Juha Kilponen – Torsten Santavirta

When do R&D subsidies boost innovation?
Revisiting the inverted U-shape

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The views expressed are those of the authors and do not necessarily reflect the views of the Bank of Finland.

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This is an updated version of a research project conducted at the Government Institute for Economic Research by the authors. We are greatful to Susan Prantl, Otto Toivanen, Mika Maliranta and Jaakko Kiander and numerous other seminar participants for many useful suggestions and comments. We would also like to thank Satu Nurmi for her help with constructing the data. Finally, we would like to acknowledge the financial support from Tekes, grant nr. 40229/03. Torsten Santavirta also greatfully aknowledges funding from Yrjö Jahnsson Foundation. The usual disclaimer applies.

http://www.bof.fi

ISBN 978-952-462-368-1
ISSN 0785-3572
(print)

ISBN 978-952-462-369-8
ISSN 1456-6184
(online)

Helsinki 2007

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Bank of Finland Research
Discussion Papers 10/2007

Juha Kilponen – Torsten Santavirta
Monetary Policy and Research

Abstract

We show theoretically that a proportional R&D subsidy accelerates innovation activity at all degrees of competition in the modern Schumpeterian growth model, but less so at high degrees of competition. We then use company-level data on patenting activity, product market competition and R&D subsidies of Finnish firms during 1990–2001 to test the theoretical prediction. The empirical findings can be summarized as follows. Firstly, we find relatively strong evidence in favour of the inverted U-shape between competition and innovation. Secondly, we find some evidence that a direct R&D subsidy increases innovative activity at all but very high degrees of competition. This can be interpreted so mean that the R&D subsidy reinforces the Schumpeterian effect due to the negative cross-effect of R&D subsidy and competition. This is evident from the finding that an increase in the R&D subsidy steepens the inverted U relationship when competition is fierce.

Keywords: competition, innovation, R&D subsidies, patents

JEL classification numbers: D40, L10, O31, H25

Lisäävätkö T&K-tuet innovaatioita? – Tarkasteluja käänteisen U-käyrän valossa

Suomen Pankin keskustelualoitteita 10/2007

Juha Kilponen – Torsten Santavirta
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Tutkimus- ja kehitystoimintaan suunnatulla suhteellisella julkisella tuella on positiivinen vaikutus innovaatioihin, mutta T&K-tuen vaikutus vaimenee hyödykemarkkinakilpailun kiristyessä teoreettisessa schumpeteriläisessä kasvumallissa. Tässä artikkelissa esitetyt empiiriset tulokset, jotka perustuvat suomalaiseen yritystason aineistoon patenteista, hyödykemarkkinoiden kilpailullisuudesta ja T&K-tuista vuosina 1990–2001, pääosin tukevat tätä tulosta. Empiiriset tulokset osoittavat myös, että kilpailun ja innovaatioiden väliselle käänteiselle U-käyrälle löytyy tilastollisesti varsin merkitsevää näyttöä. Näiden tulosten valossa voidaan todeta, että T&K-tuet voimistavat niin sanottua Schumpeteriläistä vaikutusta innovaatioihin. Tämä tulee esille kilpailun ja T&K-tuen negatiivisesta ristikkäisvaikutuksesta, jonka seurauksena yrityksille suunnatun suhteellisen T&K-tuen lisäys voimistaa kiristyvän kilpailun kielteisiä vaikutuksia innovaatioihin hyvin tiukan kilpailun hyödykemarkkinoilla.

Avainsanat: kilpailu, innovaatiot, T&K-tuki, patentit

JEL-luokittelu: D40, L10, O31, H25

Contents

1 Introduction

Modern growth theory emphasises the incentive effects of product market competition on firms' innovative activities. More intense product market competition (PMC) stimulates innovation activities through the change in the difference between post-innovation and pre-innovation rents. In other words, although not increasing post innovation rents per se, competition may increase the incremental profits from innovating and thereby encourage R&D investment. This is in contrast to Schumpeter's (1934) prediction that competition decreases the incentives to innovate, simply because it drives down firms' prospects for rents from innovating. Aghion, Harris and Vickers (1997) and Aghion et al (2001) combine these two effects into one coherent theory and show that the relationship between competition and innovation has an inverted-U shape. In their model, the inverted-U shape results from the interplay between the escape-from-competition-effect and the Schumpeterian effect.

In this paper we introduce R&D subsidies[1] into the model of Aghion et al (2001). We let R&D subsidies to decrease proportionally the costs of innovating and thus alter the difference between post- and pre-innovation rents. It turns out that R&D subsidies accelerate innovation at different degrees of competition, but this effect becomes smaller when competition is fierce. This is primarily due to strategic substitutability effect. It states that any factor – such as R&D subsidy – which increases the innovation of the neck-and-neck firm decreases the innovation of the follower firm. We show that as competition becomes more intense, this strategic substitutability effect becomes stronger. This is confirmed by the numerical simulation of the model. Simulations show that at high level of competition, inverted-U shape becomes steeper when R&D subsidies are higher. Otherwise, R&D subsidies leave the shape of the relationship between competition and innovation intact.

In order to test these hypotheses, we extend the empirical approach of Aghion et al (2005) by allowing for interaction between R&D subsidies and competition. We use firm and plant level data on patenting activity, product market competition and R&D subsidies granted for the Finnish firms over the period 1990–2001. We claim that the Finnish case suits very well to our empirical exercise. Namely, the European integration process and severe recession in 1990–1992 speed up product markets' liberalization and privatization of publicly owned companies. In particular, opening up of the product markets to foreign competition was felt heavily in the Finnish firms, forcing them to increase their productivity and competitiveness. Moreover, around the same time, competition policy became a recognized policy tool along with the founding of the national competition authority in 1988. R&D subsidies also played an important role in restructuring of the Finnish industry from a production of low-tech to high-tech products. This was reflected through the creation of Finnish Funding Agency for Technology and Innovation

[1] There is still an ongoing debate whether the public sector's intervention at the research and development markets creates additionality in the sense of boosting the private firms' innovative activities. See for instance David, Hall and Toole (2000) for a survey on this literature.

(Tekes) in 1983 and rapid increase of R&D funding since early 1990s.

Since its founding, Tekes has directed a major part of public R&D subsidies to the firms. These subsidies form a cornerstone of Tekes' funding, being roughly 40% of its total budget. Our measure of the public R&D support used in the empirical analysis correspond to these Tekes' R&D subsidies. Finally, we complete the data with the case-by-case investigations of potential distortions of competition by the Finnish competition authority, and a set of privatization decisions. They are used as quasi-natural experiment to remove the endogeneity problem associated to our competition measure, as in Aghion et al (2005).

Our empirical findings can be summarized as follows. First, we find empirical evidence in favor of the inverted-U shape between innovation and competition. This result supports the findings of Aghion et al (2005) who also find the inverted-U shape using the data on stock listed firms in the UK. Second, in line with our theoretical prediction, we find evidence that direct R&D subsidies increase innovation. However, the positive effect of R&D subsidies to innovation is smaller when competition becomes more intense. This is due to the negative cross-effect of innovation and competition found in the data.

The rest of the paper is organized as follows. Section 2 presents analytically the model of Aghion et al (2001) and develops the extensions to the model. Section 3 provides a description of the data and discusses which variables are best suited for measuring their theoretical counterparts developed in the previous section. Section 4 outlines the empirical methods used. Section 5 provides the empirical results and finally section 6 concludes.

