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Analysis of the impact of export specialisation and investment attractiveness on the processes of innovation diffusion in the processing industry in Poland

Marcin Salamaga

Department of Statistics, Krakow University of Economics, Poland

e-mail: salamaga@uek.krakow.pl

ORCID: 0000-0003-0225-6651

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Abstract: The fundamental ways of building innovativeness of the economy are the creation and diffusion of innovation, the latter of which is the dispersal of new technological, organizational, marketing solutions as well as knowledge among imitator enterprises, and copycats (the 'spillover effect'). Important determinants of innovation diffusion include the inflow of foreign capital (in the form of FDI) and foreign trade. Few empirical studies exist that attempt to explain the sources of innovation diffusion in the Polish economy applying quantitative tools used in contemporary statistics and econometrics. The existing research gap makes it difficult to reliably assess the actual cause-and-effect relationships between spillover processes and macroeconomic variables. This article sought to determine the nature and strength of the impact of investment specialisation (and investment attractiveness) as well as industry export specialisation on the phenomenon of penetration of innovation in the Polish processing industry. The occurrence of innovation diffusion and its dynamics were investigated using the logistic function econometric model. To study the impact of the specialisation, according to FDI located in Poland, and specialization of export on the process of innovation diffusion, dynamic models of error correction estimated for selected industrial processing industries were used. The obtained results allowed to answer the questions: in which industries has innovation diffusion occurred, in which was it the fastest, and to what extent was it the effect of investment attractiveness, and to what degree of the export specialization of the industry?

Keywords: ECM, RCA, FDI, innovation diffusion, Poland

1. Introduction

Innovation and the knowledge-based economy are today key categories that determine economic development and its pace. Innovation is the driving force behind modern economies and their ability to compete on a macro and microeconomic scale. Diffusion is one of the fundamental ways to implement innovation, along with its creation. This term can be understood as "the dissemination of innovation through market and non-market channels, starting with the first implementation anywhere in the world to other countries and regions and to other markets and companies" (Oslo Manual, 2006). Therefore, it is the spread of new technological, organizational, marketing solutions as well as knowledge among imitator enterprises, and copycats. An important element of the diffusion of innovation, in addition to technology, is information about innovation that is disseminated in the form of knowledge, whose flow can be a feedback loop: companies acquiring knowledge and technologies can themselves subject innovations to subsequent modifications and provide information about these modifications to the original innovator. Rogers (1983) distinguished four components that ensure the diffusion process: innovation (the object of diffusion), communication channels (allowing the transfer of knowledge), the time counted from the moment information about innovation appears until its diffusion is launched (one can also consider the time of innovation adaptation; the time of spread of innovation among the final recipients) and the social system, on which the rate of absorption of innovation depends. An important feature of innovation diffusion is the variable rate of innovation spread, which usually follows an S-shaped curve (e.g. a logistic curve), which means that the diffusion rate in its initial phase is slow, then increases more than proportionally and in the final phase decreases again. The logistic curve is one of the mostly implemented tools in the study of diffusion. Other approaches and models are also used, such as the Bass model (1969), the Rogers model (1983), the wave and the hierarchical models (Morrill, 1975), the source, the contact and the source-contact models (Kot et al., 1993), the Lotka and the Fisher-Pry model (Fisher and Pry, 1971). Over time, some models have undergone further modifications, e.g. in terms of introducing marketing variables (Robinson and Lakhani, 1975), and the generalisation of models for different stages of diffusion in different countries (Gatignon et al., 1989). Innovation diffusion occurs in both developed and developing economies and is the subject of numerous empirical analyses. Diffusion testing usually concerns selected products, services or the market. While international literature does not lack the results of research on innovation diffusion utilising the aforementioned models, research on innovation diffusion in the Polish economy using econometric tools is rare (Kolarz, 2006). The existing research gap in this area makes it difficult to reliably assess the actual cause-and-effect relationships between spillover processes and macroeconomic variables in Poland. This article tried to fill this gap to some extent.

The main objective of the study was to assess the size and rate of diffusion of innovation in the processing industry, as well as to determine the nature and strength of the impact of investment specialisation (and investment attractiveness), and industry export specialisation on this phenomenon. The objective of confirming the diffusion of innovation was achieved with the help of a logistic function, whilst to study the impact of Poland's investment attractiveness and its export specialisation on the process of innovation diffusion, dynamic error correction models (ECM) were used, which were estimated for industrial processing industries with various levels of technological development (the level of technology utilised in their operations). Thanks to this research approach, it was possible to determine in which industries innovation diffusion occurred, what was its dynamics in various industries, and to what extent the effect of investment attractiveness contributed to it, and to what degree the export specialisation.

2. Literature review

Researcher interest in the phenomenon of innovation diffusion is due to its notable role in the technological progress of many economies. Diffusion effects are seen when the majority of potential buyers implement a specific product or technology. As emphasised by Kolarz (2006), Janasz and Leśkiewicz (1995), the success of implementing innovation through diffusion requires the fulfilment of several postulates:

- the implementation of innovation should result in specific benefits for its recipients,
- innovation should be consistent with a recognised consumer value system,
- innovation should not be excessively complex,
- the results of innovation should encourage rapid imitation.

