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Too much R&D? – vertical differentiation and monopolistic competition

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Abstract

Purpose – This paper aims to discuss whether product research and development (R&D) in developed economies tends to be too high compared with the socially desired level.

Design/methodology/approach – In this context, a model of vertical and horizontal product differentiation within the Dixit-Stiglitz framework of monopolistic competition is set up. Firms compete in horizontal attributes of their products, and also in quality that can be controlled by R&D investments.

Findings – The paper reveals that in monopolistic-competitive industries, R&D intensity is positively correlated with market concentration. Furthermore, welfare and policy analysis demonstrate an overinvestment in R&D with the result that vertical differentiation is too high and horizontal differentiation is too low. The only effective policy instrument in order to contain welfare losses is a price control of R&D services.

Originality/value – Considering the extent of product R&D as well as the political efforts to promote public and private research, this paper scrutinizes its benefit incorporating income and employment effects. Thus, it goes beyond partial-analytical models of the existing industrial organization literature and provides a larger base of political analysis.

Keywords Research and development, Monopolies, Competitive strategy, Product design

Paper type Research paper

1. Introduction

Based on the results of the Fourth Community Innovation Survey (CIS4) conducted by the European Statistical Office, in 2004 about 40 percent of European firms, which account for more than 260,000 enterprises, undertook research activities for developing new products and technologies, and for improving existing products and processes, respectively. In this regard, they spent more than €222 billion[1]. With regard to the nature of research and development (R&D), more than 53 percent of the firms invest in product and about 47 percent in process innovation[2].

Against the background of empirical facts, this paper poses the question: Is the extent of product R&D in developed markets on a socially optimal level? Furthermore, in consideration of intensive policy efforts to expand private and public research activities (in the European Union within the scope of the Lisbon Strategy, for instance),

JEL classifications – D43, F12, L13, L16

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a central concern is to discuss whether a categorical research promotion is consistent with welfare maximizing policy objectives.

Based on these leading questions, an adequate modeling approach needs to meet a few requirements. First, for analyzing the allocation from a macroeconomic point of view, a general equilibrium framework is required to incorporate not only income and employment effects, but also a tax base for political intervention. Second, for implementing product R&D, the model needs to include endogenous quality and R&D decisions of firms. Third, for the sake of analytical simplicity, the modeling set up should produce a closed and stable solution set avoiding corner solutions and case differentiations.

In this context, Dixit and Stiglitz (1977) provided a powerful tool for modeling macroeconomic aggregates – the beginning of the "second monopolistic revolution," as contemplated by Brakman and Heijdra (2004). Since this pioneering work, the concept of monopolistic competition has enjoyed great popularity and has penetrated different fields of research. Basic models of international trade utilize the monopolistically competitive framework (e.g. Krugman (1979, 1980); Dixit and Norman, 1980), as well as fundamental contributions within the endogenous growth literature (e.g. Romer, 1987, 1990; Lucas, 1988).

An essential attribute in models of monopolistic competition is horizontal product differentiation, as described by Hotelling (1929) and advanced by Chamberlin (1933)[3]. Beside differentiation in terms of product characteristics (e.g. design, color or taste), newer literature considers quality as an additional vertical dimension of product space[4]. The corresponding branch of industrial organization was originated by Shaked and Sutton (1982, 1983, 1987) and Gabszewicz and Thisse (1979, 1980). Following the classification of Sutton (1991), Schmalensee (1992) distinguished Type 1 and Type 2 industries. While a Type 1 industry is characterized by horizontally differentiated (or homogenous) products, Type 2 firms compete not only in price and horizontal product attributes, but also in perceived quality. In this context, quality is influenced by R&D expenditures, so that a firm may increase its market share by increasing the quality of its product.

In this paper we implement endogenous quality and R&D in the seminal model of Dixit and Stiglitz (1977), and analyze both vertical and horizontal product differentiation. In order to meet the demands discussed above, we set up a model with three sectors:

(1) a traditional constant-return sector producing a homogenous product;

(2) a monopolistic-competitive sector producing a continuum of cross-differentiated consumer products; and

(3) a separate R&D sector.

Whereas horizontal differentiation is a result of consumer's love of diversity and fixed production costs, vertical differentiation results from R&D investments of manufacturing firms. The R&D sector receives corresponding expenditures from the manufacturing industry, and in turn, providing quality improving R&D services.

Owing to the general equilibrium setting, private households consume both types of goods, and they also provide the required labor input for this economy. The entire labor force splits up in two factor groups: production workers employed in the traditional and manufacturing sectors, and highly skilled labor, e.g. scientists, engineers, etc., exclusively engaged in the R&D sector.

The paper is structured as follows. Section 2 introduces the basic model. Section 3 analyzes the existence and stability of the equilibrium. In this context, the interdependencies that exist between quality and market concentration turn out to be the central adjustment mechanism in this model. Based on the first-best optimum as a reference for political intervention, Section 4 considers three basic policy instruments:

(1) price control of R&D services;

(2) taxation/subsidization on R&D expenditures; and

(3) a regulation of the technological potential.

Finally, Section 5 presents a concluding discussion of the main findings and their practical implications.

2. The model

Private demand

Private households consume two types of goods:

(1) a homogenous good A produced by a Walrasian constant-return sector (often described as an agricultural sector or an outside industry); and

(2) differentiated industrial products provided by a manufacturing sector.

