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The role of innovation in the Polish economy's efficiency growth: a sectoral view

1. Introduction

The paper presents results of empirical investigation concerning impacts of innovation on changes in total factor productivity (TFP) in the Polish economy at the sectoral (industry) level, taking into account the effects of inter-industry, as well as inter-country diffusion of innovation. An attempt was made to answer the question, to what extent the efficiency of the Polish industries (measured by TFP changes) is driven by their innovation potential (measured by the industry's R&D expenditure intensity), and to what extent it results from diffusion of innovation from other industries and from abroad.

The analysis was based on econometric models estimated using time-series of cross-section data for the years 1993-2005, characterizing TFP growth rates in the Polish economy by NACE sections and – in the case of manufacturing – by divisions. Accounting for innovation diffusion effects required the construction of appropriate measures, characterizing potential benefits from diffusion processes – for each section/division. In the case of domestic innovation, the measures are based on input-output methodology, thus assuming that it is intermediate flows that are carriers of innovation among industries. As far as the diffusion from abroad is concerned, imports of a particular industry, as well as foreign direct investment were assumed to be innovation carriers.

2. Total factor productivity as a measure of efficiency

Total factor productivity (TFP) is one of the measures used in assessment of economic efficiency, in the context of broadly understood technical progress (Griliches, 1995; Coe & Helpman, 1995; Welfe, 2001). It represents output per unit of a combination of production factors. In a dynamic view an increase of total factor productivity represents that part of output growth which does not result from the growth of production factors. Therefore, the rate of growth of TFP (*tfp_gr*) equals:

$$tfp\_gr_t = Y\_gr_t - \sum_{i=1}^{n} w_{it}(X_i\_gr_t) \qquad (1)$$

where:

tfp_gr_t - rate of growth of TFP in period *t;*

Y_gr_t - rate of growth of output in period *t*;

$X_i\_gr_t$ - rate of growth of the i-th factor of production in period *t*;

w_{it} - weight of the i-th factor in output growth in period *t*.

The weights (w_i) are either the shares of respective factors of production in output or the elasticities of output with respect to the i-th production factor. Assuming the weights to be the shares of production factors in output, index methods can be used to assess rates of growth of TFP (usually the Törnquist index is used – Griliches, Jorgenson, 1967; Gullickson 1995). The other approach requires the use of production function (usually of the neoclassical, Cobb-Douglas form, with constant returns to scale – Welfe, 2001; Tokarski, Roszkowska & Gajewski, 2005, Świeczewska, 2007) whose estimated (or calibrated) parameters are used to determine elasticities of output with respect to each factor of production.

In this article the estimation of TFP was based on index methods (the Törnquist index). Gross output was assumed as a measure of production of each industry[1], thus including intermediate inputs of raw materials into the list of production factors. Average shares of respective factors in gross output are the weights. Estimates of rates of growth of TFP in individual industries are presented in the following table:

[1] Estimates of TFP rate of growth for the economy as a whole was based on value added dynamics, taking into account only the primary factors of production (employment and capital stock - the latter measured by gross fixed assets).

Table 1. Average rates of growth of TFP in Poland, 1993-2005 and sub-periods, by NACE sections and divisions.