The guarantee of the success of an innovation with the above properties is, of course, its acceptance by individual imitators. Henzel (1991) showed that the adaptation of innovation by diffusion involves several successive stages: awareness (acquisition of general knowledge about the existence of innovation), interest (gathering additional information about innovation), valuation (assessment of the benefits and losses resulting from the possible application of innovation) and assimilation (adoption and implementation of innovation). Many studies provide evidence to support the claim that innovation diffusion can reduce the technological gap between companies implementing innovations and more technologically advanced enterprises. In the technological gap theory (Gerschenkron, 1962), innovation diffusion is perceived as an important factor that offers the possibility of copying and imitating the solutions of innovation leaders. This, in turn, reduces the burden of expenditure on innovation, compared to the innovation leaders. As a result, thanks to diffusion of innovation, countries that lag technologically can reap greater benefits – the greater the gap between the catching-up country and the innovation pioneer, the greater the scale of these benefits. The positive effects of innovation diffusion in the situation of a technological gap were confirmed in research by authors such as Meyer and Sinani (2009). Some researchers point to moderate effects of innovation diffusion when local companies do not have adequate absorption capacity, and an adequate level of learning ability. Teece (1977) showed that a large technological distance between countries or entities limits the transfer and diffusion of innovation, because it does not allow local companies to apply the right technology and, as a result, prevents productivity improvements. His research proved that the beneficiaries of innovation must have a certain minimum level of technological development that will allow them to participate in and benefit from the process of innovation diffusion. Similar results were obtained by Stiglitz (1994) in researching Far East markets, which showed that the diffusion rate depends on the ability to learn: technologically backward countries tend to have low absorption capacity, hence they may not be able to take advantage of all the opportunities offered by innovation diffusion. Stiglitz also proved that the effectiveness of catching-up with innovation leaders requires imitating countries to have a rate of knowledge accumulation that is higher than the rate of technological gap reduction. In the study of innovation diffusion, modelling using an S-shaped curve is quite often used. This shape is justified by confirmed hypotheses about population dynamics (Bass, 1969) and population heterogeneity. Rogers (1962) suggested that populations are heterogeneous in their propensity to innovate, and identified the different groups of actors involved in the innovation diffusion process (innovators, early followers, early and late majorities, and stragglers) and defined their percentage structure, indicating the phases of the process in which they participate. Rogers argued that the shape of the S-curve results from the successive thresholds of innovation absorption achieved by subsequent actors involved in this process. Some researchers link innovation diffusion to the distribution of income among the public. Bass and Russell (1980) showed that, if the distribution of income is close to the normal curve and the price of innovation decreases systematically, then the innovation diffusion curve is S-shaped. The importance of the cost of innovation and the income of society in the context of innovation diffusion was also studied by Bass and Bultez (1982), Kalish (1985), and Horsky (1990). Many studies emphasised that, in order to successfully launch the innovation process, it is necessary to reach an appropriate critical mass – a stage in which a sufficient number of entities exist that are open to new solutions and ready to accept them (Rogers, 1995; Mahler and Rogers, 1999). Other studies show that the success of innovation diffusion is conditioned by the interdependence between certain technologies; Bayus (1987) studied this issue in connection with a compact disc and the hardware needed to play it, whilst Teng et al. (2002) examined the diffusion of 25 information technologies using the Bass model and showed that the main driver of innovation diffusion was the so-called 'external imitation', and that the internal impact was insignificant. Among the numerous factors determining innovation diffusion, population heterogeneity resulting from socio-economic diversity was mentioned. Wareham et al. (2004) showed that the spread of mobile phones and mobile Internet are positively correlated with population income and occupations, also noting that some ethnic groups accepted mobile phones more readily than others. The impact of the geographic location factor (e.g. regional diversity) on the scale and speed of innovation were also investigated. The influence of such a factor on the market for microprocessors and digital machines in the UK was confirmed by Baptista (2000). In Poland, research on the innovation process in domestic enterprises without the participation of foreign capital and in companies with such participation was carried out by, among others, Weresa (2002) and Kolarz (2006). Research in the field of innovation diffusion in Poland can be found in the works of Klimcewicz (2011), Firlej and Żmija (2014), Wiśniewska (2004), Gwarda-Gruszczyńska (2017). While empirical studies of the process of innovation diffusion in international literature have been carried out for years with an approach employing econometric models, such as the Bass model (Van den Bulte and Stremersch 2004; Teng et al., 2002), the logistics model (Desiraju et al., 2004; Sharif and Kabir, 1976) or the Gompertz model (Bemmaor, 1994; Bemmaor and Lee, 2002), however the use of such tools in Polish literature is not frequent (Kolarz 2006). Meanwhile, the aforementioned models are already the standard in international mainstream research of innovation diffusion and allow not only to assess the actual cause-and-effect relationships between spillover processes and macroeconomic variables, but also to forecast the diffusion of innovation itself. The existing research niche in this area creates opportunities for in-depth analyses. This study focused on the proliferation of portable electronic devices allowing for mobile Internet access, with which employers in processing industry equip their employees. The analysis centred not only on the process of innovation diffusion (separately for enterprises with domestic capital and for companies with foreign capital), but also the impact of investment attractiveness and industry export specialisation on this phenomenon. In the modelling of innovation diffusion a logistic function was used, and the obtained results were then used in the construction of dynamic error correction models, which were estimated for processing industries with different levels of technological development.

3. Research methodology

In research on innovation diffusion, the use of S-shape curve generating models is common (Desiraju et al., 2004; Sharif and Kabir, 1976). Its course properly reflects the varying rate of innovation diffusion: the innovation process is first characterised by a slow and less than proportional growth rate, then this rate increases and growth becomes faster than the proportional growth rate, and then, in the final period, this rate decreases until it expires. The article applied this model for that very reason. The logistic curve is a special case of the more general family of S-shaped curves described by the Richards function (Richards, 1959; Lei and Zhang, 2004):

$$y(t) = \delta + \frac{\alpha - \delta}{(\theta + \beta exp(-\gamma t))^{\frac{1}{v}}}, \quad (1)$$

where t – time variable, α, β, γ, δ, ϑ, v – parameters of the Richards function.

The γ parameter expresses the growth rate, v is the growth parameter with the maximum asymptote, while the α and δ parameters represent the upper and lower asymptotes of the Richards function, respectively.

Assuming that $\delta = 0$, $\vartheta = v = 1$, one obtains a logistic function (2) that was used to model innovation diffusion in this article.

$$y(t) = \frac{\alpha}{1 + \beta exp(-\gamma t)}. \quad (2)$$

In modelling the diffusion of innovation, it is important to determine the rate of change of this process.

For the logistic function, the growth rate is expressed by the following formula:

$$GRL = \frac{dy}{dt}\frac{1}{y}(\gamma) = \gamma - y\frac{\gamma}{\alpha}. \quad (3)$$

In the course of the logistic function, one can distinguish an area in which it has an increasing growth rate and then an area where it is characterised by a decreasing growth rate heading indefinitely to the level of saturation expressed by the asymptote $y = \alpha$. The point separating the area of rapid growth rate from the area with decreasing growth rate is the inflection point with coordinates $\left(\frac{ln\beta}{\gamma}, \frac{\alpha}{2}\right)$.