Consumer preferences follow a nested utility function of the form:

$$U = M^{\mu} A^{1-\mu}, \tag{1}$$

where M denotes a concave subutility from the consumption of the continuum of n (potential) industrial goods[5]:

$$M = \left[\sum_{i=1}^{n} (u_i)^{1/\sigma} (x_i)^{(\sigma-1)/\sigma} \right] \frac{\sigma}{\sigma - 1}, \; \sigma > 1, \; u_i > 0. \tag{2}$$

While x_i is the quantity consumed of variety i, u_i denotes a product-specific utility parameter, henceforth labeled product quality, and σ is the constant substitution elasticity between varieties[6]. Applying two-stage budgeting, we obtain the demand function for a representative industrial product sort:

$$x^D = \mu Y u p^{-\sigma} P^{\sigma-1}, \tag{3}$$

where μY represents the share in household income for industrial products, and p the market price. Further on, P is the price-quality index defined to be:

$$P = \left[\sum_{i=1}^{n} u_i (p_i)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{4}$$

From equation (3) it can be seen that the elasticity of demand in terms of quantity is σ, and in terms of quality, it is 1. The price-quality index contains information about product quality as a result of its being the minimum cost for a given subutility M. The demand increases linearly with respect to rising product quality, which results from the constant substitution elasticity. Henceforth, we assume symmetric varieties so that the price-quality index becomes: $P = p(nu)^{1-\sigma}$.

Industrial supply

Turning to the supply side of this model, the production of a particular variety requires labor as the only input. The corresponding factor requirement is characterized by a fixed and variable cost:

$$l^M = F + ax, \tag{5}$$

where M is mnemonic for manufacturing. Because of economies of scale and consumer preference for diversity, it is profitable for each firm to produce only one differentiated variety, so that the firm number is equal to the number of available product sorts.

Furthermore, each variety is characterized by a certain level of product quality, which can be controlled by research investments of manufacturing firms according to Sutton (1991). This implies that consumer products do not only differ in terms of horizontal attributes, such as color, taste or design, but also in terms of quality as another dimension of the differentiation space, which is also referred to as vertical product differentiation. In contrast to the original Dixit-Stiglitz framework, which incorporates horizontal differentiation only, firms now have a further degree of freedom to build up a monopolistic scope.

Attaining and maintaining a certain level of quality requires research expenditures given by:

$$R(u) = \frac{r}{\gamma} u^{\gamma}, \ \gamma > 1. \tag{6}$$

The parameter, r, represents a constant cost rate and γ the research elasticity. The research expenditure function shows a convex, deterministic relation implying that it requires more and more research investments to increase product quality. Finally, research is assumed to be indispensable, because, otherwise, product quality and thus demand become zero[7].

In consideration of production and research, the profit function of a manufacturing firm is given by:

$$\pi = px - R - wF - wax, \tag{7}$$

where w denotes an exogenous wage rate. From profit maximization follows the price-setting rule:

$$p^* = \left(\frac{\sigma}{\sigma - 1}\right) aw, \tag{8}$$

where the term in brackets is the monopolistic price mark-up on top of marginal production cost. For analytical convenience, we normalize the variable production coefficient, a, by $(\sigma - 1)/\sigma$, so that the profit maximizing price becomes w.

The optimum research policy follows from the first derivative of the profit function with respect to quality:

$$\mu Yup^{-\sigma}P^{\sigma-1}(p - wa) = ru^{\gamma}. \tag{9}$$

The term on the right-hand side of (9) represents the average change in research costs in consequence of a change in quality, whereas the left-hand side shows the corresponding increase of the operating profit (profit less research costs). The optimum quality is:

$$u^* = \left(\frac{\mu Yw^{1-\sigma}P^{\sigma-1}}{\sigma r}\right)^{\frac{1}{\gamma-1}}. \tag{10}$$

From equation (10), it can be concluded:

P1. The firm's choice of quality depends upon the research cost rate and the degree of competition.

The higher the cost rate, r, the lower is the product quality due to the optimum rule in (9). Decreasing competitive pressure may result from an increase of market size, a lower substitution elasticity, or a higher profit maximizing price. In this case, firms compete in quality rather than in prices. In other words, firms expand their research activities as the degree of competition decreases.

Furthermore, we obtain central information on the interdependency between market concentration (measured in number of firms) and research expenditures:

P2. Via the price-index effect, product quality and the corresponding research expenditures are negatively correlated with the manufacturing firm number.

This becomes apparent by substituting the price index into equation (10):

$$u^* = \left(\frac{\mu Y}{\sigma rn}\right)^{\frac{1}{\gamma}} \Rightarrow R^* = \frac{\mu Y}{\sigma \gamma n}. \tag{11}$$

The firm behavior, in terms of firm number and quality, affects demand via the price-quality index. In case of an increasing firm number, the price index declines, and thus, the demand for a particular variety. In consequence, the capacity of firms to finance R&D investments decreases, which in turn leads to a reduction of product quality.

Long run equilibrium

In the long run, the equilibrium is characterized by free market entry and exit, and thus, a variable firm number. From the zero-profit condition, we obtain the equilibrium output of each firm:

$$x^* = \sigma\left(\frac{R^*}{w} + F\right) = \frac{\mu Y}{\gamma wn} + \sigma F. \tag{12}$$

Compared to the original Dixit-Stiglitz outcome, which is simply σF, the firm size in this model is larger, and the equilibrium output depends not only on exogenous parameters, but also on the endogenous research expenditures.

