Iwona Świeczewska

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THE EXTERNALITIES OF ENTERPRISES' INNOVATIVE ACTIVITY – AN INPUT-OUTPUT APPROACH

Iwona Świeczewska, Ph.D.

University of Łódź,
Department of Theory and Analysis of Economic Systems
Rewolucji 1905 r. 41, 90-214 Łódź, Poland
e-mail: iswiecz@uni.lodz.pl

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Abstract

The article assesses the impact of final demand for domestic products on the innovative activity of Polish enterprises. The activity is analysed in terms of their involvement in research and development (R&D) processes, which are considered crucial for an economy to be able to create a stock of knowledge. The main purpose of the analysis is to identify products that contribute to the largest increases in enterprises' R&D expenditures. To study the effect of final demand on enterprises' R&D activity, the input-output analysis method has been adopted. The presented analysis is part of author's research on the intersectoral diffusion of knowledge in the Polish economy.

Keywords: innovativeness of enterprises, R&D activity, input-output methods, innovation flow matrices.

JEL classification: O14, O32, O33.

Introduction

In today's world, knowledge and innovations are considered to be the key factors driving the development of contemporary economies. This view is founded on the findings of many economists who have analysed economic growth processes from both theoretical perspective[1] and empirical perspective[2]. It is worth noting that dynamic development of the modern-day economies depends as much on their knowledge stock as their capacity for absorbing knowledge and technologies from abroad.

This situation makes knowledge a special resource, a prerequisite for the creation and development of innovations. Innovation is defined as „breaking up with the existing practice, striving to attain competitive advantage by increasing the efficiency of production or distribution, or by introducing a new product"[3]. The economy's long-term ability to create and commercialise a stream of brand-new ideas and solutions known as its capacity for innovation is strongly and reciprocally related to the level and/or speed of its development. An important role in this process is played by research and development (R&D) activity, which is usually defined as „creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications"[4]. The stock of knowledge capital available to the economy is determined by scientific knowledge accumulated through R&D and the knowledge possessed by the society (its level of educational attainment).

One characteristic feature of knowledge is its ability to spread across an economic system (diffusion of knowledge, transfer of knowledge). The process can take place at every level of the system: between enterprises, between sectors (intersectoral diffusion of knowledge), as well as between regions or countries (interregional or international diffusion of knowledge). Two types of knowledge transfers are usually referred to in the literature irrespective of the level of detail of the conducted analysis[5]:

– a product-embodied knowledge transfer which occurs when an economic entity concludes a formal sale-buy transaction to purchase a new or considerably improved product, thus formally acquiring the knowledge the product contains. In this case, the embodied knowledge spreads with the flows of intermediate and investment goods, imports, foreign direct investments, patents and licences, etc.,
– a disembodied knowledge transfer, i.e. via informal contacts between economic agents. This type of transfer is related to observation, learning, and the copying of generally accessible knowledge.

The assessment of the benefits that knowledge transfers bring to the economy is very difficult to perform. The selection of the measurement methods is determined, *inter alia*, by assumptions that have been made about 1) the type of the transfer (embodied or disembodied), 2) the channels of knowledge diffusion (e.g. flows of raw materials inside or between economies, flows of investment goods, import, FDI, flows of patents, etc.), and 3) the level of the analysis itself (microeconomic, macroeconomic, sectoral, regional). The very measurement of the economy's stock of knowledge is not easy to make either.

This article concentrates on the methods used to measure the amount of economy's benefits from the transfer of knowledge "embodied" in domestic intermediate goods. The transfer takes place at the industry level and the carriers of knowledge are domestic intermediate goods flowing between industries. The factor stimulating knowledge flows in the economy is final demand for domestic goods from particular institutional sectors. An assumption is made that the knowledge stock of particular Polish industries is determined by their expenditures on research and development activity (R&D)[6]. While being only one aspect of enterprises' innovative activity, R&D[7] seems to be indispensable for creating a stock of knowledge. Hence, in this analysis, R&D externalities will be understood as an increase in R&D expenditures in the economy determined by greater domestic final demand for some groups of products.