One of the research objectives of this study was to determine how Poland's export competitiveness and investment attractiveness affect the dynamics of changes in the diffusion of innovation. Export competitiveness was measured using the revealed comparative advantage (RCA) indicator (Balassa, 1965), which allows for assessing the relative advantage of one country in the exports of a specific commodity group over other countries. The Balassa index can also be used to assess the competitiveness of a country's exports against reference countries (e.g. an economic grouping). The corresponding formula then takes the form:

$$RCA_i = \frac{Ex_{ij}}{Ex_j} : \frac{Ex_i^R}{Ex^R}, \quad (4)$$

where Ex_{ij} – the value of exports of i-th industry in j-th country, Ex_j – the total value of exports of j-th country, Ex_i^R– the export value of i-th industry in the reference countries, Ex^R– the total value of exports in the reference countries.

The values of indicator (4) smaller than 1 indicate the absence of a comparative advantage, and greater than 1 – the occurrence of such an advantage. Hinloopen and van Marrewijk (2001) found that RCA values between 1 and 2 indicated a weak comparative advantage, values between 2 and 4 indicated a moderate comparative advantage, and those higher than 4 – a strong comparative advantage. In this study, OECD countries were chosen as a reference group because they are generally characterised by technological development, therefore trade and investment links with such countries can create innovation (Weresa, 2022). The conducted calculations used a two-digit level of disaggregation of goods based on the Standard International Trade Classification (SITC) (Misala and Pluciński, 2000). On the basis of the construction of the RCA indicator, the indicator of revealed investment advantage was defined and calculated, which represents the area of inward FDI. As a result, it was possible to assess the investment attractiveness of the country via modelling. This indicator is given by the formula:

$$RCIA_i = \frac{FDI_{ij}}{FDI_j} : \frac{FDI_i^R}{FDI^R}, \quad (5)$$

where FDI_{ij} – the value of inward FDI stocks in i-th industry in j-th country, FDI_j – the total value of inward FDI stocks of j-th country, FDI_i^R– the value of inward FDI stocks in i-th industry in the reference countries, FDI^R– total inward FDI stocks in the reference countries.

The interpretation of the revealed comparative investment attractiveness index (RCIA) is similar to that of the classic RCA index, where values greater than 1 indicate the investment attractiveness of a country, and the smaller ones – a decrease in this attractiveness. This indicator was calculated for the reference group, namely all the countries in the world. The adoption of such a reference group was justified in this case, because the suppliers of FDI to Poland also come from non-OECD countries (Weresa, 2002). The relationships between indicators (3), (4) and (5) were investigated using the error correction model (ECM). This model for integrated time series consists of two equations:

- representing a long-term relationship (cointegrating equation):

$$lnGRL_t = \gamma_0 + \gamma_1 lnRCA_t + \gamma_2 lnRCIA_t + u_t \quad (6)$$

- representing short-term relationship with the first differences of variables:

$$d\_lnGRL_t = \alpha_0 + \alpha_1 d\_lnRCA_t + \alpha_2 d\_lnRCIA_t + \alpha_2 ECM_{t-1} + \varepsilon_t \quad (7)$$

If autocorrelation occurred in model (7), it was modified into the following form:

$$\begin{aligned} d\_lnGRL_t \quad = \quad & \alpha_0 + \alpha_1 d\_lnRCA_t + \alpha_2 d\_lnRCIA_t + \alpha_2 ECM_{t-1} \\ & + \sum_{i=1}^{q} \gamma_i d\_lnRCA_{t-i} + \sum_{i=1}^{S} \delta_i d\_lnRCIA_{t-i} + \eta_t \end{aligned}, \quad (8)$$

where η_t is a white noise process.

The construction of the above econometric models was preceded by the study of the internal structure of time series in terms of stationarity of the order of their integration. In the study of the stationarity of time series, the extended Dickey-Fuller test (ADF test) was used (Charemza and Deadman, 1997), while the Engle-Granger test was used regarding the time series cointegration.

4. Results of empirical research

4.1. Diffusion of innovation in the processing industry

The research on innovation diffusion was carried out based on statistical data on the number of mobile devices allowing mobile Internet access (portable computers, smartphones), with which enterprises equip their employees. Data for 2010-2021 from the Local Data Bank of the Statistics Poland were used to model logistic functions and calculate the growth rate of logistic function (GRL). Data on foreign direct investments (FDI) coming into Poland used to calculate the investment attractiveness index (RCIA) in 2010-2021, were taken from database of the National Bank of Poland, while export data used to calculate the indicator of revealed comparative advantage from Eurostat (COMEXT database). First, using the Gauss-Newton algorithm, the parameters of logistic function (2) were estimated separately for enterprises without foreign capital participation and for those with such participation. The course of the corresponding logistic curves for both types of enterprises is presented in Figure 1, and the estimation results of the parameters are presented in Table 1.