From (12), we can also derive the equilibrium labor input:

$$\left(l^{M}\right)^{*}=F+ax^{*}=\sigma F+\left(\frac{\sigma-1}{\sigma}\right)\frac{\mu Y}{\gamma wn}. \tag{13}$$

Finally, the equilibrium firm number comes from the market clearing condition: $\mu Y=p^{*}x^{*}n^{*}$:

$$n^{*}=\frac{\mu Y}{\sigma F}\left(\frac{\gamma-1}{\gamma}\right). \tag{14}$$

General equilibrium

Considering the model from a macroeconomic point of view, we adopt a simple general equilibrium framework. To internalize wages and income, we introduce a separate R&D sector receiving the corresponding expenditures of the manufacturing industry. We assume a linear constant-return technology, where one unit of R&D requires one unit of scientific input (e.g. research staff)[8].

The production labor force is employed in the traditional and the manufacturing sectors, whereas it is assumed to be intersectorally mobile. In the traditional sector, the labor is used within a linear technology in which one unit of labor generates one unit of output. The factor demand of the manufacturing sector follows equation (13).

In the long run, the GDP of the economy consists of the labor income in the manufacturing and the constant-return sectors plus the earnings of the R&D sector (manufacturing profits are zero). Because the homogenous good is the numeraire, the corresponding price is set to 1. Hence, the income of private households is given by:

$$Y=wL^{M}+L^{A}+nR, \tag{15}$$

where L^{M} denotes the manufacturing employment, and L^{A} the agricultural workforce. Normalizing the entire production labor force, $L=L^{M}+L^{A}$, with 1, the household income becomes: $Y=w+nR$.

We assume an inelastic labor supply, whereas the manufacturing wage comes from the zero-profit condition, which determines the level of prices and thus of wages at which manufacturing firms break even. This wage rate can be derived by solving equation (3) for the price, p, and using the price setting rule (8):

$$w^{*}=\left(\frac{\mu YuP^{\sigma-1}}{x^{*}}\right)^{\frac{1}{\sigma}}. \tag{16}$$

Thus, equation (16) implies the simultaneous clearing of the labor and consumer product markets. Due to intersectoral labor mobility, the equilibrium wage rates equalize in both sectors at $w=1$, so that the household income is given by $Y=1+nR$.

Turning to the R&D sector, the cost rate, r, results from the market equilibrium of research services: $rL^{R}=nR$. The supply of R&D is assumed to be fixed and price-inelastic, which conveys the idea of (a state-controlled) technological potential or an innovation frontier of this economy. Using equation (11) and setting the total supply of R&D services, L^{R}, equal to 1, the research cost rate fulfills:

$$r = \frac{\mu Y}{\sigma\gamma}. \tag{17}$$

Equation (17) implies that the cost rate of R&D services, r, decreases with a rising research cost elasticity, γ, and increases with an increasing market size, μY, and a decreasing homogeneity of consumer products, σ. Whereas the first result is self-explanatory, the second comes from the firm's quality policy given by equation (10), which states that the research expenditures increase with a lower degree of competition.

3. Equilibrium and stability

Finally, by use of equations (14) and (17), the household income can be expressed as:

$$Y^* = \frac{\sigma\gamma}{\sigma\gamma - \mu}. \tag{18}$$

Substituting this expression with the price index and the equilibrium output (12) into the wage equation (16), we obtain for the firm number:

$$n^* = \frac{\mu}{F}\left(\frac{\gamma - 1}{\sigma\gamma - \mu}\right). \tag{19}$$

Using this expression, the equilibrium firm size can be expressed as:

$$x^* = \sigma F\left(\frac{\gamma}{\gamma - 1}\right). \tag{20}$$

For the equilibrium rate of research services, we obtain:

$$r^* = \frac{\mu}{\sigma\gamma - \mu}, \tag{21}$$

so that product quality and research expenditures become:

$$u^* = \left[\frac{F}{\mu}\left(\frac{\gamma(\sigma\gamma - \mu)}{\gamma - 1}\right)\right]^{\frac{1}{\gamma}} \tag{22}$$

$$R^* = \frac{F}{\gamma - 1}. \tag{23}$$

From equations (19) and (23) follows:

P3. In consequence of fixed firm size, the equilibrium research expenditures are constant with respect to fixed production costs and the research cost elasticity.

From (20) it becomes apparent that the equilibrium firm size depends upon exogenous parameters, as it is a characteristic result of the the Dixit-Stiglitz settings[9]. Because of this scale invariance, the sales revenues and thus the financial base for R&D investments is also constant, which in turn leads to a constant product quality.

For considering the relation between the central endogenous variables, quality and firm number, equation (11) can with equations (18) and (21) be expressed as:

$$u = \left(\frac{\gamma}{n}\right)^{\frac{1}{\gamma}}. \tag{24}$$

As demonstrated in *P2*, the lower the firm number, the higher the research expenditures and product quality. Furthermore, equation (24) represents research market clearing, which can be seen by rearranging to: $n(u^{\gamma}/\gamma) = 1(= L^R)$.

The opposite relationship can be derived from the manufacturing market clearing condition: $\mu Y = n^* p^* x^*$. The firm number with respect to quality is given by:

$$n = \frac{\mu\gamma(\gamma-1)(\sigma\gamma-\mu)}{\gamma^2\sigma F(\sigma\gamma-\mu) - \mu^2(\gamma-1)u^{\gamma}}. \tag{25}$$

P4. The manufacturing firm number positively depends upon the level of product quality.

