}_{ir}$ is the number of firms that entered or exited the sector. Thus, each sector demands the usual R&D inputs D^R_{ir} plus the new R&D set-up costs which are required to produce new varieties.

However, for this specification to provide meaningful estimations on the changes in R&D expenditure associated with changes in the number of firms, we must have an empirical estimation of the R&D setup costs by sector and region. At present, these values are only calibrated in the model, and we do not have any empirical estimates of these R&D setup fixed costs.

Therefore, we use another specification where we employ the empirical results from Section 3.2. There we obtained the parameter ω, which gives us an empirical estimate of the relation between innovation and competition. In particular ω is the elasticity of R&D intensity (i.e. R&D in terms of value added) with respect to competition, such that:

$$\omega = \frac{d\left(\frac{R\&D}{VA}\right)}{dL} \frac{L}{\left(\frac{R\&D}{VA}\right)} \tag{4.27}$$

where L is the Lerner index that measures competition.

To implement this parameter into the model we need to make some assumptions. First, in the baseline scenario there is no linkage between changes in competition and R&D expenditure and the linkage is only applied to the counterfactual scenarios.[4] Second, ω is calculated using the one minus the Lerner index $(1-L)$ as a measure of competition. However, given our monopolistic competition assumption we do not have profits in the model and thus, we use $\widehat{n}$ (the percentage change in the index on number of firms with respect to the baseline scenario values) as our measure of competition. Then we have that $\widehat{n} = \frac{d(1-L)}{(1-L)}$. Finally, we use the approximation $\frac{dx}{x} = \widehat{x}$ where $\widehat{x}$ is the percentage change of variable x. Using these assumption and equation 4.27 we construct the following linkage equation:

$$R\_D_{ir} = D^R_{ir}\left(1+\Omega\right) \tag{4.28}$$

$$\Omega = \omega \widehat{n}_{ir} \widehat{v}_{ir} \tag{4.29}$$

where $\widehat{v}_{ir}$ is the percentage change in the value-added of sector i in region r. Equation 4.28 tells us that the demand for R&D is increased as a function of the new varieties that require additional R&D setup costs. Note that $\widehat{n}_{ir} = 0$ in the baseline and the competition-innovation link only applies to the counterfactual scenarios.

4.3 Simulation results

Following the model updates described above, we have now three main versions of the model:

- Perfect competition: $impc = 0$
- Imperfect competition without the competition-innovation link: $impc = 1$ & $ic = 0$
- Imperfect competition with the competition-innovation link: $impc = 1$ & $ic = 1$

In accordance to our empirical estimations in Section 3 we use the value of $\omega = 1.8$. To show what is the macroeconomic impact of including the competition-innovation link, we run two

[4] Since we do not have any scale effects implemented yet, the number of firms is directly related to changes in sectoral production. In the baseline scenario the economy is expanding and thus, the number of firms is increasing. Applying the link between competition and innovation will then result in a big increase in R&D expenditure.

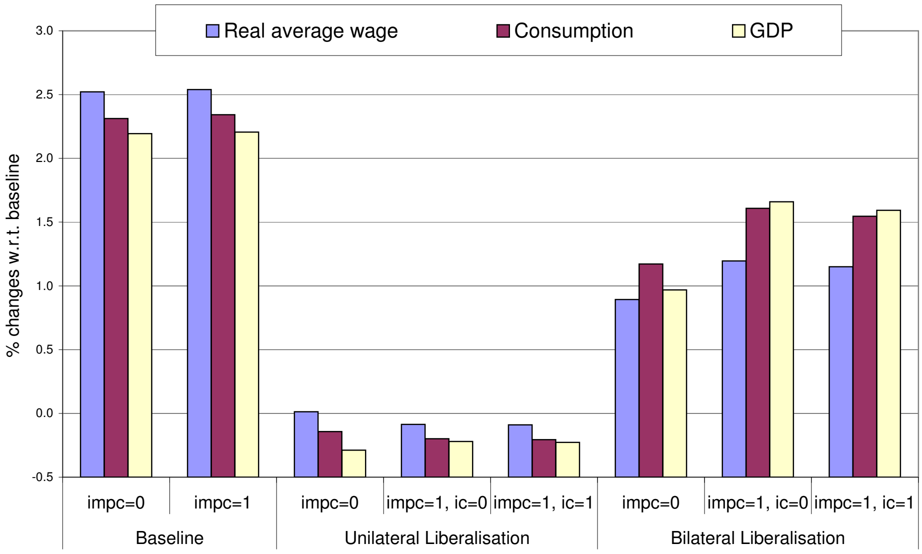
counterfactual simulations. In the first, there is an unilateral liberalisation process by the EU27, i.e. we completely eliminate the import tariffs for countries outside of the EU. The second counterfactual is a bilateral liberalisation, were in addition to the elimination of import tariffs into the EU27, countries outside the EU also eliminate their import tariffs for European products.