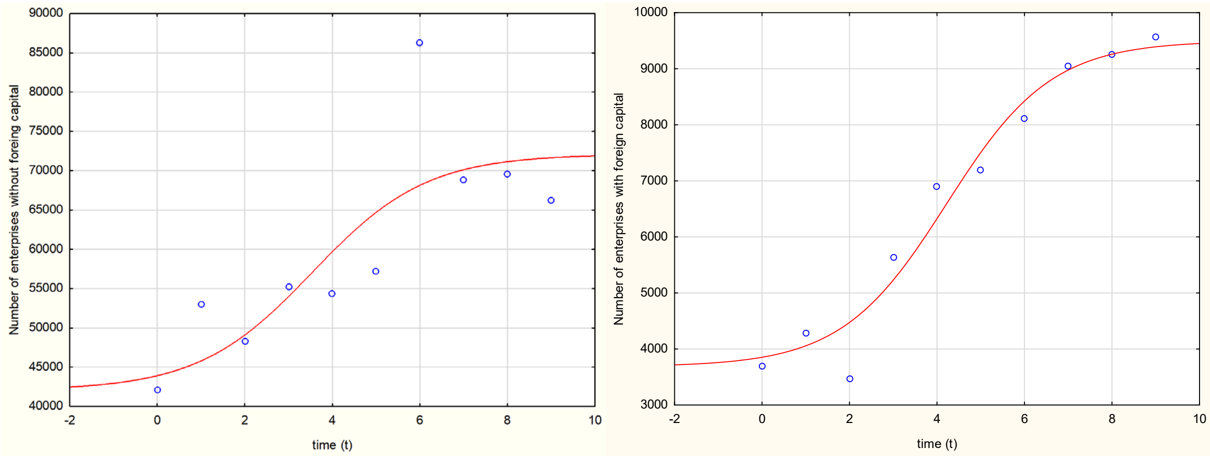

Fig. 1. The course of logistic curves for enterprises without and with the participation of foreign capital

Source: own elaboration.

Table 1. Parameters of the logistic regression function among enterprises without and with the participation of foreign capital

Enterprises	without foreign capital			with foreign capital		
Parameter	α	β	γ	α	β	γ
Coefficient	30044.801	15.164	0.767	5812.099	33.710	0.834
Standard error	6815.281	5.715	0.267	447.905	13.663	0.198
t-statistic	4.408	2.653	2.873	0.002	0.038	0.002
p-value	0.003	0.033	0.024	0.801		
R^2	0.656			0.963		

Source: authors' calculations.

In both cases, of companies operating based on domestic capital and those with foreign capital, it was possible to fit logistic functions to empirical data, which confirms the process of innovation diffusion in both groups of enterprises. The inflection point of this logistic function is 3.54 for the first group of companies and a higher value of 4.22 for the second group. This means that the phase of rapid diffusion growth in enterprises with foreign capital is longer (about 51 months) than in enterprises with domestic capital (about 42 months). Moreover, the growth rate of logistic function calculated at these points in enterprises based solely on family capital is lower (0.38) than in enterprises with foreign capital (0.42). Figure 2 illustrates the values of the logistic function growth rate in subsequent periods of time for both groups of companies. Starting from the second yearly period, they are higher for enterprises with foreign capital. It follows that such companies have a faster rate of innovation diffusion than enterprises with domestic capital and the duration of this rate is longer than in enterprises based on domestic capital.

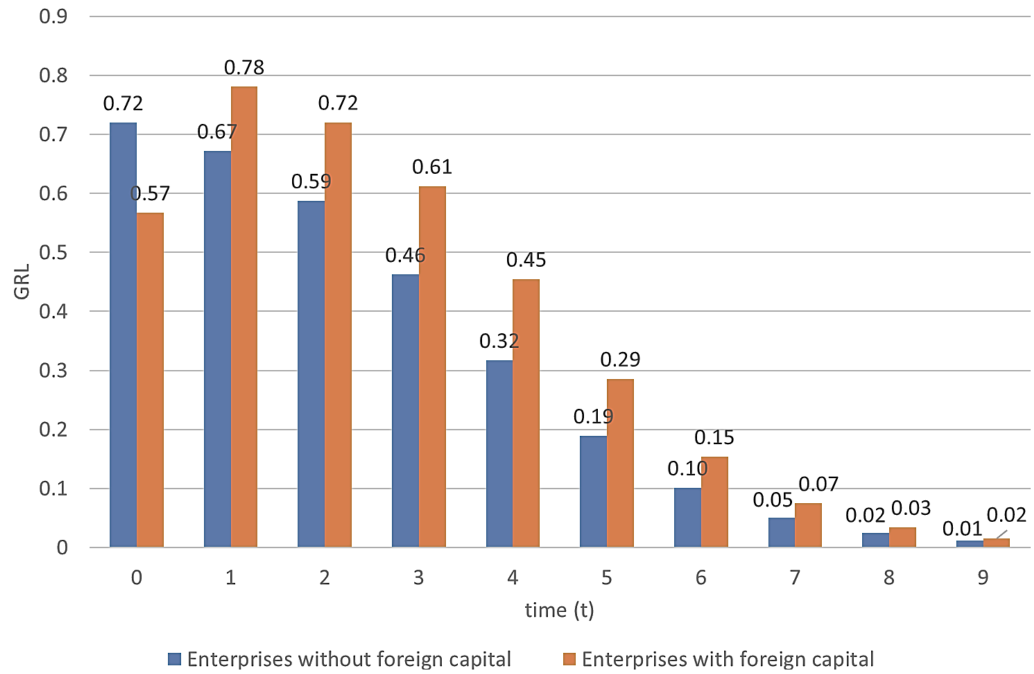

Fig. 2. Values of the logistic function growth rate for enterprises without and with foreign capital

Source: own elaboration.

Table 2 presents the estimation results of logistic regression function parameters for companies representing industries with low technologies, medium-low, medium-high and high technologies. This division of processing industries is modelled on the OECD Industry Classification (ISIC Rev. 3), which includes industries with varying degrees of knowledge intensity.

Table 2. Parameters of logistic regression function for companies from industries with different levels of technological development

Sectors	low-tech			medium-low-tech		
Parameter	α	β	γ	α	β	γ
Coefficient	1546.186	4.568	0.530	2743.454	5.713	0.558
Standard error	250.531	1.522	0.242	335.112	1.647	0.188
t-statistic	6.172	3.000	2.189	8.187	3.469	2.965
p-value	0.000	0.020	0.065	0.000	0.010	0.021
R^2	0.836				0.905	
Sectors	medium-high-tech			high-tech		
Parameter	α	β	γ	α	β	γ
Coefficient	940.663	4.649	0.708	89.098	5.247	0.459
Standard error	75.221	1.290	0,230	35.117	2.127	0.179
t-statistic	12.505	3.605	3.072	2.537	2.467	2.558
p-value	0.000	0.009	0.018	0.000	0.009	0.018
R^2	0.902			0.613		

Source: authors' calculations.