The simple market size argument indicates that the higher the quality, the higher the R&D expenditures, and thus, the corresponding proportion of household income. This leads to an increase in market size and new firm entries[10].

The interaction between equations (24) and (25) is displayed in the lower part of Figure 1 for a representative numerical example (parameter settings: $\sigma = 2$, $\gamma = 2$, $F = 1$, and $\mu = 0.2$). Both curves represent the clearing of the research and manufacturing markets, whereas the intersection of both curves indicates the equilibrium firm number and product quality.

Based on these results, we can state the following proposition:

P5. There exists a unique, positive and globally stable equilibrium.

Whereas the existence of the equilibrium directly follows from equations (18)-(23), the stability can be proven by assuming an out of equilibrium adjustment process: $\dot{n} = f(\pi)$, $f(0) = 0$, $f' > 0$[11].

Totally differentiating the profit function yields:

$$d\pi = \frac{p}{\sigma}\, dx + \left[\frac{\mu(\gamma-1)}{\sigma\gamma-\mu}\, u^{\gamma-1}\right] \frac{du}{u}. \tag{26}$$

As apparent, firm profits respond only to changes in demand and quality, while they are not affected by prices due to the price-setting rule. An increase in demand always gives rise to profits, and thus, to market entry of new firms. The same applies with a quality improvement. This dependency becomes apparent by expressing the profit function with respect to quality only:

$$\pi = \left(\frac{\gamma-1}{\gamma}\right) r u^{\gamma} - wF. \tag{27}$$

For illustration, the upper diagram in Figure 1 shows the profit function (27). According to the total differential (26), an increase in product quality out of the equilibrium makes profits become positive due to an increase in demand. This leads to

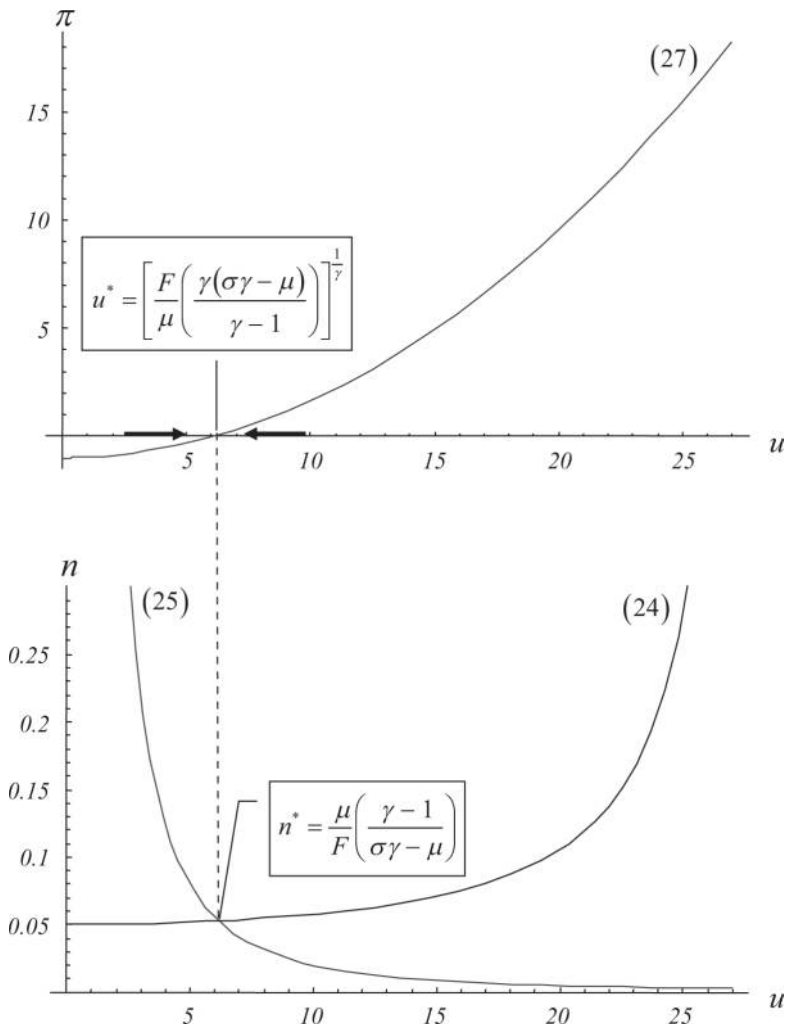

Figure 1.
Quality and firm number

market entries of new firms. However, as given by equation (24) and *P2*, respectively, an increasing firm number is accompanied by decreasing R&D investments, and thus, a reduction of product quality down to the equilibrium level again[12]. Hence, the equilibrium has been proved to be globally stable, also indicated by the directional arrows in Figure 1.

Finally, the mutual interdependencies between firm number and quality comply with the results of Sutton (1998):

P6. An increasing market concentration of industries accompanies a high R&D intensity. In the equilibrium, the R&D intensity increases with an increasing horizontal differentiation and decreasing costliness of research activities.

This outcome can be shown by use of equations (11), (18)-(20):

$$\frac{R}{px} = \frac{\mu(\gamma - 1)}{\sigma F \gamma(\sigma\gamma - \mu)n} = \frac{1}{\sigma\gamma}. \tag{28}$$

In equation (28), R&D intensity is given by the ratio of R&D expenditures to turnover, and, as apparent, it is negatively correlated with the firm number. Furthermore, in the equilibrium, this ratio only depends on substitution and research elasticity.

