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The Elasticity-Based Approach to Enterprise Innovation

Abstract

The goal of this paper is to present a formal model of firm innovation that simultaneously analyzes innovation factors characteristic to the Schumpeterian strand of industrial organization literature and the know-how strand. Corporate R&D intensity serves here as an input measure of firm innovation. R&D intensity can be defined as a ratio of firm's R&D spending to the firm's sales (total revenues). On the basis of formal analysis it is found that R&D intensity is fully determined by three complementary factors, i.e. a firm's technological competence (supply-side factor), consumer preference for quality and price of a product (demand-side factor), as well as a moderator factor associated with the knowledge spillovers, which occur between competing firms in the industry. Since the above factors are expressed in terms of elasticities, the presented model is called an elasticity-based model of firm innovation. Further, within the model framework, it is shown how horizontal R&D cooperation alleviates the free-rider problem that can discourage a firm's innovation activities. It is next postulated that horizontal R&D cooperation can be effectively treated as a complementary tool (to such traditional solutions as patent protection and public research subsidies) for solving the problem of negative externalities in an industry with pervasive knowledge spillovers.

Keywords: research and development, firm innovation, inter-firm cooperation
JEL: L1, L2, O32

Introduction

The modern industrial organization literature on enterprise innovation can be roughly divided into two, loosely related, strands in research [see e.g. Belleflamme, Peitz, 2010]. These strands focus on different enterprise innovation factors. These factors are: (1) the size[2] of the firm and its market power, (2) the productivity of the firm's spending on research and development (R&D), (3) consumer preferences towards the quality and price of the goods produced by the firm, (4) knowledge spillovers[3] in the industry, (5) the firm's absorptive capacity, (6) the nature of the research conducted by the firm (fundamental or applied research), (7) the firm's strategy in R&D (cooperation or competition).

The first, historically older, group of enterprise innovation theories focuses on factors: (1), (2) and (3) [e.g. Schumpeter, 1942; Arrow, 1962; Fisher, Temin, 1973; Nelson, Winter, 1982; Lee, Sung, 2005]. In this strand of literature, questions are posed about the relationship between the size and the market power of the company and its ability to innovate. Because this strand was initiated by Josef Schumpeter [1934; 1942], later in this paper it will be called the *Schumpeterian strand*.

The second group of theories includes factors: (4), (5), (6) and (7) [e.g. Brander, Spencer, 1983; Spence, 1984; Katz, 1986; d'Aspremont, Jacquemin, 1988; Kamien et al., 1992; Salant, Shaffer, 1998; 1999; Amir et al., 2000; Kamien, Zang, 2000]. Chronologically, this is newer literature that has been developing since the early1980 s. A key concept of this strand in the literature is know-how[4]. Researchers pose questions here about the sources of technical knowledge in the company, the processes of its creation, absorption and accumulation, and finally the impact of technical knowledge on enterprise innovation. In the following part of the paper this strand will be labelled as the *know-how strand*.

Surprisingly, none of the industrial organization theories of enterprise innovation previously proposed in the literature consider the factors from both above-mentioned strands together. The goal of this study to formally describe factors (1)–(7) and the relationships between them as part of a coherent model of firm innovation. The theoretical framework presented will then show how cooperation between companies in R&D helps solve the serious free-rider problem, which appears in the innovative activity of enterprises.

Factors of Firm Innovation. The Schumpeterian Strand of Literature

The Size of the Company and its Market Power

Investigations on the sources of innovation in the economy lead to the work of Josef Schumpeter [1934; 1942]. Schumpeter's views on the subject evolved over time. These changes are so clear and substantial that Acs and Audretsch [1988] write about "two Schumpeters". "Early Schumpeter" saw the source of innovation in the economy in the person of the entrepreneur who played a central role in the evolution of the capitalist system. A social system based on repetitive, routinized patterns of behaviour would lose the ability to develop. Therefore, according to Schumpeter, the social function of entrepreneurs was to make changes to the system, i.e. destroying the old economic order and replacing it with a new one. Over the years, Schumpeter's ideas evolved and his attention turned to large monopolistic companies. In 1942, in "Capitalism, Socialism and Democracy" [1942, p. 101], Schumpeter wrote:

The monopolistic company will produce more innovation due to its advantages, which, although they are not impossible to achieve for a competitive firm, are far better secured at the level of monopoly.

In this work Schumpeter is steadily moving away from his earlier concept of the central role of the entrepreneur. Entrepreneurial talent, according to "late Schumpeter," is internalized and constitutes an integral component of large monopolistic enterprises. It is these companies that were supposed to be the source of innovation in the economic system. In his argument [1942], however, Schumpeter left space for speculation. On the one hand, he appealed to the size of the company (its 'bigness'), and on the other to its market power. As a result, significant controversy accumulated around Schumpeter's hypothesis because researchers used different wordings of that hypothesis [Mukhopadhyay, 1985]. Kamien and Schwartz [1982] believe that two independent hypotheses must therefore be linked with the name of Schumpeter.