The logistic function was matched to the empirical data in each group of companies belonging to industries with different levels of technological development, thus the process of diffusion of innovation occurs in each industry considered, although with a different intensity (Figure 3). The longest-lasting phase of rapid growth of the logistic function was maintained by high-tech companies, as indicated by the highest inflection point value of 3.61 (about 43 months) compared to other industries. The shortest phase of rapid diffusion growth occurred in the medium-low technology industry, as evidenced by the lowest inflection point value of 2.17 (about 26 months) from among all industries. In the medium-high technology industry, the inflection point was 3.12 (37 months) and in the low technology industry, this was 2.87 (34 months). The highest growth rate of the GRL logistic function calculated in inflection points occurred in the medium-high technology industry (0.35), and the lowest growth rate – in the high-tech industry (0.23). In the low-tech and medium-low-tech industries, the GRL calculated in inflection points was 0.27 and 0.28, respectively. From Figure 4, it follows that in the first three periods of observation, medium-high-tech companies had the highest growth rate of innovation diffusion as measured by GRL. In the next two periods they were medium-low technology enterprises, while in subsequent periods such dynamics were characteristic of enterprises operating in high-tech industries. The lowest growth rate of innovation diffusion in the first three periods occurred in high-tech enterprises and, in subsequent periods, in enterprises operating in medium-high technology industries.

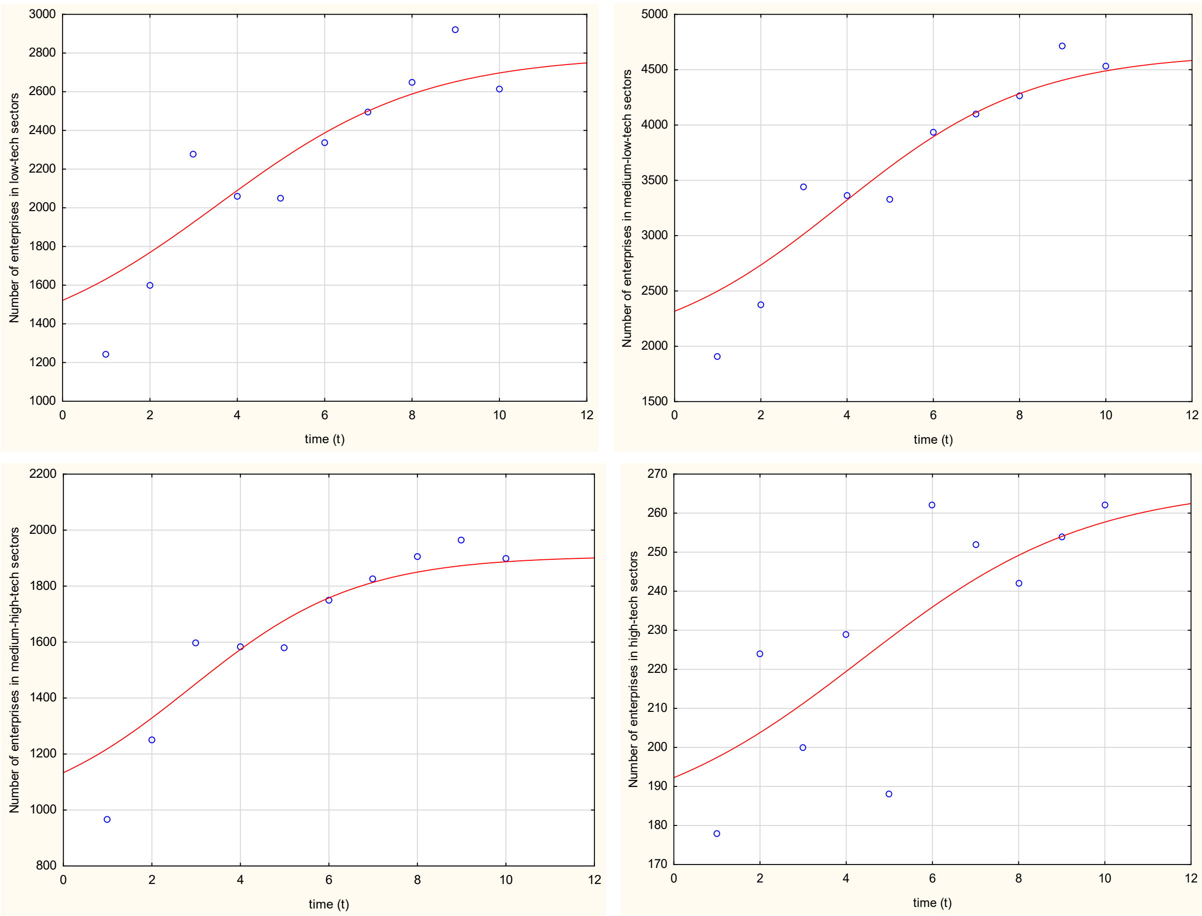

Fig. 3. The course of logistic curves for enterprises by industries utilising different levels of technology

Source: own elaboration.