Figure 4.1 shows the macroeconomic results in 2040, for different combinations of the model versions with these two new counterfactuals. First, imperfect competition has little effect on the baseline scenario. Second, the unilateral liberalisation counterfactual has slightly negative changes in GDP and consumption, but there are small differences between including imperfect or perfect competition. Moreover, the inclusion of the competition-innovation link does not affect significantly the results. There is a very small reduction in GDP and consumption, which is caused by a composition effect: sectors with increased number of varieties (more competition) increase their R&D expenditure, but the opposite occurs for sectors where there is less competition. Both effects more or less cancel out at the aggregated level and R&D expenditure does not change much and thus, GDP neither. For the last counterfactual with bilateral liberalisation both GDP and consumption increase by almost 1% with respect to the baseline values with perfect competition. With imperfect competition the increase is bigger, at around 1.5%. However, including the competition-innovation link only represent a small macroeconomic reduction, once again as a result of the composition effect of diverse sectoral changes in competition.[5]

To sum up, though the elasticity of R&D expenditure to changes in competition is significant in our empirical estimates, the aggregated macroeconomic effects of including this relationship are not very significant. This is due to compensations between different sectors, where some increase competition and R&D expenditure, while others are having the opposite effect. However, in a more disaggregated analysis, there are important sectoral changes in competition and innovation.

[5] In addition, we conducted sensitivity analysis where we doubled the value of ω to 3.5. But even when we use this new and much higher elasticity we still find similar results as before.

Figure 4.1 WorldScan simulation results in 2040, baseline values and changes with respect to baseline for counterfactuals



Appendix A Industry-specific relations between competition and innovation

In Section 3 we estimated a single, overall relation between competition and innovation. In this appendix, we consider the relation between competition and innovation per industry, with country-fixed effects by estimating:

$$\ln\left(I_{ict}\right) = \alpha_i^C \ln\left(C^{ict}\right) + \delta_c + \varepsilon_{ict}, \qquad \text{(A.1)}$$

where δ_c is a set of country-dummies. The resulting values for α_i^C, estimated for the period 2001-2007, are displayed in Table A.1.

Most of the industries have a positive relation between competition and innovation, and in particular the relation is always positive for the industries that have a significant relation at the 5% level. The magnitudes of those significant coefficients are all similar. We conclude that a similar picture emerges from the relations for individual industries with significant values. We perform our main analysis with one single overall coefficient (see equation 3.6), because the data we used were insufficient to determine coefficients for most of the sectors in WorldScan, and because many of the coefficients were insignificant. If better data was available, it may be possible to extend the model with individual, industry-specific elasticities for the relation between competition and innovation.

Table A.1 OLS regressions of innovation against competition per industry

Industry	coefficient		robust standard error
Basic metals	0.16		4.42
Construction	12.24		9.46
Chemicals and chemical products	1.57		2.18
Coke, refined petroleum products and nuclear fuel	8.42	**	3.17
Computer and related activities	5.36		3.69
Electrical machinery and apparatus, nec	5.41	***	1.10
Fabricated metal products, except machinery and equipment	– 1.82		1.99
Food products and beverages	4.70	*	2.33
Hotels and restaurants	15.02	*	8.34
Leather, leather products and footwear	– 4.06		11.10
Machinery and equipment nec	– 3.76	*	2.23
Manufacturing nec	– 0.44		3.01
Medical, precision and optical instruments	4.13	***	1.38
Motor vehicles, trailers and semi-trailers	8.13	**	3.37
Office, accounting and computing machinery	9.12	***	2.08
Other business activities	1.48		1.54
Other non-metallic mineral products	3.00	*	1.73
Other transport equipment	1.10		3.88
Printing and publishing	– 2.49		6.53
Pulp, paper and paper products	6.74	***	1.74
Radio, television and communication equipment	6.66	*	3.89
Recycling	– 2.05		2.35
Research and development	0.96		2.79
Rubber and plastic products	2.55	*	1.50
Textiles	7.58	**	3.27
Tobacco products	3.12	***	1.21
Wearing apparel, dressing and dying of fur	21.44	*	11.87
Wood and products of wood and cork	3.86	*	2.25

Notes: Regression results for the coefficient α_i^C of equation (18) for the industries for which data were available. The data are weighed by industry output. Significance levels are coded as: *** significance at 1% level, ** at 5% level, and * at 10% level.
Source: OECD STAN database and own estimations.

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