Schumpeterian Hypothesis 1: There is a positive relationship between the number of innovations and monopoly power of an enterprise, accompanied by extraordinary profits.

Schumpeterian Hypothesis 2: Large (big) companies are proportionally more innovative than small companies.

Economic theorists, referring to Schumpeter's idea, emphasized its various components. John Kenneth Galbraith [1952] exposed the importance of the bigness of the company for its innovative activities. According to Galbraith, large companies have more resources than small companies, find it cheaper to raise capital, and eventually can spread the risk associated with the implementation of research and development projects to a greater number. Therefore, according to Galbraith, large enterprises should be more than proportionally innovative than small enterprises.

Fisher and Temin [1973] decomposed Schumpeter's hypothesis into a demand side (relating to the market power of the company) and a supply side (relating to the benefits related to the size of the company). The demand side of Schumpeter's hypothesis was formalized by Kenneth Arrow [1962]. Arrow's analysis concerned only process innovations, i.e. those that lead to lower production costs. Arrow's analysis is comparative in nature. Arrow determined, respectively, the value of innovation (as an increase in the discounted value of extraordinary profits after the implementation of process innovation) for (1) a monopoly, and (2) a competing firm (competition in Bertrand fashion). Arrow discovered that the value of innovation for a monopoly is in fact smaller than for a competing company. Thus, Arrow rejected the demand version of Schumpeter's hypothesis.

The supply-side arguments, however, appeal to economies of scale. Large companies should produce more innovations if these companies attain economies of scale (1) in research and development, or (2) in financial markets. Economies of scale of the first type occur when a larger staff in the R&D department works more efficiently than a smaller team, or when an R&D team with a given number of people works more efficiently in a bigger enterprise than in a smaller one. Economies of scale of the second type occur when large companies can borrow money more cheaply on financial markets than small companies, and can borrow more money before the cost of each subsequent currency unit borrowed is higher than the cost of the previous one. The supply interpretation of the Schumpeterian hypothesis was formalized by Fisher and Temin [1973]. As the measure of the size of a company these researchers selected the number of employees. According to the supply side interpretation of the Schumpeterian hypothesis, the average product of a worker employed by the R&D department should increase with the total number of employees. Therefore the total product of workers employed in R&D should grow more than proportionally with increases in the total number of employees.

Fisher and Temin [1973] indicate that the Schumpeterian hypothesis formulated in this way had not been properly tested in the empirical literature. The evidence that "the average product of a worker employed in the R&D department increases with the total number of employees" does not lead to the conclusion that the number of workers employed in R&D is growing faster than the total number of employees. At the same time, it is this latter tendency that represented the empirical basis for verification of Schumpeter's hypothesis in the literature. Fisher and Temin's critique [1973] referred, in particular, to research by Villard [1958], Schmookler [1959], Worley [1961], Mansfield [1964], Scherer [1965] and Comanor [1967].

Productivity of Enterprise Spending on R&D

Many researchers who contributed to the Schumpeterian strand of the literature directed their attention to the issue of productivity in enterprise spending on R&D. In empirical studies [cf. Bound et al., 1984; Acs, Audretsch, 1991; Cohen, Klepper, 1996] the number of patents granted per unit of currency in which the company spending on R&D was recorded were taken as a measure of the productivity of the enterprise's spending on R&D. In most studies, it was observed that the productivity of enterprise spending on R&D decreases with the size of the company [Bound et al., 1984; Hausman et al., 1984; Pavitt et al., 1987; Acs, Audretsch, 1988; 1990; 1991].

In subsequent years, however, there were studies that indicated exceptions to the empirical trend outlined above. Erickson and Bayus [2001], although they agree that usually the marginal returns from the company's R&D spending decrease, this does not happen in the case of small enterprises in the initial stages of the life cycle of the market. Erickson and Bayus' research [2001] shows that in the initial stages of the life cycle of the market small companies are characterized by higher productivity of expenditure on R&D than large enterprises. At the stage of maturity of the market, however, this trend is reversed, and then large enterprises are characterized by higher productivity of expenditure on R&D than small enterprises. According to Erickson and Bayus, this can be explained by the fact that in the phase of market maturity large enterprises are able to spread the cost of innovation activities on longer product lines than small enterprises.

Tsai and Wang [2005] showed, however, that the productivity of enterprise spending on R&D decreases with company size, but only up to a certain critical value. Among the largest enterprises, productivity of spending on R&D rises again. Thus, in accordance with the work of Tsai and Wang [2005] a U-shaped relationship between the productivity of company spending on R&D and the size of the firm itself cannot be ruled out.

Consumer Preferences Towards Price and Quality of Manufactured Goods

In the last twenty years, in the context of the Schumpeterian strand of literature a keen interest has arisen in researchers in the issues of the impact of consumer preferences on enterprise R&D decisions. In this context, the works of Sutton [1996; 1998], Lee and Sung [2005], and Saha [2007] should be mentioned.