The analysis presented below makes use of embodied innovation flow matrices constructed for the Polish economy[8]. The matrices and the selected elements of multiplier analysis allow indicating groups of products that embody the most of domestic R&D expenditures, so an increase in final demand for these products contributes the most to increasing R&D activity in the country. The matrices also enable domestic R&D expenditures to be disaggregated into final demand categories, i.e. to determine the role of particular institutional sectors as the stimulants of domestic R&D.

The article is structured as follows. Section 1 presents the construction of an innovation flow matrix, the interpretation of its particular elements, and R&D multipliers. Section 2 provides some comments on the statistical data underpinning the analysis. Section 3 discusses the results of empirical research. The last section 4 presents the conclusions from the analysis.

1. The methodology of constructing an innovation flow matrix

The construction of an innovation flow matrix starts with a standard input-output (I-O) model defined as:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{y} \tag{1}$$

where:

$\mathbf{x} = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}$ and $\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$ are the vectors of, respectively, the gross output of each of *n* industries and of final demand for products delivered by each of the *n* industries;

$A = [a_{ij}]_{n \times n}$ is a matrix of direct input-output coefficients defined as $a_{ij} = \frac{x_{ij}}{X_j}$. The amount of a_{ij} shows the value of industry *i*'s expenditures (intermediate goods) that industry *j* needs to create a unit of gross output.

Model (1) can alternatively be written as domestic output:

$$\mathbf{x}^k = \mathbf{A}^k \mathbf{x}^k + \mathbf{y}^k \tag{2}$$

Vectors $\mathbf{x}^k$ and $\mathbf{y}^k$ denote, respectively, domestic gross output and final demand for domestic products, and the $a_{ij}^k = \frac{x_{ij}^k}{X_k^k}$ elements of matrix $\mathbf{A}^k = [a_{ij}^k]_{n \times n}$ indicate the value of industry *i*'s domestic intermediate inputs required for industry *j* to create a unit of domestic gross output[9]

Because the following part of the presentation concentrates on the flows of domestic intermediate goods as the main carriers of knowledge in the economy, model (2) will be used henceforth.

By solving model (2) with respect to domestic gross output we obtain:

$$\mathbf{x}^k = (\mathbf{I} - \mathbf{A}^k)^{-1} \mathbf{y}^k \tag{3}$$

where $(\mathbf{I} - \mathbf{A}^k)^{-1} = L^k = [l_{ij}^k]_{n \times n}$ is the Leontief-inverse matrix for domestic goods. The element l_{ij}^k denotes the amount of domestic (gross) output of industry *i* required (directly or indirectly) per a unit of domestic final demand for product *j* or, in marginal terms, an increase in domestic gross output of industry *i* induced by a unit increase in domestic final demand for the products of industry *j*. It is worth stressing that the elements of this matrix account for direct effects of additional demand for intermediate goods arising from greater final demand for the products of the given industry, as well as for indirect effects of intermediate linkages between industries. Hence the notion of a so-called total (direct and indirect) increase in the gross output of industry *i* caused by a unit increase in final demand for industry *j*'s output is frequently used.

Another important element of the input-output analysis is the sums of the elements in the Leontief-inverse matrix columns, which are called simple output multipliers[10]. The multipliers' values for the *j*-th industry determined from the matrix in equation (3), i.e. $M_j^k = \sum_i l_{ij}^k$, indicate how much gross domestic output will increase in the economy because of a unit increase in the final domestic demand from the *j*-th industry.

The construction of the flow matrix of innovations embodied in domestic intermediate goods starts with the determination of the direct coefficients of domestic R&D expenditures known as R&D intensive coefficients. Assuming that the proxy of the industry's capacity for innovation[11] is the amount of its R&D expenditures (BR_i), the R&D intensive coefficients for industry i (r_i) can be written as:

$$r_i = \frac{BR_i}{X_i^k} \tag{4}$$

The value of this coefficient indicates the value of industry *i*'s domestic R&D expenditures per a unit of its gross domestic output.