2 Theoretical issues of competition and innovation

In this paper, we focus on a specific model of Aghion et al (2001), henceforth, for convenience, AHHV. Their model gives a theoretical rationale for an inverted-U relationship between degree of product market competition and rate of innovation. The innovation process is assumed to be of a 'step-by-step' character, where the follower in any industry must first catch up with the technological leader before being able to become a leader itself. In contrast to Schumpeterian growth models, the incumbent firm may also innovate in this model.

From this it follows, that innovation incentives depend more on the *difference* between post-innovation rents and pre-innovation rents than upon post-innovation rents per se. In particular, more intense product market competition (PMC) may stimulate firms' innovative activities because it may reduce the firms' pre-innovation rents by more than it reduces their post-innovation rents. In other words, competition may increase the incremental profits from innovating and thereby encourage R&D investment. This is in sharp contrast to the Schumpeterian prediction.[2]

[2] The theoretical framework and the mathematical formalization presented in this section is that of Aghion et al (1997, 2001) except where explicitly mentioned or ascribed to others.

2.1 The basic model

AHHV formalize a step-by-step technological progress making use of a model of dynamic competition between two firms originally formalized by Budd, Harris and Vickers (1993). Their solution concept is subgame-perfect equilibrium in Markov strategies. Each firm's R&D effort depends only on its current technological state (ie on whether the firm is a leader, a follower or has equal technology as the competitor), and not on the firm, on the industry to which the firm belongs or the time.

In the basic model final output in period t, y_t, is obtained by aggregating sectoral outputs in period t, x_{it}, over a continuum of sectors

$$\ln y_t = \int \ln x_{it} di, \tag{2.1}$$

where each industry i is duopolistic with respect to both production and research activities, with firms A and B. The production technology is of the Constant Elasticity of Substitution form

$$x_i = \left(q_{Ai}^{\alpha} + q_{Bi}^{\alpha}\right)^{\frac{1}{\alpha}}, \tag{2.2}$$

where q_{Ai} and q_{Bi} denote the output of firm A and B respectively.

Competition is measured using the elasticity of substitution parameter $\alpha \in [0,1]$ and the demand functions for the intermediate goods can be derived by optimizing (2.2) subject to the budget constraint $p_{Ai}q_{Ai} + p_{Bi}q_{Bi} = 1$.[3] From this maximization problem it follows that the demand functions facing the two firms in industry i are given by

$$q_{Ai}\left(p_A, p_B, \alpha\right) = \frac{p_{Ai}^{\frac{1}{\alpha-1}}}{p_{Ai}^{\frac{\alpha}{\alpha-1}} + p_{Bi}^{\frac{\alpha}{\alpha-1}}} \tag{2.3}$$

$$q_{Bi}\left(p_B, p_A, \alpha\right) = \frac{p_{Bi}^{\frac{1}{\alpha-1}}}{p_{Ai}^{\frac{\alpha}{\alpha-1}} + p_{Bi}^{\frac{\alpha}{\alpha-1}}}. \tag{2.4}$$

Accordingly, the elasticity of demand that each intermediate inputs producing firm j in industry i faces is $\eta_j = \frac{(1-\alpha\lambda j)}{(1-\alpha)}$, where $\lambda_j = p_j q_j$ is the revenue of the firm. Thus, the symmetric revenue equation for two firms is

$$\lambda_j = \frac{p_j^{\frac{\alpha}{\alpha-1}}}{p_A^{\frac{\alpha}{\alpha-1}} + p_B^{\frac{\alpha}{\alpha-1}}}, \quad j = A, B. \tag{2.5}$$

Consequently, under Bertrand competition the equilibrium price of the inputs of each firm are given by

$$p_j = \frac{\eta_j}{\eta_j - 1} c_j = \frac{1 - \alpha\lambda_j}{\alpha\left(1 - \lambda_j\right)} c_j, \; j = A, B, \tag{2.6}$$

[3] The wage rate is normalized to unity.

and its equilibrium profit is

$$\Pi_j = \frac{\lambda_j}{\eta_j} = \frac{\lambda_j (1-\alpha)}{1-\alpha\lambda_j}, \quad j = A, B. \tag{2.7}$$

Equations (2.5), (2.6) and (2.7) can be solved for unique equilibrium revenues, prices and profits. Given the degree of substitutability α equilibrium profits of each firm j are determined by its relative production costs, ie by the ratio of firm j's unit production costs c_j to the corresponding costs of the other firm c_{-j}, $z = \frac{c_j}{c_{-j}}$. The relative production cost z is calculated by dividing the unit production cost of firm j by the unit production cost of the other firm $-j$, ie $z = \frac{c_j}{c_{-j}}$. This implies that, the industry demand being unit elastic, an equiproportional reduction in both c_A and c_B would induce the firms to adjust the price in the same proportion without affecting the degree of competition and hence not firm's revenues and profits. Consequently, only a change in relative profit levels is of interest from the firm's point of view. The profit functions

$$\Pi_A = \phi\left(\frac{c_A}{c_B}, \alpha\right) \text{ and } \Pi_B = \phi\left(\frac{c_B}{c_A}, \alpha\right) \tag{2.8}$$

are therefore implicitly defined by (2.5)–(2.7). The substitutability parameter α in the profit function (2.7) corresponds to the standard measures of competition and can be used to parameterize the degree of competition within each industry. This can also be motived by the arguments of Boone (2000). Namely, he points out that any parameter positively affecting the profitability of having lower unit production costs or products of better quality than other firms is a suitable measure of product market competition.

In the model labour is the only input employed by firms producing according to a constant-returns production function. Further, wage rate is taken as given leading to the unit costs of production c_A and c_B of the two firms in the industry being independent of the quantities produced. The technology level of a duopoly firm in a given industry is denoted as k. In order to produce one unit of the intermediate good, this firm needs to employ γ^{-k} units of labor, where $\gamma > 1$ is a parameter that measures the size of a leading-edge innovation. The state of an industry is thus fully characterized by a pair of integers (l, m), where l is the leader's technology and m is the technology gap of the leader over the follower ($m = 0$ when the firms are neck-and-neck). The equilibrium profit flow π_m (resp. π_{-m}) of a firm m steps ahead (resp. behind) of its rival depends on the size of the gap m.[4]

AHHV derive the following Bellman equations that depict the annuity value V_j, $j = m, 0, -m$, of being a technological leader (in an industry with a technology gap m, a neck-and-neck firm (both firms have equal technologies),

[4]The logarithmic final good technology, together with the nonlinear production cost structure $c(x) = x \cdot \gamma^{-k}$ imply that the equilibrium profit flows of the leader and the follower in an industry depend on only the technological gap m between them, not on their absolute technology levels.

or a follower:

$$\left.\begin{array}{l} rV_m = \pi_m + x_m\left(V_{m+1} - V_m\right) + \left(x_{-m} + h\right)\left(V_{m-1} - V_m\right) - \frac{w\beta(x_m)^2}{2} \\ rV_{-m} = \pi_{-m} + x_m\left(V_{-m-1} - V_{-m}\right) + \left(x_{-m} + h\right)\left(V_{-m+1} - V_{-m}\right) - \frac{w\beta(x_{-m})^2}{2} \\ rV_0 = \pi_0 + x_0\left(V_1 - V_0\right) + x_0\left(V_{-1} - V_0\right) - \frac{w\beta(x_0)^2}{2}. \end{array}\right\} \tag{2.9}$$