The formal approach to the problem was presented by Saha [2007]. Saha considered a dynamic model of a monopoly under vertical product differentiation. During discrete periods of time consumers took decisions to buy goods offered by a monopolist, i.e. every potential buyer bought 0 or 1 unit of the good in each period. The good was non-durable. The non-negative parameter $\theta \in [\theta_1, \theta_2]$ served to model consumer preferences. The consumer gained a utility equal to $\theta q - P$ on the acquisition of a unit of the good of quality q and price P. Consumers differed in terms of the value θ. In each successive period, the monopolist could increase the value q for the manufactured good[5] (the case of product innovation) or reduce the value of c, i.e. reduce the marginal cost of production of a given good (the case of process innovation).

Saha determined that the value of process innovation for the enterprise depends only on the number of units of the good sold, while the value of product innovation depends both on the number of units of the good sold and the willingness to pay for product innovation by the marginal buyer. Thus, the value of product innovation also depends on who acquires the good in question. Consumers differ in the Saha model in their propensity to pay for improving the quality of the good. Further, the willingness to pay for the product itself and the willingness to pay for improved quality were positively correlated, i.e. consumers with a higher propensity to pay for the product itself also tend to prefer action to improve it. As the distribution of consumer preferences (distribution θ) was unchanged in time, willingness to pay for improving the quality of goods for end buyers declined steadily. Thus, the monopolist increased the effort[6] directed towards process innovations at the expense of product innovations. This trend is reflected in business practice [cf. Klepper, 1996]. Saha's dynamic model finally enabled the claim to be formulated concerning the comparison of the nature of innovation activities of small and large companies. Saha has shown that for some period *t* a large company spends more money than a small company in the search for innovation in both product and process. However, for both of these activities the large company has a lower productivity of the expenditure borne than a small enterprise.

Lee and Sung [2005] showed, in turn, that large companies spend more than proportionally money on R&D (compared to small companies), if they have a high level of technological competence[7].

Many survey papers have been devoted to the Schumpeterian strand of literature (for extensive reviews, see e.g. [Cohen, Levin, 1989; Symeonidis, 1996]). In the present paper, the focus was primarily put on the works that made it possible to construct the model of firm innovation presented later in this article.

Factors of Firm Innovation. The Know-How Strand of Literature

Knowledge Spillovers in Industry and Corporate Strategy in R&D

The issue of knowledge spillovers in industrial organization literature devoted to innovation was introduced by Brander and Spencer [1983], Spence [1984] and Katz [1986]. However, the most important studies for understanding the impact of knowledge spillovers on the degree of company involvement in research and development were those of d'Aspremont and Jacquemin [1988] and Kamien, Muller and Zang [1992], which essentially generalized the Belgian economists' concept.

The researchers from Louvain in the 1988 paper discussed a two-stage game under Cournot duopoly, in which the company first made decisions about the value of spending on research and development, and then competed quantitatively on the product market. The Belgian economists stated that cooperation between companies in R&D is associated with a higher overall[8] level of spending on R&D than competition in R&D. This claim is true when the knowledge spillovers in the industry are significant[9]. The d'Aspremont and Jacquemin model [1988] underwent numerous modifications and extensions over the next few years. The most important extensions related to:

(1) the increase in the number of enterprises considered [Kamien et al., 1992],
(2) taking into account the possibility of product differentiation [Kamien et al., 1992],
(3) the inclusion of price competition on the product market [Kamien et al., 1992; Ziss, 1994; Qiu, 1997],
(4) taking product innovations into account [Motta, 1992; Kesteloot, De Bondt, 1993; Cohen, Klepper, 1996; Beath et al., 1997; Kaiser, Licht, 1998; Fishman, Rob, 2000],

(5) allowing the opportunity for vertical cooperation [Inkmann, 2000],
(6) the internationalization of cooperation in R&D [Brod, Shivakumar, 1997],
(7) allowing the possibility of cartelization of the industry [Prokop, Karbowski, 2013].

The generalized d'Aspremont and Jacquemin model was proposed by Kamien and others [1992]. Kamien and others [1992] demonstrated that cooperation between companies in R&D is associated with higher level of welfare in the industry than the competition in R&D. Kamien and others [1992] showed further that the profit value of a single company cooperating in R&D is not smaller than in a competitive case. In the end, researchers found that in industries characterized by sufficiently strong knowledge spillovers, the highest level of welfare in the industry is achieved under (i) cooperation between enterprises at R&D stage and at the same time (ii) competition between firms in the final product market. The findings of Kamien and others [1992] have been confirmed by Salant and Shaffer [1998; 1999] and Amir and others [2000].

The Firm's Absorptive Capacity and the Nature of the Research Carried out

The empirical papers by Cohen and Levinthal [1989; 1990], Levin [1988], Levin and others [1987] and Levin and Reiss [1988] indicate that companies differ in their ability to absorb knowledge produced by other companies. Thus, market participants have varying degrees in which they can use knowledge spillovers in the industry.