Using relations (3) and (4), total R&D expenditures in the economy can be presented as:

$$\begin{aligned} BR = \sum_i BR_i = \begin{bmatrix} r_1 & r_2 & \dots & r_n \end{bmatrix} \begin{bmatrix} X_1^k \\ X_2^k \\ \vdots \\ X_n^k \end{bmatrix} = \mathbf{r}^T \mathbf{x}^k = \mathbf{r}^T (\mathbf{I} - \mathbf{A}^k)^{-1} \mathbf{y}^k = \\ = \begin{bmatrix} \rho_1 & \rho_2 & \dots & \rho_n \end{bmatrix} \begin{bmatrix} y_1^k \\ y_2^k \\ \vdots \\ y_n^k \end{bmatrix} = \boldsymbol{\rho}^T \mathbf{y}^k \end{aligned} \tag{5}$$

Hence, the element *j* of vector **ñ** , i.e. ρ_j , shows the value of domestic R&D expenditures per a unit of final demand for domestic products of industry *j*, or – in marginal terms – an increase in domestic R&D expenditures caused by domestic final demand of industry *j* increasing by a unit. Accordingly, ρ_j can be called an R&D multiplier for industry *j* [12].

Equation (5) written with the appropriate diagonal matrices provides more detailed information on the level of industry *i*'s R&D expenditures that is required for industry *j* to satisfy its final demand for domestic goods. Because of that, the matrix:

$$\mathbf{F}_{B+R}^k = \hat{\mathbf{B}}\hat{\mathbf{R}}(\hat{\mathbf{x}}^k)^{-1}(\mathbf{I} - \mathbf{A}^k)^{-1}\hat{\mathbf{y}}^k = \hat{\mathbf{r}}(\mathbf{I} - \mathbf{A}^k)^{-1}\hat{\mathbf{y}}^k \tag{6}$$

where: $\hat{\mathbf{B}}\mathbf{R}(\hat{\mathbf{x}}^k)^{-1} = \hat{\mathbf{r}}$ – a diagonal $n \times n$ matrix of R&D intensive coefficients and $\hat{\mathbf{y}}^k$ – a diagonal $n \times n$ matrix of final demand for domestic products is called a flow matrix of innovations (embodied in domestic intermediate goods)[13].

Let us denote by **H** the product of diagonal matrix $\hat{\mathbf{r}}$ and of the Leontief-inverse matrix for domestic goods $(\mathbf{I} - \mathbf{A}^k)^{-1}$. Then the element $h_{ij} = r_i l_{ij}^k$ of the resulting matrix shows the value of R&D expenditures required to be made by industry *i* in order to satisfy a unit of industry *j*'s final demand for domestic products. The sum of the elements provided in column *j* of matrix **H** $\left(\sum_i h_{ij} = \sum_i r_i l_{ij}^k \right)$ is therefore the total amount of (domestic) R&D expenditures involved in a unit of final demand for domestic products. In other words, the sum is identical with the earlier defined R&D multiplier for industry *j*, i.e.:

$$\rho_j = \sum_i h_{ij} \qquad (7)$$

By multiplying matrix **H** by the diagonal matrix of domestic final demand we arrive at matrix $\mathbf{F}_{B+R}^k = [f_{ij}^k] = [r_i l_{ij}^k y_j^k]$. The element f_{ij}^k indicates the value of domestic R&D expenditures that are required of industry *i* to meet domestic final demand for industry *j*'s products or, alternatively, the value of domestic R&D expenditures made by industry *i*, which are embodied in domestic final demand for industry *j*'s products. The carriers of R&D expenditures flowing between industries are domestic intermediate goods. Hence the row elements of the innovation flow matrix indicate the value of sector's R&D expenditures embodied – through direct and indirect intermediate linkages – in domestic final demand for the products of particular industries. The sum of the elements in the *i*-th row of the matrix shows the value of domestic R&D expenditures that sector *i* must make to satisfy final demand for all domestic products, so it is equal to the amount of R&D expenditures incurred by industry *i*. The *j*-th column elements of matrix $\mathbf{F}_{B+|R}^k$ represent the amounts of R&D expenditures in particular industries, which are directly and indirectly embodied in industry *j*'s final demand for domestic products. Therefore, the sum of the *j*-th column elements of this matrix stands for the value of R&D expenditures that the whole the economy must make to satisfy industry *j*'s final demand for domestic products.