Here w denotes the wage rate, $\frac{w\beta(x)^2}{2}$ the R&D cost function of a firm performing R&D, and moving one technological step ahead with a Poisson hazard rate x, h is a help factor that characterize the ease of imitation of the follower, and r denotes the individual rate of time preference. In words, the annuity value of currently being a leader in an industry with gap m at date t equals the current flow π_m minus the current R&D cost $\frac{w\beta(x)^2}{2}$ plus the discounted expected capital *gain* $x_m\left(V_{m+1} - V_m\right)$ from making an innovation and thereby moving one further step ahead of the follower, minus the expected capital *loss* $\left(x_{-m} + h\right)\left(V_{m-1} - V_m\right)$ from having the follower catch up by one step with the leader. The equations for the annuity value of the follower and neck-and-neck firm are similarly explained. Notice though, that in the Bellman equation for the neck-and-neck firm there is no help factor h because the lack of a leader. Also in symmetric Nash equilibrium both neck-and-neck firms' R&D intensities are equal. Now, using the fact that each firm uses its own R&D intensity to maximize its current value, ie to maximize the RHS of the corresponding Bellman equation, the following first order conditions are obtained

$$\beta w x_m = V_{m+1} - V_m; \tag{2.10}$$

$$\beta w x_{-m} = V_{-(m-1)} - V_{-m}; \tag{2.11}$$

$$\beta w x_0 = V_1 - V_0. \tag{2.12}$$

2.2 One-step case with an R&D subsidy

AHHV also discuss a case where the size of the innovation γ is very large and the leaders do not conduct R&D. In this case, the length of a lead cannot be greater than one innovation. AHHV show that when $\gamma \longrightarrow \infty$, the equilibrium level of R&D effort of the leading firm will approach zero. When γ is very large, even a one-step lead would raise the leader's profit almost to the maximal level $\left(\phi\left(\gamma^{-1}, \alpha\right) \simeq 1 \text{ for } \alpha \geq 0\right)$, and thus the incentive to innovate would decrease. This greatly simplifies the AHHV model and allows the results to be derived analytically. The one-step case of AHHV developed in the remainder of this section is re-formulated only to the extent that we introduce a wage subsidy for R&D activity. This is done in order to analyse how a wage subsidy to R&D interacts with competition.

In the one-step case, the maximum technological gap between leader and follower in an industry is $m = 1$. In this case, the firm's R&D effort is x_m, where $m \in (-1, 0, 1)$ and the expected present value of the profit is denoted V_{-1} ,V_0 and V_1 respectively for a follower firm, neck-and-neck firm, and leader in an industry. The labour supply is perfectly elastic allowing for taking the wage rate as given and normalizing it to unity ($\beta = w = 1$). There is no help factor for the followers ($h = 0$). Let $\rho \in (0, 1)$ denote a direct R&D subsidy which reduces the costs of innovating proportionally to the R&D costs $x_m^2/2$. The Bellman equations for equilibrium R&D investments can then be written as

$$\begin{aligned} rV_1 &= \pi_1 + (x_{-1})(V_0 - V_1) \\ rV_0 &= \pi_0 + x_0 (V_1 - V_0) + x_0 (V_{-1} - V_0) - \frac{(1-\rho)(x_0)^2}{2} \\ rV_{-1} &= \pi_{-1} + (x_{-1})(V_0 - V_{-1}) - \frac{(1-\rho)(x_{-1})^2}{2}. \end{aligned} \tag{2.13}$$

In the above equations, $(1 - \rho)$ can be interpreted as the firm's own share of its R&D costs, while ρ is a direct proportional subsidy. Using the fact that the technological leader's incentives to invest in R&D are driven down to zero ($x_1 = 0$), the first order conditions for the neck-and-neck firm and the follower are derived as

$$\frac{\partial rV_0}{\partial x_0} = (V_1 - V_0) - (1-\rho)\, x_0 = 0 \tag{2.14}$$

$$\frac{\partial rV_{-1}}{\partial x_{-1}} = (V_0 - V_{-1}) - (1-\rho)\, x_{-1} = 0. \tag{2.15}$$

Consequently, the innovation probabilities of the neck-and-neck firm and the follower are

$$x_0 = -r + \sqrt{\left(r^2 + 2(1-\rho)^{-1}(\pi_1 - \pi_0)\right)} \tag{2.16}$$

$$x_{-1} = -(r + x_0) + \sqrt{r^2 + x_0^2 + 2(1-\rho)^{-1}(\pi_1 - \pi_{-1})} \tag{2.17}$$

When examining the effects of competition on the innovation probability in the one-step case, Aghion et al (2005) assume that a reduction in the neck-and-neck profits π_0 represents intensified product market competition.[5] Aghion et al (2005) argue that the analysis and the results in the one-step case can be replicated parameterizing competition by the elasticity parameter, α. Equations (2.16) and (2.17) imply that intensified product market competition, as characterized by a fall in the neck-and-neck profits π_0 will lead to an increase in the R&D effort of the neck-and-neck firm, x_0. The follower will decrease its R&D effort x_{-1} as the PMC is intensified. This opposing behavior of the neck-and-neck firm and the follower, in regard to R&D efforts, resulting from intensified PMC, is explained by two different effects.

As for the decrease in R&D effort of a follower x_{-1}. Aghion et al (2005) argue that this is the basic *Schumpeterian effect* at work, resulting from the reduced prospective rent of the successful innovator $(\pi_0 - \pi_{-1})$, which manages

[5]For simplicity it is assumed that π_{-1} and π_1 are unaffected by a change in competitiveness. According to Aghion and Howitt (1998) the analysis remains essentially unmodified also for cases where π_1 is increased and π_{-1} reduced by an increase in competition.

to catch up with its rival. More intense competition induces a neck-and-neck firm to innovate, in order to escape competition. Thus, these firms increase their innovative activity, so that x_0 increases. This is because, as the difference in profits between being a leader and being a neck-and-neck firm $(\pi_1 - \pi_0)$ increases (π_0 falls and π_1 remains unchanged), the incremental value of getting ahead increases with intensified PMC. Aghion et al (2005) refer to this effect as the *escape competition effect.* The sum of these effects is that the higher the fraction of neck-and-neck sectors in the economy, the more positive the effect of intensified PMC on the average innovation rate.

2.2.1 Competition and innovation

The aggregate effect of intensified product market competition on the steady-state innovation rate is ambiguous, because of its different effects on industries in leveled (neck-and-neck) and unleveled (leader-follower) states. The overall effect on average productivity growth depends on the time a sector spends being neck-and-neck in the steady-state. This is formulated by letting μ_1 and μ_0 respectively denote the steady-state probability of being unleveled and leveled. During any unit time interval an unleveled sector can become leveled with a steady-state probability, $\mu_1 x_{-1}$. Furthermore, the probability of a leveled sector becoming unleveled is $2\mu_0 x_0$, which is the aggregate probability of one of the firms innovating when both firms try to escape competition. In the steady-state these two probabilities must be equal

$$\mu_1 x_{-1} = 2\mu_0 x_0, \tag{2.18}$$

since the fraction of sectors in each state must remain unchanged. Combining (2.18) with the fact that the fractions of unleveled and leveled sectors sum up to one ($\mu_1 + \mu_0 = 1$) yields the steady-state distribution of the fractions μ_1 and μ_0

$$\mu_0 = \frac{x_{-1}}{x_{-1} + 2x_0} \quad \text{and} \quad \mu_1 = \frac{2x_0}{x_{-1} + 2x_0}, \tag{2.19}$$

and further the average rate of innovation

$$I = \mu_0 2x_0 + \mu_1 x_{-1} = \frac{4x_0 x_{-1}}{2x_0 + x_{-1}}. \tag{2.20}$$

Aghion et al (2005) show by numerical simulations of the model, that the relation between product market competition and the innovation rate, I, follows an inverted-U shaped pattern.