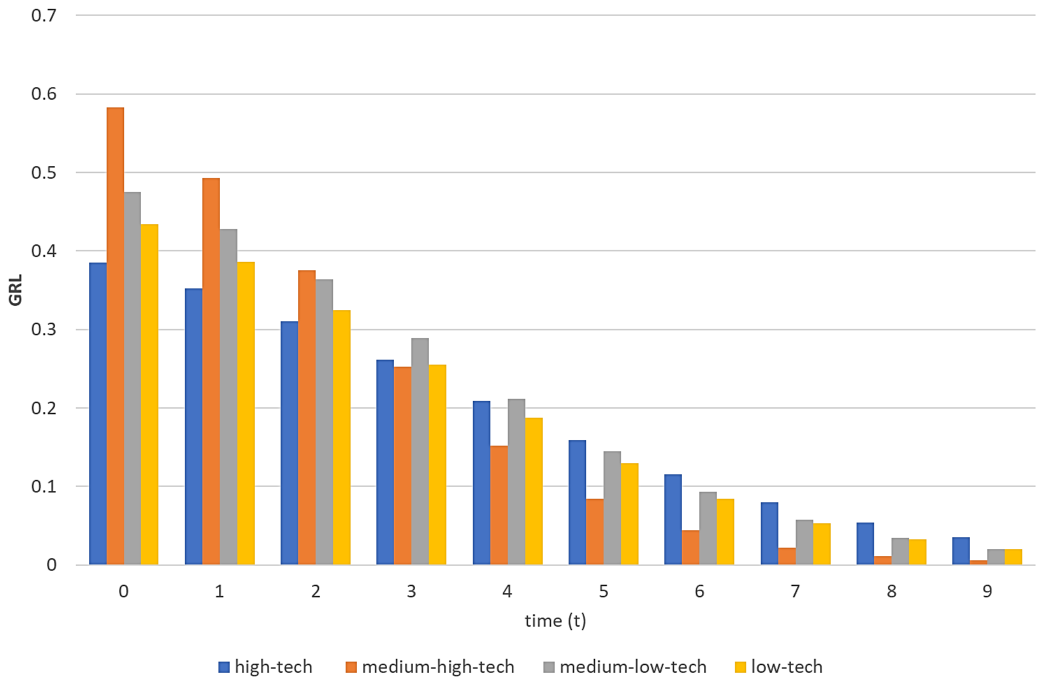

Fig. 4. Values of the growth rate of the logistic function in enterprises belonging to industries utilising different levels of technology

Source: own elaboration.

4.2. Innovation diffusion modelling

The construction of dynamic econometric models was preceded by the study of the stationarity of time series of GRL, RCA, RCIA variables using the ADF test. For the logarithmic values of these variables, their integration in grade I(1) at significance level 0.05 was confirmed, which allowed the estimation of the parameters of the relevant cointegrating equations (6). A residual-based ADF test confirmed that the residuals were integrated in degree I(0). Since the time series were integrated in the first degree, dynamic error correction models (ECMs) were estimated.

Estimation results of the parameters of the innovation diffusion rate model, which shows the long-term and short-term relationship for enterprises in Poland (in all the industries combined) are presented in Tables 3 and 4.

Table 3. Parameters of the single-equation ECM model of the rate of innovation diffusion for enterprises in Poland

Variable	Coefficient	Standard error	t-statisic	p-value
constant	-3.158	0.387	-8.163	0.001
d_lnGRL_1	1.420	0.246	5.766	0.004
d_lnRCA	0.857	0.257	3.332	0.029
d_lnRCIA	1.517	0.238	6.373	0.003
ECM_1	-0.179	0.057	-3.145	0.035
R^2	0.981			

Source: authors' calculations.

Table 4. Parameters and the cointegration equation for enterprises in Poland

Variable	Coefficient	Standard error	t-statistic	p-value
constant	-3.236	1.092	-2.963	0.018
lnRCA	1.414	0.389	3.632	0.007
lnRCIA	3.576	1.558	2.294	0.051
R^2	0.531			

Source: authors' calculations.

Based on the estimation results of the parameters contained in Table 3, it can be concluded that in manufacturing, the determinants of diffusion are both specialisation in exports and investment attractiveness, with the impact of the latter factor being almost twice as strong: an increase in Poland's investment attractiveness index by 1% implies an increase in the pace of innovation by an average of about 1.52% *ceteris paribus*, while the same increase in the export competitiveness index increases the rate of innovation by an average of 0.86%. The estimation of the error correction mechanism parameter was negative and statistically significant, which indicates the adjustment of short-term changes to the long-term balance. In terms of the long-term relationship, the positive impact of RCA and RCIA on the rate of change in innovation diffusion measured by the GRL index was also confirmed, but this time the impact of the investment attractiveness index was more than three times stronger than the export competitiveness index. Thus, foreign investment is a more effective channel for the transmission of innovation diffusion than foreign trade. This may occur because the share of techno-logically advanced goods is small – in recent years it amounted to several percent (Ambroziak et al., 2020), and the inflow of FDI to Poland is still growing and has recently been quite dynamic, despite the economic crisis caused by the COVID-19 pandemic. Data from PI&TA[1] seem to confirm that Poland benefited from the global trend of shortening supply chains due to the pandemic and continues to be an attractive country for foreign investors. Naturally, not every type of FDI and not every direction or object of investment is a transmission belt for the diffusion of innovation. For this reason, this study was supplemented by a further analysis of innovation diffusion from the perspective of industries. Tables 5 and 6 present

Table 5. Parameters of a single-equation ECM model describing the rate of innovation diffusion for enterprises belonging to industries utilising different technology levels

Low-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-0.063	0.017	-3.765	0.020
d_lnGRL_1	1.294	0.282	4.589	0.010
d_lnRCA	0.069	0.024	2.928	0.043
d_lnRCIA	0.128	0.033	3.889	0.018
ECM_1	-0.095	0.021	-4.494	0.011
R^2	0.920			
Medium-low-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-5.016	2.035	-2.465	0.069
d_lnGRL_1	1.285	0.175	7.362	0.002
d_lnRCA	1.789	0.583	3.070	0.037
d_lnRCIA	1.536	0.354	4.335	0.012
ECM_1	-0.267	0.181	-1.479	0.213
R^2	0.978			
Medium-high-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-0.181	0.033	-5.409	0.006
d_lnGRL_1	0.771	0.071	10.941	0.000
d_lnRCA	-0.086	0.021	-4.054	0.015
d_lnRCIA	3.096	0.325	9.512	0.001
ECM_1	-0.061	0.021	-2.843	0.047
R^2	0.934			
High-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-0.183	0.054	-3.427	0.027
d_lnGRL_1	0.499	1.115	0.448	0.677
d_lnRCA	-1.213	0.406	-2.987	0.040
d_lnRCIA	1.241	0.634	1.956	0.122
ECM_1	-0.093	0.024	-3.852	0.018
R^2	0.583			

Source: authors' calculations.