4. Welfare and policy analysis

With respect to the allocation outcome in imperfect markets and the basic question of this paper, this section considers R&D policy instruments and their efficiency in terms of social welfare. First, we determine the first-best optimum as a reference to the cases in which public institutions are in position to: regulate the price for R&D services;impose a tax/subsidy on R&D expenditures; and control the technological potential.

First-best optimum

For considering the product quality as the central concern of this paper, we need to determine the socially optimal degree of vertical differentiation.

The optimization problem of a social planner is to maximize household utility subject to technological and resource constraints[13]:

$$\underset{(M,A,n,u)}{maxU} = M^{\mu}A^{1-\mu}\,\text{s.t.}\,L^M = A + n(F + ax),\, L^R = \frac{n}{\gamma}\,u^{\gamma}. \tag{29}$$

From the first-order conditions, we obtain a firm size, which is the same as in the equilibrium (20). In contrast, the socially optimal firm number and quality differ[14].

$$n^* = \frac{\mu(\gamma - 1)}{F[\gamma(\sigma - 1) + \mu(\gamma - 1)]} > n^e \tag{30}$$

$$u^* = \left[\left(\frac{\gamma}{\gamma - 1}\right)\frac{F}{\mu}\left(\gamma(\sigma - 1) + \mu(\gamma - 1)\right)\right]^{\frac{1}{\gamma}} < u^e \tag{31}$$

From these equations follows:

P7. While the first-best firm size complies with the equilibrium firm size, the socially optimal quality is lower, and thus, the socially optimal number of varieties is higher than the laissez-faire equilibrium.

This results from the monopolistic scope of manufacturing firms. Because prices are set above marginal costs, firms overinvest their additional revenues in R&D to further increase demand. As a consequence of *P2*, if the equilibrium quality is too high, the firm number is too low[15]. The equilibrium welfare is[16]:

$$W^e = \gamma^{\frac{\mu}{\sigma-1}}\left(\frac{\sigma\gamma}{\sigma\gamma - \mu}\right)\left[\frac{\mu}{F}\left(\frac{\gamma}{\gamma - 1}\right)\left(\frac{1}{\sigma\gamma - \mu}\right)\right]^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}. \tag{32}$$

From these results it can be concluded that setting minimum quality standards would miss the welfare maximum, whereas maximum standards are not practicable.

Optimal control of research costs

With regards to the unconstrained optimum discussed above, there are lifelike more constraints for real economic policy. Deviating from the social planner approach, we now consider a constrained optimum, where policymakers are restricted in their instruments.

We assume that the state can control the research cost rate, which may be motivated by a publicly owned/-regulated R&D sector. The argument for public intervention is the failure not of the competitive research market itself, but rather of the corresponding downstream sector.

In consideration of the inelastic supply of R&D services, the choice of a research cost rate is linked with excess supply or demand, so that case differentiation is required for the derivation of the welfare function.

First, we consider a cost rate above the equilibrium value, so that the demand for R&D becomes the limiting factor. While household income, firm number, and firm size remain constant, quality decreases due to the firm's policy. Although research investments do not change, employment in the R&D sector declines. The welfare function with respect to the research cost rate can be expressed as:

$$W(r > r^*) = \left[\frac{\sigma\gamma}{\sigma\gamma - \mu}\right]\left[\left(\frac{F\gamma}{\gamma - 1}\right)\frac{\mu(\gamma - 1)}{F(\sigma\gamma - \mu)}\right]^{\frac{\mu}{\sigma-1}} r^{\frac{\mu}{\gamma(1-\sigma)}}. \tag{33}$$

The terms in square brackets are positive: the welfare decreases monotonically with increasing cost rate so that a scale-up of r leads always to welfare losses.

If the cost rate is set below the equilibrium value, the demand for R&D services is larger than the market capacity. Consequently, quality becomes:

$$u = \left[\frac{\gamma\sigma F}{\mu - r(\sigma - \mu)}\right]^{\frac{1}{\gamma}}, \tag{34}$$

The welfare function is now:

$$W(r < r^*) = (1 + r)\gamma^{\frac{\mu}{\gamma(\sigma-1)}}\left[\frac{\mu(1 + r) - r\sigma}{\sigma F}\right]^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}. \tag{35}$$

The limiting values of equation (35) are $(\mu/\sigma F)^{\mu(\gamma-1)/\gamma(\sigma-1)}$ for $r \rightarrow 0$ and $-\infty$ for $r \rightarrow \infty$[17]. From (35), the welfare maximizing research cost rate is:

$$r_{\max} = \frac{\mu[\mu(\gamma - 1) + \sigma - \gamma]}{\sigma[\gamma(\sigma - 1) - \mu] + \mu[\gamma - \mu(\gamma - 1)]} < r^e. \tag{36}$$

If we do not allow for negative values of (36), the socially optimal research cost rate is defined as:

$$r^{**} = \begin{cases} r_{\max} \forall \gamma < \frac{\sigma-\mu}{1-\mu} \\ 0 \forall \gamma > \frac{\sigma-\mu}{1-\mu} \end{cases} \tag{37}$$

From this outcome it can be concluded:

P8. The second-best research cost rate, r^{**}, is always lower than the equilibrium value, r^e. The corresponding second-best quality and firm number are equal to the first-best values but implying a lower welfare level: $W^* > W^{**} > W^e$.