	1993-2005	1993-96	1997-99	2000-02	2003-05
	%				
TOTAL	**1.4**	**1.5**	**1.3**	**1.8**	**2.2**
Agriculture, hunting and forestry	1.4	0.1	0.9	0.5	4.4
Fishing	0.9	-3.6	2.7	6.2	2.3
Industry	2.0	3.0	2.1	1.2	1.3
Mining and quarrying	1.5	3.1	1.7	-0.3	-0.1
Manufacturing	2.1	3.1	2.5	1.2	1.3
manufacture of food products	1.3	1.9	2.0	0.6	1.2
manufacture of tobacco products	-1.2	-0.8	-4.4	1.3	1.4
manufacture of textiles	2.2	3.8	3.6	1.6	1.1
manufacture of wearing and fur products	1.7	4.8	1.2	-1.4	-1.5
manufacture of leather and leather products	0.3	4.9	0.3	-1.3	-2.6
manufacture of wood and wood products	0.6	0.1	0.0	0.3	0.7
manufacture of paper and paper products	1.8	0.8	4.7	0.9	0.8
publishing and printing	0.8	5.9	0.9	-3.1	-2.5
manufacture of coke and refined petroleum products	-0.1	3.2	-3.7	-3.0	-3.8
manufacture of chemicals and chemical products	1.5	1.3	2.0	0.7	1.3
manufacture of rubber and plastic products	2.9	3.0	5.4	1.0	2.0
manufacture of other non-metallic and other mineral products	4.5	3.7	3.8	8.5	2.8
manufacture of basic metals	0.9	1.8	1.2	1.3	0.5
manufacture of fabricated metals	3.6	3.6	3.3	3.9	3.5
manufacture of machinery and equipment	4.2	5.8	3.2	2.4	4.3
manufacture of office machinery and computers	10.1	17.3	15.0	2.7	9.4
manufacture of electrical equipment	2.9	3.2	3.9	3.2	3.9
manufacture of radio, television and communication equipment	5.1	12.7	3.6	-0.6	1.8
manufacture of medical, precision and optical instruments, watches and clocks	3.5	8.7	7.8	-2.6	2.3
manufacture of motor vehicles	2.4	2.4	0.7	2.7	2.8
manufacture of other transport equipment	0.6	-0.7	6.6	-2.8	-0.6
manufacture of furniture	1.7	3.3	1.1	1.5	2.2
recycling	-0.1	-2.1	5.0	-1.4	4.4
Electricity, gas distribution, water supply	0.6	0.6	-0.8	0.7	1.2
Construction	0.0	1.9	0.8	-1.7	0.1
Trade and repair	-1.6	-1.5	-3.1	-0.6	-0.1
Hotels and restaurants	0.5	1.2	1.9	-1.6	0.0
Transport, storage and communication	1.7	0.5	2.6	1.9	1.3
Financial intermediation	7.3	14.5	4.5	2.0	3.0
Operation of real estate and services delivered to firms	-0.2	0.4	-2.0	0.3	0.5
Public administration and defence	-2.4	-1.4	1.0	-8.4	1.6
Education	0.9	0.6	2.4	1.0	1.5
Health care and social security	0.9	1.1	-2.6	3.6	1.8
Other services, public utilities, social and individual services	-2.9	-5.3	-3.8	-1.0	0.1

Source: Own calculations based on Central Statistical Office (CSO) data on gross output, intermediate use, fixed assets and employment, included in CSO Statistical Yearbooks 1995-2006 and Statistical Yearbooks of Industry 1996-2006.

Inspection of the above data leads to the following conclusions.

– Average annual rates of growth of TFP for the economy as a whole in the years 1993-2005 was around the level of 1.4%, with the highest being 2.2% in the last two periods of the analyzed time-span (2003-2005). It seems however that the rates of growth in the last subperiod are substantially overestimated. The reason here might be the overestimated TFP growth rate in agriculture (4.4% in the years 2003-2005), resulting from a change in the way of calculating employment in that sector by the CSO, all the more since rates of growth of TFP in industry and services were significantly lower[2].

– The rate of growth of TFP in the industry sector (including mining and quarrying, manufacturing and energy supply) in the whole sample time-span was at the level of approximately 2% annually, the highest rates being observed in the nineties. It was caused by fast development of that sector, arising from – on the one hand – considerable investment activity of industry (average annual rate of growth of investment outlays in 1993-1998 was 13.3%), as well as by the increasing inflow of foreign direct investment (according to the Polish Information and Foreign Investment Agency – PAIiIZ – the average annual rate of FDI growth in industry reached 50% in 1994-1998) [3]. The slowdown of the rate of economic growth observed after 1999 resulted in the slowdown of TFP growth rates to 1.2% (in the years 2000-2002). The acceleration after 2003 lead to a slight increase of TFP growth rate to 1.3% in 2003-2005.

– Similar dynamics characterized the manufacturing sector, whose share in industry exceeds 80%. Rate of growth of TFP in other industrial sectors, i.e. mining and quarrying, and supply of electricity, gas and water, was significantly lower, and in some sub-periods plainly negative (meaning that output grew slower than factor inputs).

– Among the manufacturing industries, the highest TFP growth rates were found for high- and mid-technology industries, such as manufacture of office machinery and computers (average annual rate of TFP growth was 10.1%, the highest being in the nineties), manufacture of radio, television and communication equipment (5.1% annually, with the highest being in the years 1993-1996), manufacture of machinery and equipment (4.2% annually), and manufacture of medical, precision and optical instruments, watches and clocks (3.5% annually). The mentioned industries attracted foreign investors, particularly in the years 1993-1996 (according to PAIiIZ the share of FDI flow into those industries was 15%-26% of total FDI in the industry as a whole). Moreover, in the case of manufacture of machinery and

[2] The share of agriculture in the Polish economy is still significant. That sector contributes to over 4% of GDP, the employment being over 20% of the total number of employed in the economy. Estimation of TFP growth rates was based on CSO data, according to which the number of employed in agriculture fell by over a half in 2003 compared to the previous year. That was not actually the decrease in employment, but the change in methodology of its estimation for agriculture. Since 2002 that estimate excludes persons working on farms of area below 1 hectare, producing exclusively or mainly for their needs. Thus, the share of employed in agriculture in the total number of employed decreased from 28% (in 2002) by over 10 percentage points, significantly increasing the rate of growth of TFP.