[1] https://www.paih.gov.pl/files/?id_plik=46159

Table 6. Parameters of the cointegrating equation for enterprises in industries with different levels of technology

Low-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-3.846	1.363	-2.821	0.022
lnRCA	2.882	1.073	2.684	0.028
lnRCIA	2.576	1.083	2.378	0.045
R^2	0.548			
Medium-low-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-7.499	0.922	-8.136	0.000
lnRCA	8.960	3.556	2.520	0.036
lnRCIA	3.726	0.742	5.021	0.001
R^2	0.935			
Medium-high-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	0.345	0.110	3.148	0.014
lnRCA	-3.484	1.083	-3.216	0.012
lnRCIA	3.828	0.908	4.215	0.003
R^2	0.416			
High-tech				
Variable	Coefficient	Standard error	t-statistic	p-value
constant	-3.866	1.411	-2.740	0.025
lnRCA	-2.761	0.890	-3.102	0.015
lnRCIA	4.381	2.856	1.534	0.164
R^2	0.680			

Source: authors' calculations.

the results of GRL modelling for companies representing industries utilising different levels of technology. Analysing the model parameters for individual industries in Table 5, in the short term, export specialisation in industries with advanced technology as well as with intermediate technology is an important distiller of the GRL index. Such a situation may mean that only an increase in the competitiveness of foreign entities (their growing comparative advantage in foreign trade) encourages companies to intensify their innovative activity and results in an increase in the rate of innovation diffusion. This is changing in industries with medium-low and low technology, where Polish export competitiveness has a positive and statistically significant impact on the rate of innovation diffusion. In turn, Poland's investment attractiveness does not significantly affect the rate of innovation diffusion in industries utilising advanced technology, while in other industries it is an important determinant for GRL variables. The impact of this indicator on the dependent variable is greatest in low-tech industries, while the impact of RCA on the rate of innovation diffusion is greatest in medium-low technology industries. It should be concluded that industries with low and medium-low technologies provide better conditions for absorbing innovation than those with high and medium-high technologies. The reason for this situation may also be the structure of the Polish economy, in which the share of industries utilising very advanced technologies is inferior to those with less advanced technologies.

In the long term, as in the short term, in industries with high and intermediate technologies, export attractiveness limits the rate of innovation diffusion, while in industries with medium-low and low technologies it is an important stimulant for innovation diffusion (Table 6). Moreover, in the long term, the impact of this variable on GRL turned out to be the strongest in industries with medium-low technologies: an increase in RCA by 1% results in an increase in the rate of innovation diffusion by an average of about 9% *ceteris paribus* in the long term. Poland's investment attractiveness, in the long run, supports the rate of innovation diffusion in all industries except high-tech industries, where the impact of RCIA has proven to be negligible. The impact of this indicator is greatest in industries with medium-high technologies: an increase in RCIA by 1% results in an increase in the rate of innovation diffusion by an average of approximately 3.8% *ceteris paribus*. It should be noted that in the long term, the impact of RCIA on the rate of innovation diffusion increases with the level of possessed technology.

5. Conclusion

The obtained research results allowed the author to conclude that the diffusion of innovation in Poland takes place in all considered industries with different levels of utilised technology, with its pace varying depending on the degree of technological development of the industry. The research showed that the longest phase of the increasing rate of innovation diffusion occurs in high-tech industries, and the shortest in medium-high tech industries. It was also demonstrated that the highest dynamics of diffusion rate growth in the phase of increasing dynamics growth rate was recorded by industries with medium-high technology, and in the phase of decreasing dynamics – those with high technology. The situation where, in the first observation periods, industries with advanced technologies gave way in diffusion dynamics to other industries, may result from the fact that advanced technologies do not have a majority share of the economy. In addition, there may be some barriers to the diffusion process in some high-tech industries, or the innovation development process takes place through channels other than diffusion. Another factor that differentiates the time and rate of innovation diffusion is the ownership structure of the enterprise's capital. In enterprises with foreign capital, diffusion occurs more intensively: the growth phase of the diffusion rate is longer, and the growth rate is higher than in enterprises based on domestic capital. On this basis it can be assumed that enterprises with foreign capital are more open to innovation and have a greater capacity to absorb innovation through diffusion. The research also showed that in industries with low and medium-low technology, both specialisation in export and investment attractiveness support innovation diffusion. Therefore, strengthening the competitive position of companies on foreign markets in the industries in question, as well as introducing facilities for foreign investors on the domestic market (also in industries with intermediate technologies), promotes the diffusion of innovation. However, in industries utilising advanced and intermediate technologies, a comparative advantage in exports significantly reduces innovation diffusion. Thus, in these industries, the motivating factor for strengthening the innovation process in enterprises may be the weakening of the position of domestic enterprises on foreign markets and their displacement by external competition.

The study's research results are to a large extent a consequence of the structure of the Polish economy, which only recently started developing industries with high technologies and sectors with a high intensity of knowledge. For the time being, the development of these sectors is, to a large extent, conditioned by the supply of foreign capital in the form of FDI. The optimal situation from the point of view of strengthening national competitiveness would be the creation of innovation by domestic companies based on their own resources, but in the era of globalisation and fragmented international supply chains, this may be difficult to implement on a large scale and requires significant financial outlay.

It should be remembered that innovation diffusion is a dynamic process, therefore its study should be repeated in the future, which will allow for continuously monitoring changes in the ability to absorb innovation in individual industries. Such changes are to be expected in the context of the further development of knowledge-based industries. For a more in-depth analysis of innovation diffusion, other technological solutions and ideas (than those analysed in this study) that are disseminated in various industries, can also be utilised.

References

Aghion, P., Bergeaud, A., Lequien, M., & Melitz, M. J. (2018). The impact of exports on innovation: Theory and evidence. *Banque de France Working Paper*, 678.

Ambroziak, Ł., Chojna, J., Gniadek, J., Krawczyk, A., Marczewski, K., & Sawulski, J. (2020). *Transformacja polskiego eksportu – 30 lat wzrostu i co dalej?*. Wąsiński, M. (współpr.), Polski Instytut Ekonomiczny.

Bemmaor, A. C. (1994). Modelling the diffusion of new durable goods: Word-of-mouth effect versus consumer heterogeneity. In G. Laurent, G. L. Lilien, B. Pras (eds.), *Research traditions in marketing* (pp. 201-213). Kluwer.

Bemmaor, A. C., & Lee, J. (2002). The impact of heterogeneity and ill-conditioning on diffusion model parameter estimates. *Marketing Science*, 21(2), 209-220.