2.2.2 Inverted-U relationship

An inverted-U relationship is obtained between PMC and the average innovation rate.[6] From the analysis of how intensified competition affects

[6] An early contribution concluding that arrives to the result that some intermediate degree of rivalry is most conducive to technological advance is Kamien and Schwartz (1974).

the average innovation rate, it follows that, when competition is initially low, intensified competition may raise the rate of innovation through the escape from the competition effect on neck-and-neck firms. When competition is already fierce, the Schumpeterian effect may decrease the innovation rate, by decreasing the followers' incentive to innovate. The inverted-U shaped pattern between competition and innovation results from the interplay between the escape competition and the Schumpeterian effects. The reason why one effect is stronger for low degrees of competition, whereas the other dominates for high degrees, is due to the *composition effect* on the steady state distribution of leveled and unleveled industries.

The composition effect can be seen more clearly from the steady state distribution of the fraction of industries in the leveled state and the unleveled state in equation (2.19). When there is no competition ($\pi_0 = \pi_1$), it is clear from equation (2.16) that $x_0 = 0$, and thus the industry is always leveled ($\mu_0 = 1$ in (2.19)). Under perfect competition ($\pi_0 = \pi_{-1}$), (2.16) and (2.17) imply that neck-and-neck R&D efforts will be larger than followers' R&D efforts, $x_0 > x_{-1}$. Thus, the overall rate of innovation is at least twice as high in the leveled state as in the unleveled state. Hence the fraction of time μ_1 spent in the leveled state is less than 1/3 under perfect competition.

At low levels of PMC, most sectors will be leveled, and the escape competition effect dominates on average, whereas at high levels of PMC, most sectors will be unleveled, and the Schumpeterian effect on followers' R&D efforts dominates on average. This in turn implies that intensified PMC will have a positive effect on innovative activity at low initial levels of PMC and a negative effect at high initial levels of PMC.

2.3 Innovation and direct R&D subsidies

2.3.1 Individual industries

In order to see how a proportional R&D subsidy affects incentives to innovate in different industries, we start by noticing from (2.16) that

$$\frac{\partial x_0}{\partial x_{-1}} = 0. \tag{2.21}$$

In other words, when neck-and-neck firms choose their R&D effort x_0 optimally, they only take into account their own R&D investment, as the rivals effort equals x_0 in a symmetric Markov equilibrium. Important strategic interaction, however, arises from the fact that the innovative activity of the follower is affected by the responses of the neck-and-neck firm. In fact, it can be shown that in the symmetric equilibrium

$$\frac{\partial x_{-1}}{\partial x_0} = -\frac{x_{-1} + r}{x_{-1} + r + x_0} < 0. \tag{2.22}$$

Given that the derivative $\partial x_{-1}/\partial x_0$ is negative, there is a strategic substitutability between the innovative activity of the follower and that of the neck-and-neck firm: any factor that *increases* the innovative activity of the neck-and-neck firm, will *decrease* the innovative activity of the follower. Moreover, looking at $\partial x_{-1}/\partial x_0$ from a partial equilibrium perspective, we can see that strategic substitutability is 'strongest' when the innovative activity of the neck-and-neck firm x_0 is very small. In fact, it can easily be seen that

$$\left|\frac{\partial x_{-1}}{\partial x_0}\right|_{x_0 \to 0} \to 1 \tag{2.23}$$

On the contrary, as x_0 starts to deviate from zero, we find that the strategic substitutability effect starts declining. Furhermore, from (2.16) it is clear that

$$\frac{\partial x_0}{\partial \rho} > 0 \tag{2.24}$$

for all realistic values of the profit difference $(\pi_1 - \pi_0)$. In other words, an increase in the R&D subsidy will always increase the R&D effort of a neck-and-neck firm x_0. In the case of the follower, however, the effect is more complicated, precisely because of the strategic substitutability. By direct application of the chain rule, we however know that

$$\frac{dx_{-1}}{d\rho} = \underset{(-)}{\frac{\partial x_{-1}}{\partial x_0}} \underset{(+)}{\frac{\partial x_0}{\partial \rho}} + \underset{(+)}{\frac{\partial x_{-1}}{\partial \rho}}. \tag{2.25}$$

Given that the partial derivatives on the right hand side are of opposite sign, the effect of direct R&D subsidy on the followers incentives to innovate remains ambiguous. The strategic substitutability factor $\frac{\partial x_{-1}}{\partial x_0}$ plays here obviously an important role. When there is no competition, we know that $x_0 \to 0$ and thus the follower's response to R&D subsidies depend solely on the direct effect $\frac{\partial x_{-1}}{\partial \rho}$. Thus, it is clear that the direct R&D subsidy will have a positive effect on the follower's innovating activity when the degree of competition is low. As competition gets more fierce and $x_0 > 0$ the sign of (2.25) becomes ambiguous. After some straightforward algebra, it can however be shown that

$$\frac{dx_{-1}}{d\rho} > 0$$

$$\Leftrightarrow$$

$$\frac{x_{-1}(\pi, x_0) + r}{x_0(\pi) + r} < \frac{\pi_1 - \pi_{-1}}{\pi_1 - \pi_0}. \tag{2.26}$$

Condition (2.26) needs to be interpreted at the model's equilibrium. It is solely an implicit condition, given that the left hand side still depends upon profits. As competition is getting more intense $(\pi_0 \to \pi_{-1})$ we know that $\frac{\pi_1 - \pi_{-1}}{\pi_1 - \pi_0} \to 1$. Moreover, we know from above that the neck-and-neck firm's R&D effort will be larger than the follower's, ie $x_0 > x_{-1}$, when product market competition is fierce. Consequently, condition (2.26) still holds at high levels of competition. This means that the R&D subsidy increases the followers innovative activity also at high levels of competition. However according to 2.25, it is still clear that the strategic substitutability effect $\left(\frac{\partial x_{-1}}{\partial x_0}\right)$ starts moderating the direct effect of an R&D subsidy when competition becomes tougher.

2.4 Average innovation rate and R&D subsidy

Until know, we have derived the result that R&D subsidy affects positively both the neck-and-neck firms' and the followers' incentives to innovate at low and high levels of competition. We have also shown that the strategic substitutability effect moderates the direct effect of an R&D subsidy when competition becomes harder. However, the overall effect of R&D subsidy needs still to be analyzed by taking into account that the degree of competition has a dynamic effect determining the steady state distribution of leveled and unleveled industries in the economy (see section 2.2.2).