[3] The PAIiIZ data concerns only the FDI of values over USD 1 mln.

equipment one could observe relatively high (compared to other manufacturing industries) outlays on innovation activity. Also the manufacture of "other non-metallic" products deserves notice, with its 4.5% average annual TFP growth rate, the highest rates being observed in 2000-2002. In this case the efficiency growth can be attributed to the intensified inflow of FDI since 1998.

– Rates of growth of TFP in other manufacturing industries never reached 4%, the lowest (or even negative) appearing in material- and labour-intensive branches, even though some of those branches recorded high expenditures on innovation activity (manufacture of food products and beverages, manufacture of paper and paper products).

– Rates of TFP growth in the service sector were considerably lower than in the industrial branches, which is partly due to the specific character of part of their products. The highest rate was reported for financial intermediation (7.3% across the whole investigated time-span, with the highest rates being in 1993-1996) and for transport, storage and communication services (1.7% annually, the highest being in the years 1997-1999). High efficiency of those sectors might have resulted from substantial FDI inflows, as well as active investment in the nineties.

3. Impact of innovation on the efficiency of the economy: methodological aspects

The basic tool used in assessment of innovation impact on the efficiency of the economy is an extended production function (usually of the Cobb-Douglas type) in which – apart from primary factors of production – knowledge-capital stock is included, usually being represented by cumulative R&D expenditures (Clark, Griliches, 1982; Griliches, 1995). This relationship can be written as:

$$Y_t = TFP_t \cdot F(RDC_t, K_t, L_t), \qquad (2)$$

where:

Y_t - volume of output in period *t*;

TFP_t - total factor productivity in period *t*;

RDC_t - volume of cumulative R&D outlays in period *t*;

K_t - capital stock;

L_t - labour force.

Differentiating relationship (2) with respect to time and dividing both sides by Y_t leads – after simple transformations – to determining the rate of growth of TFP as a function of cumulative R&D expenditures growth rate (RDC_gr_t):

$$TFP\_gr_t = \lambda + \gamma \cdot RDC\_gr_t \qquad (3)$$

or, alternatively (assuming that the rate of depreciation of cumulative R&D expenditures is close to zero), as a function of R&D outlays intensity (measured as the share of R&D expenditures, *RDexpend*, in output):

$$TFP\_gr_t = \lambda + \mu \frac{RD_t}{Y_t} \qquad (4)$$

The above relationship is the departure point for analyses concerning the influence of innovations on the efficiency of the Polish economy.

One of the most important features of innovations is their ability to spread among economic agents. The diffusion process can come into effect through transactions connected with purchases of diverse products (intermediate, investment or consumption goods), new technology – in the form of licenses and rights to apply them, as well as through introduction of similar technological solutions based on common knowledge (Griliches, 1979). It can take place both within an economy and at the inter-country level. Accounting for innovation diffusion in empirical studies requires development of a measure representing benefits from the diffusion processes. It is usually assumed that the scale of those benefits is proportional to knowledge stock (usually measured by current and/or cumulative R&D expenditures) in all possible sources from which diffusion ensues, i.e.:

$$RDspill_j = \sum_{i \neq j} v_{ij} RD_i \qquad (5)$$

where:

$RDspill_j$ - potential R&D outlays in industry *j*, stemming from diffusion of innovation from source *i* (industry *i*);

RD_i - R&D expenditures in the sources, from which innovation transfer ensues;

v_{ij} - proportionality coefficients (weights).

In this article it was assumed that benefits from diffusion processes for a given industry are proportional to R&D outlays intensity (the ratio of R&D outlays to gross output) in those branches from which the transfer of innovation ensues, i.e.:

$$\overline{RDspill_j} = \sum_{i \neq j} v_{ij} \frac{RD_i}{Y_i}, \tag{6}$$

where Y_i - gross output of the *i* industry.