The question of an enterprise's absorptive capacity[10] was formalized by Kamien and Zang [2000]. The researchers considered a three-stage game in a Cournot duopoly. In the first stage, the companies made decisions about the level of generality[11] of the research. The company's absorptive capacity was defined as follows: $(1-\delta_i)x_i^{\delta_i}$ where δ_i[12] is the degree of generality of firm's research, and x_i is the value of the company's own expenditures on research and development. Higher values of δ correspond to a more specialized nature of research. For $\delta_i = 1$ the i-th company conducts such specialized studies that the knowledge produced by rivals is of no useful value to it. Thus, when δ value reaches its upper limit, the i-th company does not absorb knowledge spillovers in the industry. When $\delta_i = 0$, the i-th company conducts general enough research (fundamental research) that the knowledge produced by rivals may be directly and fully utilized by the i-th company. In the second stage of the game, the companies make decisions about the value of spending on research and development, and in the next stage about the production of goods (quantitative competition in Cournot fashion).

Kamien and Zang [2000] have shown analytically that an increase in the degree of generality of research leads to higher company spending on research and development, provided that the initial degree of generality of research was sufficiently high. In addition, Kamien and Zang's paper shows that cooperation between companies in R&D is more likely when prospective partners conduct fundamental research.

This last conclusion achieved an empirical basis thanks to a paper by Tsai [2009]. Tsai found[13] that with increase in the absorptive capacity of enterprises, correlations between the sales results of innovative products and cooperation in the field of R&D become stronger. Thus, when companies increase the degree of generality of research (and thus develop the ability to absorb knowledge), the relationship between R&D cooperation and the results of the sale of innovative products becomes stronger. Therefore, companies with a high absorptive capacity should be more willing to cooperate in R&D, because for these companies the effects of cooperation are clearly reflected in the increase in sales. It should be however noted that the relationship detected by Tsai was not statistically significant for the largest enterprises, which for Tsai were companies employing at least 500 workers.

The Elasticity-Based Approach to Firm Innovation

Introduction to Modelling

The model presented in this part is an original concept, which combines the factors discussed in the literature both within the Schumpeterian and know-how strand.

From the technical perspective, this model combines the approaches of Lee and Sung [2005] and Saha [2007] from the Schumpeterian strand, as well as Kamien, Muller and Zang [1992] and Kamien and Zang [2000] from the know-how strand.

Lee and Sung's model [2005] has been enhanced in this paper with the ability to undertake R&D cooperation by companies operating in the relevant product market. In contrast to Lee and Sung's model [2005], knowledge spillovers in the industry were treated as endogenous variables, i.e. explained within the model. Knowledge spillovers are modelled using a mathematical formula that is based on the work of Kamien, Muller and Zang [1992] and Kamien and Zang [2000]. Goods offered on the market are differentiated vertically, and firms via R&D activities can improve the quality of produced goods [cf. Saha, 2007].

Assumptions of the Model

Consider a duopoly market. The set of companies operating in the relevant product market is denoted as $N = \{i, j\}$. Assume further that each firm belonging to the set N manufactures only one product. Goods offered on the market are vertically differentiated.[14] The marginal cost of production (MC) for each company is constant and equal to the average cost of production. The entry of new firms to the industry is unprofitable.

The utility of a good for the consumer is a function of the price and quality of a good. The good's quality is determined by the technology embodied by the good[15]. Formally, we can write: $U_i = U(p_i, A_i)$[16] where p_i means the price of the good produced by company i, A_i the size of technology input embodied by the good produced by company i, and U_i the buyer's utility drawn from the consumption of the good produced by company i. The utility function decreases with respect to the argument p_i and increases with respect to the argument A_i.

Assume further that the technology production function is given as: $A_i = A(X_i)$, where X_i is the effective[17] value of company i's spending on research and development [Kamien et al., 1992]. The technology production function is a power function[18], continuous and differentiable. Suppose further that the first derivative of the technology production function is positive ($\frac{dA_i}{dX_i} > 0$), while the second derivative is negative ($\frac{d^2 A_i}{dX_i^2} < 0$). Both the choice of power function and the assumption of diminishing marginal returns from effective spending on R&D are grounded in the empirical literature [cf. Scherer, 1980; Kamien and Schwartz, 1982; Baldwin and Scott, 1987; Griliches, 1998; Erickson, Bayus, 2001].

Effective expenditures (of the i-th company) on research and development are modelled as follows: $X_i = x_i + (1-\delta_i)\beta_j x_j$. This specification synthesizes the approaches of Kamien, Muller and Zang [1992] and Kamien and Zang [2000]. As in the paper by Kamien and others [1992], x_i is the value of the company i's own spending on research and development. The parameter $\beta \in [0,1]$ refers to knowledge spillovers between companies competing in the relevant product market. When company i cooperates with company j in R&D, $\beta_j = 1$[19], otherwise $\beta_j < 1$[20]. Parameter $\delta \in [0,1]$ denotes, as in the work of Kamien and Zang [2000], the degree of generality of the research carried out. For larger values of δ_i company i conducts more specialized research. Thus, it will use the knowledge from rivals less. For larger values of δ_i knowledge spillovers derived from rivals will therefore be smaller.