We rely here on numerical simulations, which enable us to examine the effects of direct R&D subsidy on incentives to innovate in the world located between monopoly and perfect competition. Figure 1 depicts the average innovation rate at different degrees of competition as well as at three different levels of R&D subsidy (0, 2%, 4%). The vertical axis measures the average innovation rate and the two other axis measure the R&D subsidy and degree of competition respectively. The degree of competition is measured by letting π_0 increase from 0 to π_1.[7] This gives an inverted-U shape relationship between average rate of innovation and competition, just as in the original AHHV article. We observe that an R&D subsidy accelerates innovation at all levels of competition. However, as product market competition gets more intense, the positive effect of an R&D subsidy becomes weaker. This is due to the fact that the strategic substitutability effect discussed above becomes stronger. Alternatively, we can argue that when the Schumpeterian effect starts dominating, the R&D subsidy makes it relatively stronger. This is implied by the fact higher R&D subsidy makes the inverted-U shape curve steeper at the high degrees of competition (see Figure 1).

3 The data and measurement issues

We construct our unbalanced panel using data on the financing decisions of Tekes as our base population. We match to this data set firm level accounting data and plant-level data on output from the data sets at the Business Structures Unit (BSU) of Statistics Finland. We further match R&D expenditures from the R&D panel data of the BSU and patent data from a data file constructed by combining data drawn from the National Board of Patents and Registration of Finland (NBPR) and the so-called NBER patent citations file (cf Hall, Jaffe and Trajtenberg (2001)).[8] Concentrating on firms which have received grants for R&D we expect to screen out the firms conducting unsuccessful R&D. This is because we assume that evaluators of grant applications of the technology agency assess the feasibility of the R&D projects. Another advantage of using the grant data as the base population is

[7] The values of the profits should be interpreted as price-cost margin between zero and ten per cent that is, high on the scale equals 10 per cent price-cost-margin. The values of subsidy should be intrepreted as percentage of the total R&D expenditures.

[8] We match patents by their application date.

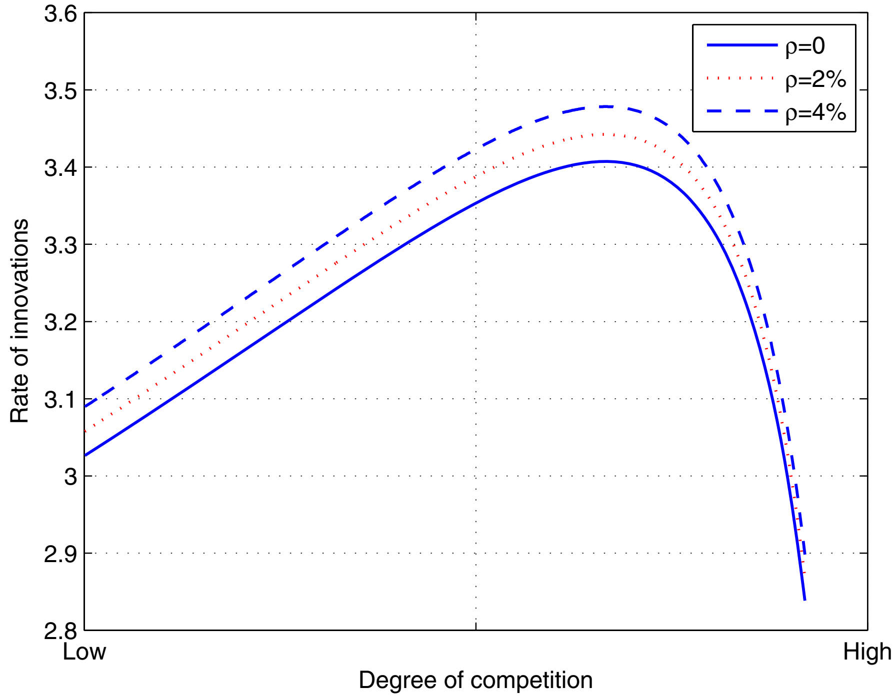

Figure 1: Interaction between competition, R&D subsidy and innovation in the model.
Note: ρ measures the proportional R&D subsidy in the model.

that we reduce the problem of excess zeros of the dependent variable, the US patents, since the firms applying for R&D subsidies are expected to conduct more R&D than the average firm. We treat the observations with more than 50 patents per year as outliers and exclude them as well as outliers with respect to the competition measure. Finally, after excluding the industries without any US patents during the period of observation our entire sample comprises 3340 observations of 1487 manufacturing companies between the years 1990 and 2001. The final sample contains 1514 US patents and 368 positive firms/year observations of the dependent variable, that is patent counts.[9]

3.1 Measuring innovation intensity

Before turning to the empirical analysis it is worth discussing briefly the relevant measurement issues. Following Aghion et al (2005), we use patent counts as the main indicator of innovative activity. We use information on patents granted by the United States Patenting Office (USPTO) and originating in Finland. We assume that most major Finnish innovations are patented in the US and thus, many low value patents should be screened out

[9]We also make use of complete data on patents applied at the Finnish Patents Office (Patentti- ja Rekisterihallitus). In our final sample there are 693 firm/years with positive observations including altogether 3820 patents.

by focusing on USPTO patents.[10]

3.2 Measuring the degree of market power and product market competition

As discussed above, product market reforms are mainly expected to affect innovation outcomes through the level of rents, or economic profits, in the market. To capture this we follow Nickell (1996) and Aghion et al (2005) and use the industry level Lerner index, a well established measure for measuring firms' price-cost margins. Boone (2000) shows that the use of Lerner index as a measure for competition is preferred to most other commonly used measures. It is more theoretically robust than particularly those based on concentration or market shares. We calculate the inverse of the size-weighted industry level average of the Lerner index using a two-digit SIC code precision level. The measure takes value 0 for industries where no competition exists and 1, or larger, indicates perfect competition. Our plant level Lerner index is calculated as the annual output minus labor, intermediate good, capital costs and depreciation divided by output.[11] The industry level Lerner index is computed using the entire population of plants within the industry. Following Aghion et al (2005), we also construct an alternative measure for competition by removing the effect of market share on a firm's profit margin. Market share is measured as the firm's share of output of the total output produced by firms in the same two-digit industry.

3.3 Measuring public funding

In general, any public intervention that aims at removing market imperfections and creates additionality in research could be considered as a form of R&D subsidy. However, since our theoretical measure of an R&D subsidy is most closely related to a direct R&D subsidy that decreases the innovation costs proportionally, we chose to consider only direct R&D subsidies. We thus use data on the financing decisions of subsidies granted to product development by the National Technology Agency of Finland (Tekes). More specifically, we measure direct R&D funding as Tekes direct subsidies for product development. Direct R&D subsidies to firms form the cornerstone of Tekes' funding (roughly 40% of the total budget of EUR 407.2 million) along with the other type of direct subsidy, grants for research projects. However, grants for research projects are mainly directed to universities and research institutes and would

[10] We run robustifying estimations using patent counts of patents filed at the Finnish patents office as the dependent variable and find that the results remain qualitatively the same.

[11] The annual depreciation rate is set at 15 per cent, the capital stock is calculated using PIM assuming a 15 per cent depreciation rate and deflated to year 2000 prices. We then inflate the measure back to current prices using the implicit price index from the data. We assume that the capital cost is 5 per cent for all firms across time.

thus not contribute much to our analysis even if considered.[12] We construct our empirical measure by relating the annually received direct R&D subsidies to the firms annual inhouse R&D expenditures.[13]

3.4 Real life experiments as instruments

The final measurement issue concerns a potential endogeneity problem of our competition measure. One reason for endogeneity is that the variation in the Lerner index might be mainly caused by the variations in fixed costs. This could lead to biased relationship between Lerner index and patenting. We follow Aghion et al (2005) and make use of real life experiments such as the implementation of the EU Single Market Programme and investigations by the Finnish competition authority (Kilpailuvirasto) as well as privatizations of large publicly owned enterprises in 8 two-digit industries to deal with the endogeneity problem.[14] We end up with 23 excluded industry level instruments.