2. Statistical data used in the research

The innovation flow matrix for the Polish economy was constructed with the symmetric input-output tables of inter-sectoral flows for domestic products. In the Eurostat database, this type of matrices is only available for 2000 and 2005. For the purpose of this analysis, the tables were aggregated to 54 × 54 group of products[14]. Even though the periods covered by the tables are quite distant in time, Przybyliński has demonstrated (2012, pp. 81–85) that they are still capable of producing relatively stable coefficients, which seems to confirm their usefulness for economic analysis despite their being published with considerable lags[15].

The data on R&D expenditures made in 2000 and 2005 were obtained from the OECD database (STAN). The database was selected because its data show R&D expenditures made by both manufacturers and service providers (the national data from these years are quite comprehensive regarding the R&D expenditures of manufacturers, but rather fragmentary with respect to service providers). The data (available at the second and sometimes also at the third level of the Statistical Classification of Economic Activities in the European Community, NACE) were transformed into a product-based system using a supply matrix as described by Przybyliński (2012, p. 70). The values of R&D expenditures were additionally converted into PLN using the average USD exchange rate.

3. The results of empirical research

The structures of R&D expenditures made by the manufacturing sector in both analysed years were not considerably different from each other (a similarity rate of around 83%). In both 2000 and 2005, most expenditures were made to manufacture goods, mainly machinery and equipment (respectively 11% and 9.5%), chemicals and chemical products (9.8% in both years), motor vehicles, trailers and semi-trailers (6.7% and 10.2%), other transport equipment (7.1% and 6.4%), and electrical machinery and apparatus (5.1% in both years). In the services sector, R&D services (2.8% in 2000 and 2.5% in 2005) are worth noting, as well as computer and related services the importance of which was considerably greater in 2005 (increasing from 0.1% to 3.9%). The changes are also reflected in the R&D multipliers (see Table 1) determined from formula (5).

Table 1. Multiplier values[16] for domestic R&D expenditures in 2000 and 2005

No.	Groups of products (abbreviated names)	2000	2000 ranking	2005	2005 ranking
1	2	3	4	5	6
1	products of agriculture, hunting	0.375	33	0.236	26
2	products of forestry	0.373	34	0.243	24
3	fish and other fishing products	0.584	19	0.291	17
4	coal and lignite; peat	0.996	12	0.519	10
5	crude petroleum and natural gas, metal ores, other mining and quarrying products	0.768	16	0.351	14