The model provides for the opportunity to establish R&D cooperation between companies operating in the relevant product market. Companies cooperating in R&D coordinate decisions on the R&D expenditures incurred. Effective expenditures on R&D for a cooperating company may be modelled as follows: $X_i^C = x_i^C + (1-\delta_i)x_j^C$[21]. In turn, effective spending on R&D for a non-cooperating company may be given as follows: $X_i^N = x_i^N + (1-\delta_i)\beta_j x_j^N$[22]. For simplicity, in further analysis we consider the case of symmetrical[23] R&D cooperation whereby the cooperating companies bear equal spendings on R&D ($x_i^C = x_j^C$).

Suppose finally that demand for the good produced by company i is described by the following function: $Q_i = Q(U_i, U_j)$[24], where U_i is the consumer utility drawn from the consumption of the good produced by company i, and U_j is the utility drawn from the consumption of the good produced by company i's rival. The utility function increases with respect to the argument U_i and decreases with respect to the argument U_j. Because the values of the utility function depend both on the argument p_i and A_i, in the model we deal with simultaneous price and quality competition in the market of the final product.

A measure of the size of company in the model is the value of attained sales ($S_i = p_i Q_i$). The measure of firm innovation is, in turn, the corporate R&D intensity[25]. The R&D

intensity is the ratio of the company's own spending on R&D to the value of company's sales (total revenues). Only product innovations are considered.

Model Construction

Companies seek to maximize profits depending on the price of the product and the value of their own expenditures on R&D. Formally, the profit function of the *i*-th company (π_i) can be written in the following form:

$$\pi_i = p_i Q_i - MC_i Q_i - x_i. \tag{1}$$

The decision variables in the model are (i) the price of the product and (ii) the value of the company's own expenditures on R&D.
From the condition of profit maximization with respect to the price of the good we obtain:

$$\frac{\partial \pi_i}{\partial p_i} = 0 \Rightarrow Q_i + (p_i - MC_i)\frac{\partial Q_i}{\partial p_i} = 0. \tag{2}$$

From the condition of profit maximization with respect to the company's own expenditures on R&D we obtain:

$$\frac{\partial \pi_i}{\partial x_i} = 0 \Rightarrow -1 + (p_i - MC_i)\frac{\partial Q_i}{\partial x_i} = 0. \tag{3}$$

Note further that the elasticity of demand for the good produced by company i with respect to the price of the good (ε^{Qp}) is equal to

$$\varepsilon^{Qp} = -\frac{p_i}{Q_i}\frac{\partial Q_i}{\partial p_i}. \tag{4}$$

Then

$$\frac{\partial Q_i}{\partial p_i} = \frac{-\varepsilon^{Qp} Q_i}{p_i}. \tag{5}$$

After substituting the fifth formula into the second formula we obtain the following:

$$S_i = (p_i - MC_i)\varepsilon^{Qp} Q_i. \tag{6}$$

Observe further that the elasticity of demand for the good produced by company i with respect to the company's own spending on R&D (ε^{Qx}) is equal to

$$\varepsilon^{Qx} = \frac{x_i}{Q_i}\frac{\partial Q_i}{\partial x_i}. \tag{7}$$

Then

$$\frac{\partial Q_i}{\partial x_i} = \varepsilon^{Qx} \frac{Q_i}{x_i}. \tag{8}$$

After substituting the eighth formula into the third formula we obtain the following:

$$x_i = (p_i - MC_i)\varepsilon^{Qx} Q_i. \tag{9}$$

Let us now determine the intensity of company *i*'s spending on R&D as a ratio of its own R&D expenditures to the value of attained sales. The company *i*'s R&D intensity is denoted as $\alpha_i = \frac{x_i}{S_i}$. Note, on the basis of formulas (6) and (9), that corporate R&D intensity for the company maximizing its profits is

$$\alpha_i = \frac{x_i}{S_i} = \frac{\varepsilon^{Qx}}{\varepsilon^{Qp}}. \tag{10}$$

Observe further that the elasticity of demand for the good produced by the *i*-th company with respect to its own spending on R&D is equal to

$$\varepsilon^{Qx} = \frac{x_i}{Q_i}\frac{\partial Q_i}{\partial x_i} = \frac{x_i}{Q_i}\frac{\partial Q_i}{\partial U_i}\frac{\partial U_i}{\partial A_i}\frac{dA_i}{dX_i}\frac{\partial X_i}{\partial x_i}. \tag{11}$$

Price elasticity of demand for the good produced by company *i* is in turn equal to

$$\varepsilon^{Qp} = -\frac{p_i}{Q_i}\frac{\partial Q_i}{\partial p_i} = -\frac{p_i}{Q_i}\frac{\partial Q_i}{\partial U_i}\frac{\partial U_i}{\partial p_i}. \tag{12}$$

Let us next define the elasticity of demand for the good produced by company *i* with respect to the utility drawn from the consumption of the good produced by this company:

$$\varepsilon^{QU} = \frac{U_i}{Q_i}\frac{\partial Q_i}{\partial U_i}. \tag{13}$$