If we complete the welfare function for the whole range of *r*, we must consider both equations (33) and (35). The graphs intersect at their lower and upper limits: the non-regulated equilibrium r^e. Thus, we obtain a continuous but non-differentiable welfare function. Figure 2 depicts the socially optimal and unregulated research cost rate and the corresponding welfare values for the same parameter values as in Figure 1.

The welfare statement of *P8* can be proved as follows. The firm size with respect to quality and research cost rate is:

$$x = \sigma \frac{r}{\gamma} u^{\gamma} + \sigma F. \tag{38}$$

Accordingly, the firm number can be expressed as:

$$n = \frac{\mu}{\frac{r^{**}}{\gamma} u^{\gamma}(\sigma - \mu) + \sigma F}. \tag{39}$$

From the research market clearing condition we obtain: $1 = n/\gamma u^{\gamma}$. Substituting equation (39) and solving for the research cost rate yields:

$$u^{**} = \left(\frac{\sigma \gamma F}{r^{**}(\sigma - \mu) - \mu} \right)^{1/\gamma} \tag{40}$$

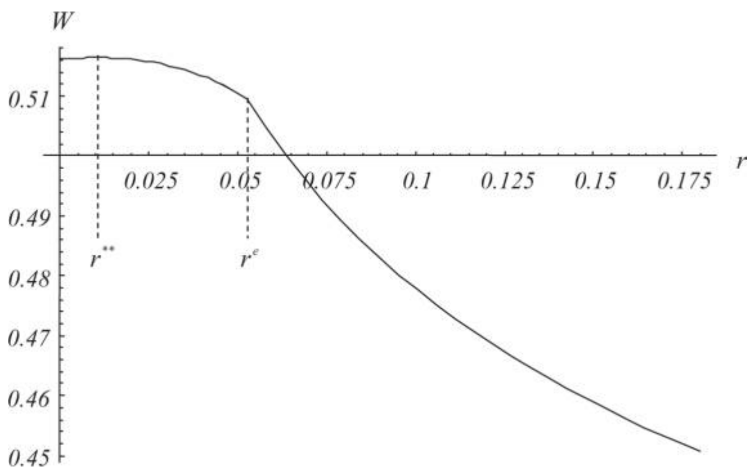

Figure 2.
Research cost rate and welfare

From equations (39) and (40) it can easily be derived that $u^* = u^{**}$ and $n^* = n^{**}$. The difference between first-best and second-best allocation is the manufacturing output given by equation (38). Because $r^{**} < r^e = r^*$, $x^{**} < x^* = x^e$. This leads to lower economies of scale, and thus, to a lower welfare level of the second-best solution compared to the first-best[18].

Including a tax to finance the research price reduction, leads to exactly the same results. The subsidized research price becomes: $r = r^e - \tau$, where τ is a non-negative transfer to R&D firms. In turn, private households pay a lump-sum tax on income: $Y = 1 - \tau + r^e$. Solving the model via the clearing condition of the R&D market yields a firm number and quality on the first-best levels given by equations (30) and (31). The corresponding welfare function with respect to the research subsidy is:

$$W(\tau) = \gamma^{\frac{\mu}{\gamma(\sigma-1)}} \left[\frac{\sigma\gamma(1-\tau) + \mu\tau}{\sigma\gamma - \mu}\right] \left[\frac{\sigma\mu(\gamma-1) + \tau(\sigma\gamma - \mu)(\sigma - \mu)}{\sigma F(\sigma\gamma - \mu)}\right]^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}. \tag{41}$$

Figure 3 shows the welfare function (41).For $\tau = 0$, the welfare takes the equilibrium value and becomes 0, if the maximum tax base is totally exhausted: $\tau = Y^e$. Maximization leads to the second best subsidy level:

$$\tau^{**} = \left(\frac{\gamma - 1}{\sigma\gamma - \mu}\right)\left(\frac{\mu\sigma\gamma}{\sigma - \mu}\right)\left(\frac{1 - \mu}{\mu(\gamma - 1) + \gamma(\sigma - 1)}\right), \tag{42}$$

which corresponds with the research policy (37).

However, it is a noteworthy fact that reducing quality to the optimum level is only realizable by a reduction/subsidization of the research market price. This seems to be contrary to intuition and partial analytical results. In general, this dependency can be traced back to the disequilibrium in the research market. The decreasing research cost

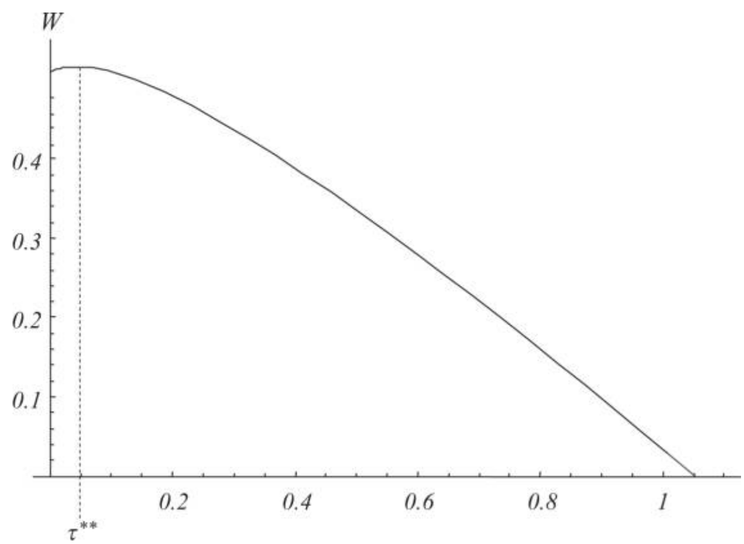

Figure 3.
Second-best R&D subsidy

rate increases demand for R&D services. Because the supply is fixed and inelastic, the limited research output is rationed to the number of manufacturing firms. In consequence, the quality remains unchanged, whereas the research investments, and thus the fixed costs, decline, which makes firm profits become positive and new firms enter the market. Because of equations (24) and (38), the quality and firm size decrease to the (constrained) optimum level.