1	2	3	4	5	6
6	food products and beverages	0.247	41	0.219	30
7	tobacco products	0.868	14	0.180	41
8	textiles	1.046	11	0.356	13
9	wearing apparel and furs	0.175	50	0.088	53
10	leather and leather products	0.352	36	0.110	50
11	wood and products of wood	0.404	31	0.183	40
12	pulp, paper and paper products	0.477	27	0.271	20
13	printed matter and recorded media	0.176	49	0.157	45
14	coke and refined petroleum products	0.342	37	0.246	23
15	chemicals and chemical products	1.814	6	0.887	5
16	rubber and plastic products	0.720	17	0.280	18
17	other non-metallic mineral products	0.557	21	0.278	19
18	basic metals	1.241	10	0.322	15
19	fabricated metal products	0.919	13	0.257	22
20	machinery and equipment	2.456	4	0.842	6
21	office machinery and computers	1.637	8	0.471	11
22	electrical machinery an apparatus	2.003	5	0.820	7
23	radio, television and communication equipment and apparatus	3.253	3	0.589	9
24	medical, precision and optical instruments	1.735	7	1.137	3
25	motor vehicles, trailers and semi-trailers	1.408	9	0.654	8
26	other transport equipment	3.914	1	2.020	1
27	furniture and other manufactured goods	0.490	25	0.313	16
28	secondary raw materials	0.479	26	0.202	36
29	electrical energy, gas, steam and hot water	0.554	22	0.261	21
30	collected and purified water, distribution services of water	0.559	20	0.207	34
31	construction	0.450	28	0.175	42
32	trade, maintenance and repair services of motor vehicles and motorcycles	0.245	42	0.086	54
33	wholesale trade and commission trade services	0.227	44	0.164	43
34	retail trade services	0.144	53	0.112	49
35	hotel and restaurant services	0.168	51	0.105	51
36	land transport and transport via pipeline services	0.535	23	0.219	29
37	water and air transport services	0.829	15	0.359	12
38	supporting and auxiliary transport services; travel agency services	0.533	24	0.231	27
39	post and telecommunication services	0.627	18	0.199	38
40	financial intermediation services	0.135	54	0.229	28
41	insurance services	0.190	48	0.237	25
42	services auxiliary to financial intermediation	0.207	47	0.200	37
43	real estate services	0.242	43	0.097	52
44	renting services of machinery and equipment	0.167	52	0.208	33
45	computer and related services	0.221	45	0.917	4
46	research and development services	3.345	2	1.383	2
47	other business services	0.213	46	0.116	48
48	public administration services	0.299	39	0.160	44
49	education services	0.266	40	0.136	47
50	health and social work services	0.414	30	0.192	39
51	sewage and refuse disposal services	0.396	32	0.212	31
52	membership organisation services	0.371	35	0.208	32
53	recreational, cultural and sports services	0.416	29	0.205	35
54	other services; services provided by households	0.313	38	0.156	46

Source: calculated by the author.

The multiplier values decreased between 2000 and 2005 for most of the analysed groups of products (50 out of 54). This means that in 2005 domestic R&D expenditures stimulated by domestic final demand were smaller than in 2000 for most products. The decline in the multiplier values was caused by R&D intensity coefficients growing smaller for the majority of the analysed groups of products (mainly because of lower R&D expenditures), but also by reduced demand for domestic intermediate goods (declining direct input-output coefficients for domestic products).

The products that can be recognised as the best drivers of domestic R&D activity (i.e. products embodying the greatest amounts of R&D expenditures) include[17]: other transport equipment, R&D services, medical, precision and optical instruments (ranked 7th in 2000), computer and related services (ranked 45th in 2000), chemicals and chemical products (ranked 6th in 2000), machinery and equipment (6th in the 2005 ranking and 4th in 2000) and electrical machinery and apparatus (7th in the 2005 ranking and 5th in 2000). The above industrial goods involve high and mid-high technologies and the products of the service sector are knowledge-intensive. It is worth noting, though, that while these groups of products embody a significant proportion of the domestic expenditure on R&D, their role in stimulating domestic R&D activity decreases, as proven by the diminishing values of multipliers for the majority of the aforementioned groups of products. An exception is computer services for which the multiplier increased more than fourfold. This increase was driven by growing demand for this type of service from final users (mainly households) and more than a tenfold increase in R&D expenditure on these services. Higher values of the multipliers of domestic R&D expenditures were also noted in the case of financial and insurance services and machinery and equipment rental services.

With the innovation flow matrix derived from relation (6), R&D expenditures were decomposed into final demand categories (see Figure 1).

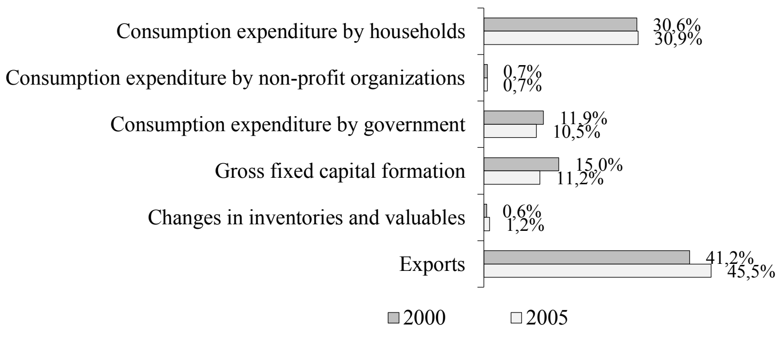

Fig. 1. The decomposition of R&D expenditures by category of final demand

Source: developed by the author.