By

$$\theta_i^q = \frac{A_i}{U_i}\frac{\partial U_i}{\partial A_i} \tag{14}$$

we further denote elasticity of the utility drawn from the consumption of the good produced by company *i* with respect to the size of the technology input embodied by the good. The parameter θ_i^q indicates the sensitivity of consumer preferences with respect to the quality of the good. The higher the value of the parameter θ_i^q, the greater importance consumers give to the quality of the good. By

$$\theta_i^p = -\frac{p_i}{U_i}\frac{\partial U_i}{\partial p_i} \tag{15}$$

we further denote elasticity of the utility drawn from the consumption of the good produced by company *i* with respect to the price of the good. The parameter θ_i^p indicates the sensitivity of consumer preferences with respect to the price of the good. The higher the value of the parameter θ_i^p, the greater importance consumers give to the price of the good. Furthermore, note that the ratio $\theta_i = \frac{\theta_i^q}{\theta_i^p}$ simultaneously describes consumer preferences[26] towards the quality and price of the good on the relevant product market.

Let

$$a_i = \frac{X_i}{A_i}\frac{dA_i}{dX_i} \tag{16}$$

be *technological competence*[27] [cf. Lee and Sung, 2005; Knudsen, 2005] of company *i*. Companies for which a_i achieves a higher value have more competence in technology creation than companies for which a_i has a lower value.

By

$$\varphi_i = \frac{x_i}{X_i}\frac{\partial X_i}{\partial x_i} \tag{17}$$

we finally denote the elasticity of company *i*'s effective spending on R&D with respect to its own expenditures on R&D. When incoming spillovers are equal to zero, $x_i = X_i$[28]. Eventually, using the formulas (11)–(17) and substituting them into equation (10), we obtain the following:

$$\alpha_i = a_i\theta_i\varphi_i. \tag{18}$$

Interpreting relationship (18), we can conclude that corporate R&D intensity (as a measure of firm innovation) for a company maximizing its profits is fully determined by three factors:

- the company's technological competence (a_i, supply-side factor),
- consumer preferences towards quality and price of goods (θ_i, demand-side factor),
- the moderating factor (φ_i), which refers to the knowledge spillovers between companies competing in the industry.

Since these factors are expressed in the form of elasticities, the model will hereafter be referred to as the *elasticity-based model of firm innovation*. It is worth noting that it is both a technology-push and demand-pull concept. The factors a_i (supply-side) and θ_i (demand-side) should be considered primary, because they constitute the two sides of the market mechanism. The factor φ_i, associated with knowledge spillovers in the industry, moderates the impact of the primary factors on corporate R&D intensity.

At this point it is also worth emphasizing the complementarity of the factors in expression (18). Note that these factors are mutually reinforcing or weakening. For example, a deficiency in one factor reduces a company's R&D intensity in a multiplicative manner, and consequently, in the light of the proposed model, negatively impacts on the product innovations developed by the firm.

The importance of the complementarity of factors in modern microeconomic modelling is accurately covered by Garbicz [2005, p. 20]:

In many modern fields of production the key to success is the reliability of all factors of production. A symphony orchestra consisting almost wholly of virtuosos will note a dramatic artistic failure if just one of the musicians misplays a note. Standard economics assumes wide possibilities of substitution between factors, while economic realities rather make us think in terms of complementarity, as if the weakest link were decisive. Quality cannot, significantly, be substituted by quantity.

Horizontal R&D Cooperation in the Framework of the Elasticity-Based Model of Firm Innovation

In this section the horizontal[29] cooperation between companies in R&D is analyzed. According to the classification of the forms of R&D cooperation proposed by Kamien and others [1992] companies cooperating horizontally in R&D coordinate decisions on the values of the R&D expenditures (cooperation in the research phase), but at the same time compete in the final product market after introducing the invention (competition in the innovation phase).

In this paper, we consider symmetric R&D cooperation, where participants bear equal values of expenditures on R&D. Therefore, in the case of R&D cooperation, we obtain the following: $\frac{\partial X_i^C}{\partial x_i^C} = 1 + (1 - \delta_i)$. When companies do not cooperate, the value of the corresponding derivative is equal to: $\frac{\partial X_i^N}{\partial x_i^N} = 1$.

In this section, attention will be focused on analysing the R&D intensity of an enterprise. In fact, two scenarios are considered, i.e. (i) the case in which company *i* does not establish R&D cooperation with company *j* (the R&D rivalry variant); and (ii) the case in which cooperation in R&D has occurred.