3.5 Descriptive statistics

Table 1 presents the descriptive statistics for our entire sample of 3340 observations. To begin with, it is first easy to see that, as usually when dealing with count data, our patent count distribution is highly skewed, with the majority of the firms taking out no patents in any given year. The mean of the industry level Lerner index is 0.076, implying that the firms' average price-cost margin is roughly 8 per cent. The average firm sales per year of roughly 92.2 million EUR against the median of 6.2 million EUR indicates that the data are severely skewed with respect to firm size. Also the employment figures give an indication of a highly skewed distribution of size of firms in our sample, with roughly 376 workers in the average firm while the median firm has 53 workers. The average R&D investment for a firm is roughly EUR 2.8 million (of which the average fraction conducted internally is 2.5 million), yet there is wide variation within the sample; the median yearly investment on R&D almost a tenth of the mean. The average R&D subsidy (ie direct subsidy by Tekes to industry R&D) is EUR 209 000 and quite naturally, following from the distribution of R&D expenditures, this figure is also skewed with the median yearly subsidy being EUR 70 000. The median of the R&D subsidy over

[12]Since the founding of Tekes in 1982, its role in the national innovation system has increased steadily and direct subsidies have become the main form of financing. An increasing part of the funding is directed at SMEs which got roughly 60% of industry funding in 2001. Tekes can provide SMEs with R&D grants of up to 35% of total project finance and R&D loans of up 70% of the predicted costs of a project. These figures are lower for large companies, and finance is granted only on condition of some degree of networking or other cooperation.

[13]We consider the the firm/year observations where zero inhouse R&D expenditures were reported despite received R&D subsidies as irregularities and exclude them from the analysis.

[14]See Appendix for a full description of the policy changes used as instruments for the Lerner index

inhouse R&D expenditures is roughly 24 percent of a firm's in-house R&D investments. The unusually high mean of this relation is perhaps explained by the fact that some firms have been unable to commit themselves to spending allocated R&D shares reported in grant applications.

Table 1: Descriptive statistics

	Observations	Mean	S.E	Median
Patents	3340	0.453	2.508	0
Lerner index	3340	0.076	0.052	0.070
Employment	3120	376	1057	53
Sales (1000 EUR)	3120	9220	45500	620
Total R & D expenditures (1000 EUR)	2038	2774	9016	327
Inhouse R & expenditures (1000 EUR)	2037	2468	7520	288
R & D subsidies (1000 EUR)	3340	209	484	70
Relative R & D subsidies	1748	0.56	1.349	0.24

4 Empirical specification

Our analysis follows that of Aghion et al (2005) in that we start from a semiparametric log-linear specification. In line with the theory, we assume that the innovation process, ie our discrete random variable x, is Poisson distributed with hazard rate $x = \exp(g(c))$. The expected count of patents p satisfies a relation $E[p \mid c] = \exp(g(c))$ where c is a measure of competition and g is some unknown function to be specified later on. When industry fixed effects, η_j, and time effects, τ_t are included to control for different permanent levels of patenting activity and common macroeconomic shocks, the average patent behavior is related to industry level competition according to

$$E[p_{ijt} \mid c_{jt-1}, x_i] = \exp\left(g(c_{jt-1}) + x_i'\gamma + \tau_t + \eta_j\right) \tag{4.1}$$

where i indexes firms, j indexes industries and t indexes years. We control for the firm specific time-invariant heterogeneity using pre-sample patent information following Blundell, Griffith and Van Reenen (1995). More specifically, we add a vector x_i including the firm's pre-sample patent stock and an indicator for non-zero pre-sample patent values to proxy for a firm's technological knowledge stock. In this case, the Fixed Effects Poisson Estimator provides a consistent estimator for the expected number of patents. However, we acknowledge the fact that our patent counts data are excessively dispersed, as is usually the case with patent data sets. This leads to an incorrectly estimated variance-covariance matrix. We calculate the so called GLM standard errors to obtain the corrected variance-covariance matrix.[15] Following Aghion et al (2005), we first estimate the model where $g(c)$ is approximated

[15] See Wooldridge (2002, Ch. 19) and Allison and Waterman (2002).

with a quadratic specification.[16] The potential endogenity of our competition measure, the inverse of the Lerner index, is modeled following Wooldridge (1997), as dependence in the error terms of the form $\ln(\epsilon_{ijt}) = \theta v_{ijt} + u_{ijt}$, where v is the residual in the first stage equation of our competition measure, the inverse of the Lerner index c_{jt} against the policy instrument z_{jt}, discussed above. Here u_{ijt} is assumed to be independent of v_{ijt} and of z_{jt}. Equation (4.1) can then be written as a conditional expectation

$$E\left[p_{ijt} \mid c_{jt-1}, x_{ijt-1}, v_{ijt-1}\right] = \exp\left(g\left(c_{jt-1}\right) + x_i'\gamma + \tau_t + \eta_j + \theta v_{ijt-1}\right) \quad (4.2)$$

Wooldridge (1999) shows that this can be estimated consistently by the standard fixed-effect Poisson regression of Hausman, Hall and Griliches (1984). Wooldridge (1999) also provides a method for calculating robust standard errors.[17] Note that v_{ijt} is not observed, so we must replace it by its predicted values $\hat{v}_{ijt}$ from the first stage equation.[18] We bootstrap the standard errors in order to remove the bias caused by the use of the prediction of v_{ijt} as a variable in specification (4.2). Only if $\theta = 0$ will c_{jt} be exogenous.

In order to study the interaction between product market competition and R&D subsidies, we allow the inverted-U relationship to change as the R&D subsidies are introduced. We add the interaction between competition, c_{jt}, and the relative R&D subsidies (direct R&D subsidies per inhouse R&D expenditures), ρ, to the basic quadratic specification. We thus acquire a specification of the form where

$$\begin{aligned} &E\left[p_{ijt} \mid c_{jt-1}, \rho_{ijt-1}, x_{ijt-1}\right] \quad (4.3)\\ &= \exp(\alpha + \beta_1 c_{jt} + \beta_2\left(c_{jt-1}\right)^2 + \beta_3 \rho_{ijt-1} + \beta_4 c_{jt-1}\rho_{ijt-1} \\ &\quad + \beta_5\left(c_{jt-1}\right)^2 \rho_{ijt-1} + x_{ijt-1}'\gamma + \tau_t + \eta_j). \end{aligned}$$

Here x_{ijt-1} is a vector of firm covariates that control for other factors that might affect the innovation performance of firms. These covariates are the size of the firm and the size interacted with a dummy variable which separates firms at the median amount of subsidies.The theoretical results deliver clear testable predictions. The inverted-U shape between competition and innovation imply that the sign of the coefficient β_1 in the quadratic specification (4.3) should be significantly positive and that β_2 should be significantly negative, and that $2 \times \beta_2 > \beta_1$, in order to turn the curve into an inverted-U shape within the range of the Lerner index. Our theoretical results further predict that β_3 should be positive, thus shifting the level of the inverted-U shape upwards

[16] In an earlier version of the paper (cf Kilponen and Santavirta (2004)), we experimented with non-parametric methods, such as Kernel estimation and spline estimation, in order to adopt more flexible functional form. We found evidence of a two peaked relationship between citation weighted patents and degree of competition, both using a cubic spline and a Gaussian Kernel regression.