If the transfer of innovations is realised through formal transactions among industries (and thus applies to the embodied innovations) the weights v_{ij} based on transaction values. The transactions may relate to investment goods as well as intermediate goods and patents. In the case of research on inter-sectoral diffusion of innovation within an economy, it is essential to have available the data on investment goods flows between suppliers and purchasers (Terleckyj, 1974, Sveikauskas, 1981; Sterlacchini, 1989), as well as data on raw material flows (Brown, Conrad, 1967; Wolff & Nadiri, 1993; Wolff, 1997; Dietzenbacher, 2000). As far as inter-country innovation transfer is concerned, the crucial role is played by imports from particular economies (especially the investment imports – Coe, Helpman, 1995), foreign direct investment (Lichtenberg, van Pottelsberghe de la Potterie, 1996), and foreign patent flows (Jaffe, Trajtenberg, 1999). In the case of common knowledge (diffusion of intangible innovation assets), the volume of transfer depends on the tightness of technological links between suppliers and receivers. Such technological proximity can be connected for example with similarities of innovation activities (Goto, Suzuki, 1989; Jaffe, 1986; Verspagen 1997).

In the paper we attempt at estimating benefits from inter-industry diffusion of innovation through intermediate inputs. It was not possible to take into account the flows of investment goods, as carriers of innovation embodied in respective industries' products, because of the unavailability of matrices of investment goods flows. Input-output approach was used in the analysis. In the simplest case it was assumed that innovations "produced" in a given industry and transferred to other industries are proportional to intermediate flows, characterized by input-output coefficients (direct input coefficients - usually denoted by a_{ij}, representing values of materials originating from industry *i* necessary to produce a unit of gross output in industry *j*. They were treated as weights in determining a given industry's benefits from inter-sectoral diffusion processes.

The point of input-output models is to follow indirect links between industries. They are characterized by means of multipliers (elements of the "Leontief inverse" matrix $(\mathbf{I}-\mathbf{A})^{-1}$, where $A=[a_{ij}]$ is the matrix of direct input coefficients). It was noticed by Momigliano and Siniscalaco (1982), who proposed using Leontief inverse components as weights measuring advantages of innovation diffusion.

A more developed methodology of investigating inter-sectoral diffusion of innovation in the input-output framework – also making use of input-output multipliers – was proposed by Dietzenbacher (2000). An undoubted advantage of the Dietzenbacher's method is the distinction between diffusion of process and product innovations. Theoretical considerations led the mentioned author to define measures of impact of both process and product innovation diffusion. Those measures were, among others, used as weights in the assessment of benefits of inter-industry diffusion of domestic innovations in the Polish economy (Świeczewska, Tomaszewicz, 2007). They were not, however, satisfactory as far as explanation of TFP growth rates (by industry) is concerned. Eventually, the direct input coefficients a_{ij} were assumed as weights thereinafter.

Regarding foreign innovation transfer it was assumed that their main carrier is imports into a given sector, as well as foreign direct investments. On the basis of data on import structure for respective industrial branches (imports from selected OECD countries are concerned[4]) appropriate weights – essential to determination of innovation transfer benefits – were estimated. Though being an important carrier, FDI in industrial branches were not taken into account, by reason of lack of open-accessible and comparable data at the level of NACE divisions[5]. Some approximate data obtained by the authors require evaluation and were not used in this study. For the service sector the potential advantages of innovation transfer were approximated by FDI intensity in a given period (FDI inflow per unit of sector's gross output). Poland's six greatest foreign trade partners (of the most developed economies) were considered, i.e. Germany, France, Netherlands, Italy, Great Britain and the U.S.A.

Despite the unavailability of data on investment imports made by particular industries, an attempt was made to account for this foreign innovation carrier. Based on import structures of

[4] The relevant data come from the OECD Bilateral Trade Database (BTM) – they show imports of products of different foreign industry branches made by individual industry branches in Poland.
[5] The main source of FDI data used in this study is PAIiIZ. However, in 2004 the Agency abandoned publishing FDI figures by industries.

industries being the suppliers of investment goods[6], potential advantages from the transfer of innovation embodied in such products were estimated for each of the industry divisions.