R&D tax/subsidy

Based on the results above, it may be a political option to raise a tax on R&D expenditures. Thus, the firm's profit function becomes:

$$\pi = px - awx - wF - R - \tau R, \tag{43}$$

where τ is a tax rate with respect to the R&D expenditures. At the first stage, the firms decrease their quality and R&D investments, whereas the price setting given by equation (8) holds. However, the supply of R&D is fixed and totally employed so that a reduction in demand leads to reduction of the research price and the corresponding income of R&D suppliers. Overall, the market size decreases, and thus, the number of firms, whereas the quality remains on the equilibrium level. This implies a reduction of social welfare.If we assume for simplicity that the tax is used to pay a lump-sum grant for consumers, $Y = 1 + n\tau R + nR$, the market size is constant because of a 1:1 transfer between households. The overall effect is a decrease of the equilibrium research cost rate only, while the income, firm number and quality remain on the equilibrium values. In conclusion, this policy instrument turns out to be non-effective[19].

Technological potential

An alternative policy instrument exists in the control of the supply of R&D services and scientific personnel. In the first stage, we neglect the financing of public market intervention, but rather consider the impact on allocation and welfare.

In Section 2, we set the supply of R&D equal to 1. Here we relax this restriction and allow L^R to be non-zero positive. As a result, the equilibrium research cost rate becomes:

$$r^* = \frac{\mu}{L^R(\sigma\gamma - \mu)}, \tag{44}$$

where income remains constant at (18). The equilibrium quality can now be expressed as:

$$u^* = \left[\frac{FL^R\gamma(\sigma\gamma - \mu)}{\mu(\gamma - 1)}\right]^{\frac{1}{\gamma}} \tag{45}$$

As a result of the price inelasticity, an increase in the research supply allows firms to improve the quality without increasing their research investments. In consequence, market concentration and firm size remain unchanged. If the firm number is constant with increasing quality, the price index declines, ultimately increasing real income and welfare. In summation, these results imply:

P9. An increase in R&D supply leads to a higher quality with unaffected market concentration. However, this policy increases social welfare, but it always fails to meet the welfare maximum.

In the next step, we assume that the technological potential can be expanded by public expenditures financed by a lump-sum tax on household income. Up to now, the model was subject to a linear relationship of scientific work input and research output. Relaxing this restriction, market clearing requires:

$$L^R = \alpha \frac{n}{\gamma} u^{\gamma}, \tag{46}$$

where α denotes a productivity parameter in the production of R&D services. This technological capacity can be controlled by public expenditures given by:

$$\alpha(\tau) = (1+\tau)^{\beta},\ 0 < \beta < 1. \tag{47}$$

Accordingly, household income is:

$$Y = 1 + nR - \tau,\ 0 < \tau < 1. \tag{48}$$

From these settings follows that firm size and R&D expenditures are on the *laissez-faire* equilibrium level, whereas product quality and firm number become:

$$n = \frac{\mu}{F}\left(\frac{\gamma - 1}{\sigma\gamma - \mu}\right)(1-\tau) < n^e \tag{49}$$

$$u = \left[\frac{F}{\mu}\left(\frac{\sigma\gamma - \mu}{\alpha(1-\tau)}\right)\left(\frac{\gamma}{\gamma - 1}\right)\right]^{\frac{1}{\gamma}} > u^e. \tag{50}$$

From equations (49) and (50) it can be seen that for $\tau > 0$ the firm number is lower and the product quality is higher compared with the unregulated results. This leads us to the conclusions:

P10. A publicly financed enhancement of product R&D capacities corresponds with a loss of social welfare in comparison with the *laissez-faire*, and thus, also with the first-best and second-best solution.

The welfare function with respect to the tax rate is given by:

$$W = (1+\tau)^{\frac{\mu\beta}{\gamma(1-\sigma)}} W^e < W^e. \tag{51}$$

Figure 4 plots this function for the standard numerical example.

From equation (51) follows a monotonic decreasing function, where $W(\tau = 0) = W^e$ and $W(\tau = 1) = 0$.