[17] In practice robust standard errors are obtained by rescaling the variance-covariance matrix by the square root of the ratio of the sum of squared Pearson residuals to the degrees of freedom.

[18] Under the maintained assumption that our 1**st** stage regression is correctly specified, the estimated **values of** $\hat{v}_{ijt}$ can be used in place of v_{ijt}. This is because $\text{plim}_{T\to\infty}\hat{v}_{ijt} = v_{ijt}$. Although the use of these regressors does not affect consistency, the standard errors need to be corrected. We apply the bootstrapping method.

when R&D subsidies are increased. The coefficient of the quadratic interaction term β_5 should be negative in order to steepen the inverted-U relationship when competition becomes more intense. The strength of the latter effect also depends on the coefficient of the linear interaction term β_4, which, relative to β_5, should not be too large in absolute terms.

5 Results

5.1 The inverted-U relationship

The estimation results from the quadratic specification of Aghion et al (2005) model are presented in Table 2. In general, these findings provide mixed evidence of an inverted-U relationship between competition and innovation. In column I, where we estimate the standard fixed effects Poisson regression without controlling for possible endogeneity of competition, the estimated coefficient for the inverse of Lerner index c_{jt-1} is insignificant. The same applies for the squared term c_{jt-1}^2. Furthermore, the estimated coefficient of c_{jt-1}^2 is not large enough to turn the function into an inverted U-shape. After controlling for endogeneity, the results are somewhat more promising (column II). In column II, we present the results from the estimation similar to specification in column I, but treating the inverse of the Lerner index as endogenous.[19] The estimation is based on the control function approach. In other words, we estimate two reduced form equations, one for c_{jt-1} and one for c_{jt-1}^2, and use the prediction of the residuals from these regressions as a control function in the second stage regression. The statistics of the reduced form regressions are provided in the lower part of Table 2. The estimated coefficients suggests now that there is an inverted-U shape relationship between innovations and competition. However, the coefficients for c_{jt-1} and c_{jt-1}^2 turn out to be imprecisely estimated, although we control for firm size and firm specific heterogeneity.

[19] The results do not change qualitatively when the effect of the market share is removed from this measure.

Table 2: The basic exponential quadratic specification

	Dependent variable: Patent counts$_{ijt}$	
Independent variables:	I	II
intercept	-26.296	-13.073
	(20.784)	(33.033)
c_{jt-1}	48.508	24.616
	(46.506)	(70.065)
c_{jt-1}^2	-24.189	-14.143
	(25.999)	(37.116)
patent stock$_{i,\text{ pre-sample}}$	0.072	0.068
	(0.014)	(0.014)
D(patent stock$_{i,\text{ pre-sample}}$ > 0)	1.362	1.710
	(0.249)	(0.236)
First stage equations:		
c_{jt} :	$R^{2\ (1}$	0.224
	$F^{(2}$	5.10(22)***
c_{jt}^2 :	$R^{(2}$	0.248
	F	5.74(22)***
τ_t	yes	yes
η_i	yes	yes
F-test$^{(3}$	5.50**	0.66
number of observations	1271	1510

Notes: The sample consists of 3340 observations of manufacturing firms in industries with patenting activity between years 1990 and 2001. In Column I we report the Fixed-effects Poisson regression, while in column II we report the results where we control for potential endogeneity of c_{jt-1} using a control function approach. The standard errors reported in brackets are Wooldridge (1999) distribution- and heteroscedasticity robust. In column II the standard errors are bootstrapped with 100 replications. 1) The partial R^2 for the excluded instrument in the reduced form regression. 2) The joint significance test of excluded instruments. The superscript *** implies that the P-value of the F test is < 0.01. 3) F test of joint significance of competition and competition. The superscript *** (**) in the table implies that the P-value of the F test is < 0.01 (0.05).

5.2 Interaction between product market competition, innovation and R&D subsidies

In this section we discuss the estimation results where we control for the possible interaction between competition and R&D subsidies. As discussed above, this is done by including interaction terms in the conditional mean function of innovations (see equation 4.3). The results are summarised in Table 3.

Table 3: Exponential quadratic specification: R&D subsidies

		Dependent variable: Patent counts$_{ijt}$
Independent variables:	I	II
intercept	-77.903	-129.601
	(17.352)	(70.855)
c_{jt-1}	148.180	232.345
	(38.471)	(149.211)
c^2_{jt-1}	-79.611	-125.381
	(21.412)	(78.872)
ρ_{ijt-1}	9.931	25.277
	(5.069)	(19.933)
$c_{jt-1} \times \rho_{ijt-1}$	-10.601	-26.806
	(5.504)	(21.703)
$c^2_{jt-1} \times \rho_{ijt-1}$	-0.070	-0.159
	(0.182)	(0.699)
patent stock$_{i, \text{ pre-sample}}$	-0.001	0.08
	(0.014)	(0.037)
D(patent stock$_{i, \text{ pre-sample}} > 0$)	1.02	0.938
	(0.222)	(0.537)
log sales$_{ijt-1}$	0.692	0.673
	(0.060)	(0.109)
log sales$_{ijt-1}\times$D(ρ_{ijt}>median)	-1.577	-1.521
	(0.624)	(1.475)
χ^2, *exogeneity of* c_{jt-1}, c^2_{jt-1}, $c_{jt} \times \rho_{ijt-1}$ *and* $c^2_{jt} \times \rho_{ijt}$:		3.51(4)
First stage equations:		
c_{jt-1} :	R^2 1)	0.150
	F 2)	36.56(20)***
c^2_{jt-1} :	R^2	0.169
	F	41.78(20)***
$c_{jt-1} \times \rho_{ijt-1}$:	R^2	0.016
	F	4.26(20)***
$c^2_{jt-1} \times \rho_{ijt-1}$	R^2	0.016
	F	4.20(20)***
τ_t	yes	yes
η_i	yes	yes
F-test 3)	21.40***	2.78
number of observations	854	835

Notes: The sample consists of 1739 observations of manufacturing firms in industries with patenting activity between years 1990 and 2001. In column I we reports the Fixed-effects Poisson regression, while in column II we report the results where we control for potential endogeneity of c_{jt-1} using a control function approach. The standard errors reported in brackets are Wooldridge (1999) distribution- and heteroscedasticity robust. In column II the standard errors are bootstrapped with 100 replications. 1) The partial $R^2$for the excluded instrument in the reduced form regression. 2) The joint significance test of excluded instruments. 3) F test for the joint significance of competition. The superscript *** (**) in the table implies that the P-value of the F test is < 0.01 (0.05).

In column I we show the results of the Fixed-Effects Poisson estimation. An inverted-U shape is obtained with the coefficients for c_{jt-1} and c_{jt-1}^2 both being highly significant. The coefficient of R&D subsidies is positive and significant at the 5 per cent level, suggesting that an R&D subsidy per se has a positive effect on patenting activity. The coefficient of linear interaction term $c_{jt-1}\rho_{ijt-1}$ is negative, but significant only at 10 percent level. There is thus weak evidence that R&D subsidies steepen the inverted-U shape between competition and innovation at high degrees of competition. The coefficient of the quadratic interaction term $c_{jt-1}^2\rho_{ijt-1}$ is also negative as predicted by the theory. However, this coefficient is rather imprecisely estimated.