4. Impact of innovation on the efficiency of the economy – empirical results

The estimates of innovations impact on the Polish economy's efficiency are based on the model (4), in which intensity of innovation outlays in each industry was decomposed into intensity of innovation expenditures borne by the industry itself, benefits resulting from inter-sectoral diffusion of innovation through raw material flows, and advantages from innovation diffusion coming from abroad. Thus, model (4) takes the following form:

$$TFP\_gr_{jt} = \lambda + \mu_1 \frac{RD_{jt}}{Y_{jt}} + \mu_2 \overline{RDspill_{jt}}^{(domestic)} + \mu_2 \overline{RDspill_{jt}}^{(foreign)} + \varepsilon_{jt} \qquad (7)$$

where:

TFP_gr_{jt} - rate of growth of TFP in industry *j*, period *t*;

$\frac{RD_{jt}}{Y_j}$ - intensity of R&D expenditures made by industry *j* in period *t*;

$\overline{RDspill_{jt}}^{(domestic)}$ - benefits for industry *j* in period *t* from intersectoral diffusion of innovations;

$\overline{RDspill_{jt}}^{(foreign)}$ - benefits for industry *j* in period *t* from diffusion of innovations coming from abroad;

ε_{jt} - error term.

Model (7) or, precisely speaking, its different variants, were estimated on the basis of time series of cross-section data, including 32 industries (NACE divisions for manufacturing, NACE sections elsewhere) for the following years: 1993-96, 1997-99, 2000-02, 2003-05. Such a time-aggregation was applied, as annual data on TFP changes in particular industries show significant fluctuations, reflecting demand-supply shocks rather than actual changes of production efficiency. In all tested model variants, dummy variables were introduced for chosen industries and periods. The results are shown in table 2.

[6] It boils down to such industries as manufacture of machinery and equipment, manufacture of office machinery and computers, manufacture of electrical equipment, manufacture of radio, television and communication equipment.

Table 2. Estimation results for model (7)

Variables	Estimates (t-value in brackets)			
	I	II	III	IV
Constant	-0.07 (-1.32)	0.02 (0.64)	0.05 (0.92)	0.03 (0.91)
$\frac{RDexpend_{jt}}{Y_j}$	**0.14 (1.92)***	**0.14 (1.92)***	**0.17 (1.81)***	**0.17 (2.45)****
$\overline{RDspill}_{jt}^{(domestic)}$		0.39 (1.33)	0.40 (1.40)	
$\overline{RDspill}_{jt}^{(foreign)}$	**0.18 (3.20)*****	**0.17 (3.06)*****	**0.29 (3.71)*****	**0.30 (3.88)*****
Dummy for industries	yes	yes	yes	yes
Dummy for periods	yes	yes	yes	yes
R^2 adjusted	0.47	0.48	0.51	0.49
No. of observations	128			

Source: own calculations; * - statistically significant at the level of 0.1; ** - statistically significant at the level of 0.05; *** - statistically significant at the level of 0.01.

Channels of innovations diffusion in different variants of the model: (I) – diffusion of innovations from abroad *via* imports and FDI, (II) – domestic diffusions of innovations through raw material flows, diffusion of innovations from abroad *via* imports and FDI, (III) – domestic diffusion of innovations through raw material flows, diffusion of innovations from abroad *via* investment imports and FDI, (IV) - diffusion of innovations from abroad *via* imports and FDI.

The conclusions from the parameter estimates of model (7) are the following:

Firstly, in all tested variants the industry R&D outlays parameters have proven to be positive and statistically significant. The 1 pp. growth of domestic R&D expenditure intensity in a given industry resulted in 0.14-0.17 pp. increase of TFP growth rate, on average.

Secondly. In all variants of the model the effects of innovations diffusion from abroad were positive and statistically significant, both for diffusion *via* imports (total as well as investment imports) and *via* FDI. In the light of these results it can be concluded that innovation diffusion from abroad invokes TFP growth rate increase by, on average, 0.17-0.30 pp., the impact obviously being stronger with investment imports (machinery and equipment) as the diffusion channel.

Thirdly. The effects of domestic innovations spreading through inter-industry raw material flows turned out to be positive, though not significant.

5. Conclusions

The study hereby was focused on as carriers of innovation in the diffusion process, which in the case of domestic diffusion were intermediate inputs. It did not account for investment good flows, as well as another important carrier – the foreign direct investment in industries. In both cases the lack of appropriate statistical data was the reason. The authors hope that self-estimated data will shed some more light on innovation sources in the Polish economy. So far the investigation indicates that the role of foreign sources is particularly important, as the 1 percentage point growth of R&D expenditure intensity in the countries being Poland's main import suppliers increases the efficiency of the Polish economy more (0.17-0.30 pp. increase of TFP growth rate) than the analogous growth of domestic R&D expenditure intensity (0.14-0.17 pp.). Apart from the already mentioned enhacement of the list of innovation diffusion carriers (flows of investment goods, FDI by industry) and investigation of their impact on efficiency increase of the Polish industries, the authors have started research on application of alternative methods allowing to determine paths of inter-sectoral diffusion of innovation.

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