5. Conclusions

The welfare and policy analysis pointed out that in economies with monopolistic-competitive industries, the degree of vertical differentiation, and thus the extent of product R&D, is higher than the socially optimum level. Furthermore, the

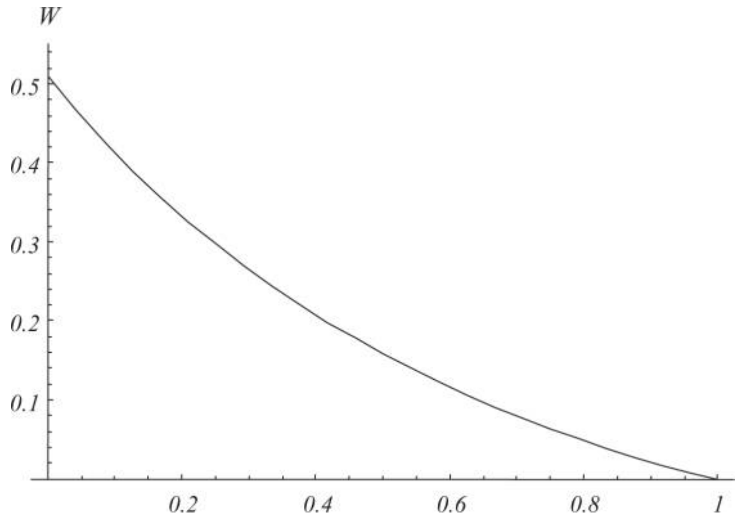

Figure 4.
Technological potential (required tax) and welfare

horizontal product diversity is too low, which is primarily a result of too few manufacturing firms and a consequently higher price index.

As the paper reveals, the only effective policy instrument to contain welfare losses to the second-best optimum is to regulate the market price within the research sector. The basic idea is to generate a disequilibrium in the R&D market, and thus, to decrease the level of a firm's R&D expenditures by a rationing process. As demonstrated, this outcome critically depends upon the assumption of a fixed and price-inelastic R&D supply here conveying the idea of a technological potential. Relaxing this assumption would also make the research subsidization of manufacturing firms become efficient. However political intervention is realized, a public technology promotion in terms of product R&D has been shown to be the wrong way.

Hence, the efficiency of real economic policy requires a differentiated consideration. A categorical promotion of private or public R&D has to be questioned according to the nature on innovation and its impact on social welfare. Practically, policy efforts encounter some problems. Oftentimes a clear distinction between product and process R&D is difficult, even more so in the case of fundamental research and future applications.

Furthermore, the model considers an aggregate of manufactures and evaluates the optimum quality level by means of real income. Because of the macroeconomic perspective of this paper, an individual perception of quality is neglected. Thus, the argumentation of social welfare is not less a matter of the consumer's preferences but rather of income and employment effects. Finally, the results differ with respect to variations in market structure and partial analysis[20].

In the face of the underlying assumptions, the model neglects two important issues. First, the paper does not include R&D cooperations among (manufacturing) firms due to the non-strategic Dixit-Stiglitz settings. Second, it may be interesting to consider spillover effects. In this context, the quality of a particular firm i is not only dependent on the input of its own research input, $u_i(L_i^R)$, but also on the R&D efforts of the whole sector: $u_i(L_i^R, \sum_{j=1}^{n} L_j^R)$. Including both sources of market failure, increasing returns and (positive) externalities, would produce allocation outcomes differing from the results presented in this paper. Nonetheless, they may expand political options and open up combinations of regulation instruments.

Notes

1. Data source: EUROSTAT database, Eurostat (2008), newly acceded countries not included.
2. The distinction between product and process innovation follows the definitions of the *Oslo Manual* (Eurostat and OECD (2005)).
3. See Skinner (1986) and Rothschild (1987).
4. Furthermore, product differentiation is formalized by the Goods Characteristics approach, as pioneered by Lancaster (1966). See Tirole (1988, Ch. 2).
5. Henceforth, the traditional sector is treated as the numeraire.
6. The functional form of the subutility is based upon the numerical example of Sutton (1991, p. 48 *et seq.*).
7. Sutton (1991) assumes a minimum product quality of 1, even if no research is undertaken. For analytical convenience, we simplify this proposition.
8. In fact, instead of considering an autonomous sector, it may be possible to regard R&D as an in-house process of the manufacturing industry that is staffed from a particular labor market.
9. The firm size in the present model is times the term in brackets higher than the firm size of the original Dixit-Stiglitz model.
10. The polynomial (25) has a pole at $u = [\gamma^2 \sigma F(\sigma\gamma - \mu)/\mu^2(\gamma - 1)]^{1/\gamma}$, which is always below the equilibrium value (22).
11. See Neary (2001).
12. Alternatively, the profit function may be plotted with respect to firm number, which yields a monotonously decreasing hyperbola intersecting zero-profits at the equilibrium firm number. A firm number higher (lower) than this point implies negative (positive) profits, and thus, market exits (entries).
13. Rearranging equation (2) provides an expression for x.
14. In this section, the superscript, e, denotes the market equilibrium outcome, * the first-best and ** the second-best values, respectively.
15. This complies with the welfare results of the Dixit-Stiglitz model. See the introduction of Brakman and Heijdra (2004, p. 19 *et seq.*), for instance.
16. We neglect the term $\mu^{\mu}(1 - \mu)^{1-\mu}$.
17. If $(\gamma - 1/\gamma) < (\sigma - 1/\mu)$ holds, the domain of r is: $]0, \mu/\sigma - \mu[$ due to a negative root. The upper limit is greater than the equilibrium cost rate without regulation so that it is not a part of the total (piecewise-defined) welfare function (33) and (35).
18. It follows from the second resource constraint in equation (29) implying perfect competition in the research market that the research cost rate is the same for equilibrium and first-best solution: $r^e = r^*$.
19. The same implications hold, if we assume an R&D subsidy financed by a lump-sum tax on household income.
20. See, e.g. Symeonidis (2003).

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