In column II we add a control function similar to the one in the basic quadratic estimation (see column II of Table 2). Since the interaction terms could also be endogenous, we run four first stage regressions using the policy instrument discussed in section (3.4). The statistics of the first stage regressions are provided in the lower part of Table 3 confirming the validity of the instruments. In the second stage regression, we obtain an inverted-U shape between competition and innovation although the significance of the coefficients of c_{jt-1} and c_{jt-1}^2 exceed the 10 per cent level. The interaction terms are no longer significant, but the coefficients have the same signs as in the basic fixed-effect Poisson case of column I.

Two features stand out clearly from columns I and II in Table 3. First, firms receiving more R&D subsidies show a higher level of innovation activity for any level of competition except for nearly perfect competition. Second, the results provide at least weak evidence that the inverted-U shape becomes steeper when R&D subsidies are increased.[20]

Perhaps the most illustrative way to compare our empirical findings with the theoretical results is to simulate the estimated relationship between innovation and competition. The results of this exercise are shown in Figure 2, where we simulate the estimated model, first at the median level of R&D subsidies, and then inducing a 10 and 20 per cent increase to the level of subsidies. We let the inverse of the Lerner index to vary roughly between 0.7 and 1. The simulated model is based on the estimation results shown in column II of Table 3. From Figure 2 we can see, that the Schumpeterian effect is indeed stronger at high levels of product market competition, ie when (1-Lerner) index approaches one on the horizontal axis. There is some weak evidence that a negative cross-effect of innovations and competition leads eventually into counteracting effect of the R&D subsidy on innovative effort. Finally, contrary to the theoretical results, the simulation suggests that increasing the level of R&D subsidies does not stimulate the innovative activity at low degrees of competition equally much as at moderate degrees.

[20] When using data on domestic patents we obtain similar results. The following coefficients (*standard errors*) for c_{jt-1}, c_{jt-1}^2, $c_{jt-1} \times \rho_{ijt-1}$ and $c_{jt-1}^2 \times \rho_{ijt-1}$ were obtained: 48.519 (*27.395*), -24.818 (*15.181*), -2.901 (*7.435*) and 0.133 (*0.109*) respectively.

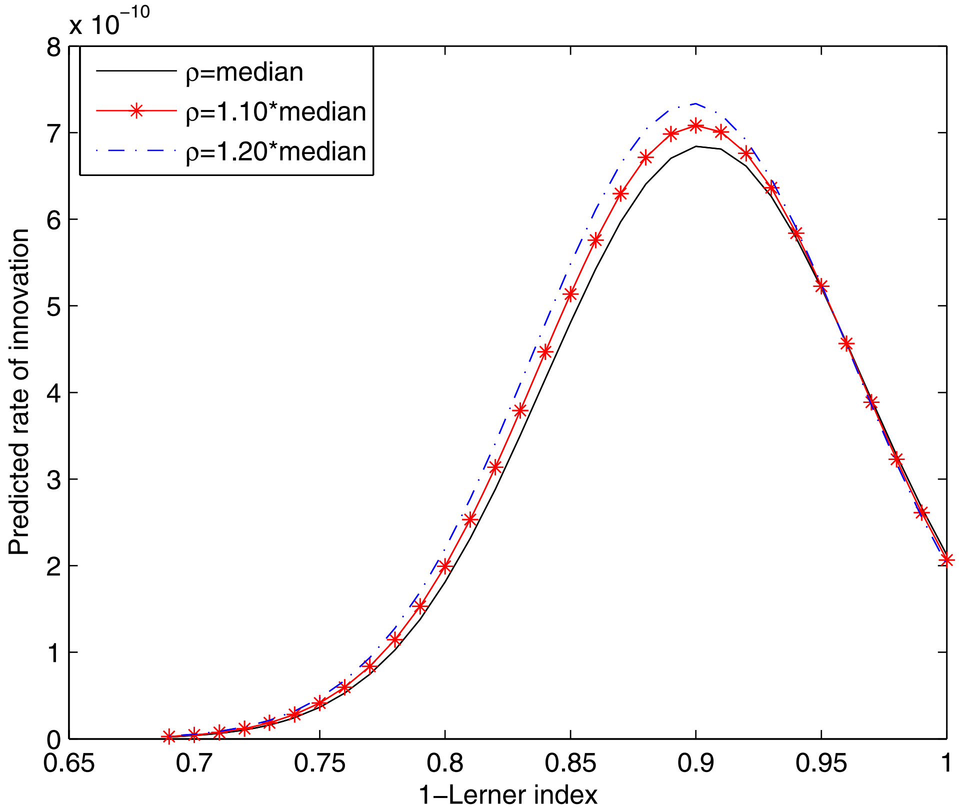

Figure 2: Simulation of inverted U-shape using the estimated coefficients of instrumental variable estimation.

6 Conclusions

The modern Schumpeterian growth theory predicts that more intense competition increases the firms innovative activities, at least up to a certain level. A proportional R&D subsidy, which decreases the costs of innovating, also accelerates innovations, but this effect is smaller when competition is fierce. In other words, the proportional R&D subsidy reinforces the Schumpeterian effect of innovation. Our empirical results are in general compatible with these views. Using the firm and plant level data on patenting activity, product market competition and R&D subsidies for Finnish firms, we find support for an inverted-U shape relationship between patenting activity of the firms and the degree of competition. We also find some evidence that R&D subsidies increase innovative effort at medium level of competition. This effect becomes smaller when competition becomes more intense. In fact, a negative cross-effect of innovations and competition leads eventually into counteracting effect of the R&D subsidy on innovative effort at very high levels of competition.

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Appendix

Policy instrument

We follow Aghion et al (2005) and use three types of exogenous policy instruments: the implementation of the EU Single Market Programme (SMP), investigations by the Finnish Competition Authority (Kilpailuvirasto), and major privatizations. The aims of the SMP were to remove internal barriers in the EU in order to achieve the free movement of goods, services, capital and labor. The European Commission's White Paper (1985) outlined around three hundred specific measures which were designed to implement the SMP. The measures that were aimed at promoting competition include instituting common rules on regulation, takeovers, state assistance to industry, patents and copyrights, company accounting and disclosure of information, opening up of public procurement to competitive tender and reducing intervention in agriculture. The, so called, Cecchini report attempts to measure the size of non-tariff barriers existing before the SMP. They use a series of surveys and technical papers to assign numerical values to the size of non-tariff barriers in each industry before the SMP. Mayes and Hart (1994) classify the industries that were ex ante expected to be strongly or moderately affected by the implementation into 41 3-digit industries. The initial SMP programme was announced in 1986 and the implementation was scheduled to take place between 1988 and 1992. For countries such as Finland, that joined EU in 1995, division into pre- and postimplementation periods is all but self evident. We use here 1993 as the first post-implementation year, arguing that Finland as a candidate country participated in the ETA negotiations between 1990–1992. The Finnish competition authority undertakes the case-by-case investigations of potential distortions of competition, increasing prices or reducing consumer's choice. In cases where the competition authority finds that this is the case, some remedial action is recommended. We use information on all cases in manufacturing industries betweeen 1988–2002. The complete list of cases including case numbers is supplied by the authors on request. We additionally use information on major Finnish privatizations of publicly owned companies in 8 two-digit manufacturing industries. We codify the privatization to affect all firms in the respective industry. A list of the privatizations are available from the authors upon request.

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