The graph shows exports to embody the greatest proportion of domestic R&D expenditures. An increase in the importance of export as the stimulant of domestic R&D activity is also noticeable. Slightly more than 30% of R&D expenditures in the country are allocated to domestic products addressed to households. This rate was stable in both investigated years. Another observation is a minor decrease in domestic R&D expenditures resulting from less active government consumption and investment processes.

Conclusions

The above analysis of the externalities generated by enterprises' innovation activities was undertaken to identify the role of final demand for domestic products as a stimulant to research and development activity in the country. The analysis was based on the multipliers of domestic R&D expenditures and the flow matrices of innovations embodied in domestic intermediate products. The results of this study point to a diminishing effect of final demand for domestic products on domestic R&D activities. Lower values of the R&D multipliers (in the case of some products they are several times lower) are caused by decreasing domestic R&D expenditure and its unfavourable structure – the business sector's contribution is relatively small compared with that in the technologically advanced countries. The trend is particularly marked in manufacturing (lower multiplier values for all manufacturing products). Conclusions must be formulated with caution, though, because the balanced input-output tables become available with a delay. The changes that have been observed in the R&D sphere in recent years, such as increased expenditures on R&D activity, seem to promise that despite the structure of the expenditures being still unfavourable from the perspective of their effectiveness the role of domestic R&D will increase.

As found, the R&D activity in Poland is mainly stimulated by exports and household final demand. The analysis of domestic demand for particular groups of products that aimed to determine their effect on domestic R&D activity has revealed the central role of demand for knowledge-intensive products and services. The stable structure of R&D expenditures made by institutional sectors indicates that the main drivers of domestic R&D will be exports (particularly of medium- and high-tech manufacturing products) and household consumption.

The analysis is part of author's research into inter-sectoral diffusion of knowledge in Polish economy.

Notes

[1] Romer (1990); Lucas (1988); Aghion, Howitt (1998).

[2] Coe, Helpman (1995); Bayoumi, Coe, Helpman (1999); Engelbrecht (1997, 2002); Zhu, Jeon (2007).

[3] Dworak (2012), p. 32.

[4] *Frascati Manual...* (2002), p. 30.

[5] Dietzenbacher, Los (2002); Leoncini, Montresor (2003); Świeczewska (2007).

[6] R&D expenditures are a stream allowing the amount of knowledge stock in the economy to be estimated. A typical proxy of the economy's knowledge stock is the amount of cumulative R&D expenditures calculated allowing for the appropriate rate of depreciation. More on this subject in Świeczewska (2007) and Welfe (Ed.), (2009).

[7] Research and development activity (R&D) is defined as systematic creative process conducted to increase the stock of knowledge (…) and to find new applications for it.

[8] The matrices are constructed with symmetric input-output tables that in the case of Polish economy are available as product-by-product tables.

[9] Przybyliński (2012).

[10] Miller, Blair (2009).

[11] Industry's capacity for innovation is meant as its capability to create and implement novel solutions. It is directly dependent on the industry's stock of knowledge. In the introduction to this article, strong R&D activity is mentioned as a major factor stimulating the creation of new knowledge.

[12] Dietzenbacher, Los (2000, 2002); Belegri-Roboli, Michaelides (2005); Gurgul (2007).

[13] Düring, Schnalbal (2000); Dietzenbacher, Los (2000, 2002); Leoncini, Montresor (2003).

[14] Aggregation was necessary because the originally published tables (59 × 59) had zero rows and columns, which prevented the determination of the Leontief inverse matrix. Its result was a 54 × 54 group of products.

[15] Only the supply and use tables by product and industry are published for later years, which are used to construct symmetric input-output tables comparable with those employed in this analysis.

[16] To make the multiplier values obtained from formula (5) more understandable they were multiplied by 100.

[17] According to the 2005 ranking.

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