R&D Rivalry

Note that based on equation (18), the R&D intensity of company (maximizing its profit) that is in R&D competition can be written as follows:

$$\alpha_i^N = a_i \theta_i \frac{x_i^N}{x_i^N + (1 - \delta_i)\beta_j x_j^N}. \tag{19}$$

The first two factors of the product on the right hand side of equation (19) are written without superscripts because under the assumptions of the model these elasticities are constant[30]. Let us further develop equation (19) in the following form:

$$\frac{x_i^N}{S_i^N} = a_i\theta_i \frac{x_i^N}{x_i^N + (1-\delta_i)\beta_j x_j^N}. \tag{20}$$

After simple algebraic transformations we get the value of the R&D intensity of company (maximizing its profit) that applies R&D rivalry strategy:

$$\alpha_i^N = a_i\theta_i - \frac{(1-\delta_i)\beta_j x_j^N}{S_i^N}\text{[31]}. \tag{21}$$

Now let us compare this result with the result in a situation of cooperation in R&D.

R&D Cooperation

Note that based on equation (18), the R&D intensity of a company (maximizing its profit) that is in R&D cooperation can be written as follows:

$$\alpha_i^C = a_i\theta_i \frac{x_i^C}{x_i^C + (1-\delta_i)x_j^C}(1+(1-\delta_i)). \tag{22}$$

After simple algebraic transformations we get the value of the R&D intensity of company (maximizing its profit) that applies R&D cooperation strategy:

$$\alpha_i^C = a_i\theta_i. \tag{23}$$

If we compare expressions (21) and (23), we see that the discussed intensities differ by the component:

$$-\frac{(1-\delta_i)\beta_j x_j^N}{S_i^N}. \tag{24}$$

The proposition. $\alpha_i^C \geq \alpha_i^N$. A profit-maximizing company cooperating horizontally in R&D attains a higher or equal[32] level of R&D intensity than under R&D competition.

The value of expression (24) can be considered as the size of the free-rider problem, which occurs in the innovative activity of enterprises. Enterprises in the presence of knowledge spillovers in the industry limit the values of their expenditures on research and development. This is because the knowledge produced by the *i*-th company penetrates to rivals[33], raising the levels of their profits as a result (therefore, the competitors of the *i*-th company become free-riders). The component (24) in the majority of cases is negative[34], leading to private underinvestment in innovation.

It is worth stressing the clear conflict between the public and the private interests in terms of knowledge spillovers. From a public point of view, knowledge spillovers in an industry are a desirable phenomenon as they contribute to the diffusion of knowledge in a society [cf. Wölfl, 1998; Arrow, 1962; Romer, 1986]. From the private standpoint (maximizing profits perspective) however, knowledge spillovers in an industry may be viewed negatively as unintentional transfers that benefit rivals of the company. Drawing on a presented model, we see that R&D competition could lead to lower levels of corporate investments in R&D (especially, in relation to socially desirable levels [Peneder, 2008]). This is the welfare economics argument for cooperation between enterprises in the field of R&D.

As shown in the model, horizontal R&D cooperation can be an effective solution to the free-rider problem occurring in the innovative activity of enterprises. R&D cooperation alleviates the adverse impact of knowledge spillovers in the industry on the degree of innovation in enterprises. Cooperation in the field of R&D contributes to the internalization of the negative externality that arises as a result of imperfect knowledge absorption and control by companies creating know-how. In our simple model of a duopoly, the full internalization of the negative externality is shown since the free-rider problem is here completely eliminated (component 24 disappears).

Equation (23) shows that corporate R&D intensity in case of cooperation is determined only by basic factors (economic fundamentals), there are no "confounding" factors here associated with imperfect knowledge absorption by the company producing it. In business practice we must, however, reckon with the fact that horizontal R&D cooperation will not remove[35]the free-rider problem, but rather will reduce it. But still, horizontal R&D cooperation may be regarded as a complementary method with regard to the traditional (standard) solutions (patent protection and government research subsidies) of alleviating the negative impact of knowledge spillovers in the industry on firms' innovation activities. It is also worth noting here that the cooperation mechanism being discussed is a purely market phenomenon and does not require such a significant involvement of the government, as is the case with patent protection or a research subsidy scheme.

Conclusions

Microeconomic research on firm innovation can be found in the literature of industrial organization (see e.g. [Belleflamme, Peitz, 2010]). Existing models, belonging to the dominant know-how strand of IO literature, take account of the following factors in company innovation: the company's R&D strategy, knowledge spillovers in industry, the absorptive capacity of a company, and the degree of generality of the research conducted by a company. In this paper, these models have been enhanced by factors specific to the Schumpeterian strand of research on innovation, i.e. the size of the enterprise, productivity of the corporate spending on R&D, and consumer preferences towards the quality and the price of goods manufactured by the company.

The model presented here is a formal description of the above-mentioned innovation factors and the relationships between these factors. Specifically, it was shown that the corporate R&D intensity (as a measure of firm innovation) for a company maximizing profits is fully determined by: the company's technological competence (supply-side factor), consumer preferences towards quality and price of goods (demand-side factor), as well as a moderating factor, which refers to knowledge spillovers between competing companies. Supply-side and demand-side factors should be considered primary, because they constitute the two sides of the efficient market mechanism. The factor associated with knowledge spillovers in the industry moderates the impact of the primary factors on the firm's R&D intensity.

In the theoretical framework presented, it was shown how cooperation between companies in R&D helps solve the free-rider problem, which occurs in the innovative activity of enterprises. It is also postulated that horizontal R&D cooperation may be regarded as a complementary method with regard to the standard solutions (patent protection and government research subsidies) for alleviating the negative impact of knowledge spillovers in the industry on company innovation activities.

Notes

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[2] The size of a firm can be measured by the number of employees, the value of sales of goods, and the value of business assets [Morck, Yeung, 2000].

[3] We speak of presence of knowledge spillovers in an industry when part of the knowledge generated by company *i* is shared by company *j*, while only company *i* incurred the costs of creating that knowledge.

[4] Knowledge within the meaning of know-how, which is a specific technical knowledge that enables a particular good to be produced.

[5] Improve the quality of the good.

[6] These efforts are measured by the value of enterprise spend on a given kind of innovation activity.

[7] This ability is operationalized later in the paper.

[8] Each company in an industry spends more money on R&D in conditions of R&D cooperation than in a R&D competition.

[9] They exceed the critical value equal to 1/2 in the d'Aspremont and Jacquemin model [1988].

[10] The ability to absorb knowledge produced by other companies.

[11] R&D generality.

[12] $\delta_i \in [0,1]$.

[13] Based on a representative sample of the population of Taiwanese industrial companies.

[14] For consumers goods are associated with different values of the utility function.

[15] *The technology embodiment theory* was proposed by Lee and Sung [2005]. According to these researchers, the quality of a good depends on the technological effort that was used in the production of that good. Technologies used in the production process are in some sense "embodied" by the final product. Improving the quality of existing products using technological effort leads to product innovations.

[16] The function U is continuous and differentiable.

[17] In the presence of knowledge spillovers in an industry a distinction should be made between knowledge derived solely from a company's own R&D work (own research) and the total knowledge acquired by the company (also taking into account the knowledge coming from spillovers in the industry). The first category is called, in brief, *own knowledge*, and the latter *effective knowledge*. X_i is then a function of the own level of expenditures on R&D (x_i) and the sums from incoming knowledge spillovers ($\sum_{i \neq j} x_j$).

[18] The particular case of the Cobb-Douglas function for one production factor.

[19] Company j perfectly shares its knowledge (know-how) with company i.

[20] The value of β depends, among others, on the distance between the laboratories of enterprises i and j.

[21] The superscript C stands for the cooperation.

[22] The superscript N stands for the lack of cooperation (non-cooperation), i.e. competition in R&D.

[23] Such a treatment is used, among others, in the papers of d'Aspremont and Jacquemin [1988] and Kamien and others [1992].

[24] The function Q is continuous and differentiable.

[25] Corporate R&D intensity is one of the relative (referring to the size of the company) measures of firm innovation. Researchers working in the field of industrial organization take the following as measures of firm innovation [Tirole, 1988]: (1) the absolute or relative value of the enterprise's R&D spend (input measure), (2) the number of patents granted to the company (output measure) or (3) the number of innovations introduced by the company to the marketplace (output measure). For Polish literature on firm innovation, see e.g. Janasz and others [2002] or Janasz and Kozioł [2007].

[26] To simplify further analysis, we assume that consumer preferences towards good quality and price are fixed. A similar procedure was applied e.g. in the model developed by Lee and Sung [2005].

[27] The capacity to create technologies [see e.g. Lee and Sung, 2005].

[28] This case excludes knowledge spillovers from further analysis. It is so purely theoretical that it oversimplifies the inquiry on the issues of enterprise innovation.

[29] Horizontal R&D cooperation is defined as sharing knowledge (know-how) by enterprises competing with each other on a given product market, and at the same time coordinating decisions about the values of expenditures on research and development [Kamien et al., 1992; Becker, Dietz, 2004; Belderbos et al., 2004a; 2004b]. According to Kamien, Muller and Zang [1992] companies in horizontal R&D cooperation coordinate decisions about the value of R&D expenditures (research stage), but at the same time compete on the final product market after the invention is implemented (innovation stage). Many authors emphasize that horizontal R&D cooperation brings enterprises many benefits [Camagni, 1993; Robertson, Langlois, 1995; Becker, Peters, 1998; Becker, Dietz, 2004]. These include: access to the rival's resources, specialization and economies of scale in research and development, reducing the uncertainties associated with the creation of innovation, as well as shortening the duration of the development period (a chance for faster introduction of the invention on the market).

[30] The constant value a_i is due to the mathematical properties of the power function, which is a particular case of the Cobb-Douglas function. The elasticity of the power function with respect to the argument is constant.

[31] $S_i^N \neq 0$.

[32] Component (24) is equal to zero when $\delta_i = 1$ (the case of extreme research specialization) or $\beta_j = 0$ (no physical conditions for the formation of knowledge spillovers) or $x_j^N = 0$ (the rival does not conduct R&D activities). These cases are, however, purely theoretical and of little interest from the perspective of business practice and empirical verification of the model.

[33] Without financial compensation.

[34] In a very specific case it may be zero.

[35] Due to the larger number of companies competing in the market, a greater number of products, or other aspects of the market reality not included in the model.

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