Balassa, B. (1965). Trade liberalization and revealed comparative advantage. *The Manchester School of Economic and Social Studies*, 33, 99-123.

Baptista, R. (1999). Do innovations diffuse faster within geographical clusters? *International Journal of the Economics of Business*, 6(1), 107-129.

Bass, F. M. (1969). A new product growth model for consumer durables. *Management Science*, 15(5), 215-227.

Bass, F. M., & Bultez, A. V. (1982). A note on optimal strategic pricing of technological innovations. *Marketing Science*, 1(4), 371-378.

Bayus, B. (1987). Forecasting sales of new contingent products: An application to the compact disc markets. *Journal of Product Innovation Management*, 4(4), 243-255.

Charemza, W., & Deadman, D. (1997). *Nowa ekonometria*. Polskie Wydawnictwo Ekonomiczne.

Desiraju, R., Nair, H., & Chintagunta, P. (2004). Diffusion of new pharmaceutical drugs in developing and developed Nations. *International Journal of Research in Marketing*, 21(4), 341-357.

Firlej, K., & Żmija, D. (2014). *Transfer wiedzy i dyfuzja innowacji jak źródło konkurencyjności przedsiębiorstw przemysłu spożywczego w Polsce.* Fundacja Uniwersytetu Ekonomicznego w Krakowie.

Fisher, J. C., & Pry, R. H. (1971). Simple substitution model of technological change. *Technological Forecasting and Social Change*, 3, 75-88.

Gatignon, H. A., Eliashaberg, J., & Robertson, T. S. (1989). Modelling multinational diffusion patterns: An efficient methodology. *Marketing Science*, 8(3), 231-247.

Gerschenkron, A. (1962). *Economic backwardness in historical perspective: A book of essays*. Belknap Press of Harvard University Press.

Gwarda-Gruszczyńska, E. (2017). Dyfuzja innowacji – następstwo komercjalizacji nowych technologii. *Organizacja i Kierowanie*, 2 (176), 383-396.

Henzel, H. (1991). Determinanty upowszechniania innowacji technicznych w przemyśle. *Prace Naukowe*. Akademia Ekonomiczna w Katowicach.

Hinloopen, J., & Van Marrewijk, C. (2001). On the empirical distribution of the Balassa index. *Weltwirtschaftliches Archiv*, 137, 1-35.

Horsky, D. (1990). A diffusion model incorporating product benefits, price, income and information. *Marketing Science*, 9(4), 342-365.

Janasz, W., & Leśkiewicz, I. (1995). *Identyfikacja i realizacja procesów innowacyjnych w przedsiębiorstwie.* Wydawnictwo Uniwersytetu Szczecińskiego.

Kalish, S. (1983). *Monopolistic pricing with dynamic demand and production cost*. Marketing Science, 2, 135-160.

Klimcewicz, K. (2011). *Dyfuzja innowacji. Jak odnieść sukces w komercjalizacji nowych produktów i usług.* Wydział Zarządzania UW.

Kolarz, M. (2006). *Wpływ zagranicznych inwestycji bezpośrednich na innowacyjność przedsiębiorstw w Polsce.* Wydawnictwo Uniwersytetu Śląskiego.

Kot, S., Karska, A., & Zając, K. (1993). *Matematyczne modele procesów dyfuzji innowacji.* PWN.

Lei, Y. C., & Zhang, S. Y. (2004). Features and partial derivatives of Bertalanffy-Richards growth model in forestry. *Nonlinear Analysis: Modelling and Control*, 9 (1), 65-73.

Mahler, A., & Rogers, E. M. (1999). The diffusion of interactive communication innovations and the critical mass: The adoption of telecommunications services by German banks, *Telecommunications Policy*, 23 (10-11), 719-740.

Meyer, K., & Sinani, E. (2009). When and where does foreign direct investment generate positive spillovers? A meta-analysis. *Journal of International Business Studies,* 40(7), 1075-1094.

Misala, J., & Pluciński, E. (2000). *Handel wewnątrzgałęziowy między Polską a Unią Europejskiej.* Kolegium Gospodarki Światowej SGH, Dom Wydawniczy ELIPSA.

Morrill, R. L., & Manninen, D. (1975). Critical parameters of spatial diffusion processes. *Economic Geography*, 51(3).

Oslo Manual (2005). *Guidelines for collecting and interpreting innovation data*, 3rd edition, OECD-Eurostat, Paris.

Richards, F.J. (1959). A flexible growth function for empirical use. *Journal of Experimental Botany*, 10(2), 290-300.

Robinson, B., & Lakhani, C. (1975). Dynamic pricing models for new product planning. *Management Science*, 10, 1113-1122.

Rogers, E. M. (1983). *Diffusion of innovations*, 3rd edition. Free Press.

Sharif, M. N., & Kabir, C. (1976). System dynamics modelling for forecasting multilevel technological substitution. *Technological Forecasting and Social Change*, 9(1-2), 89-112.

Stiglitz, J. E. (1994). Economic growth revisited. *Industrial and Corporate Change*, 3(1), 65-110.

Teece, D. (1977). Technology transfer by multinational firms: the resource cost of transferring technological know-how. *Economic Journal*, 87(346), 242-61.

Teng, T. C., Grover, V., & Guttler, W. (2002). Information technology innovations: General diffusion patterns and its relationships to innovation characteristics. *IEEE Transactions on Engineering Management*, 49(1), 13-27, 2002.

Wareham, J., Levy, A., & Shi, W. (2004). Wireless diffusion and mobile computing: Implications for the digital divide. *Telecommunications Policy*, 28 (5-6), 439-457.

Weresa, M. A. (2002). *Wpływ handlu zagranicznego i inwestycji bezpośrednich na innowacyjność polskiej gospodarki*. SGH.

Wiśniewska, J. (2004). *Ekonomiczne determinanty dyfuzji innowacji produktowych i technologicznych w banku komercyjnym.* Wydawnictwo Naukowe Uniwersytetu Szczecińskiego.

Van den Bulte, C., & Stremersch, S. (2004). Social contagion and income heterogeneity in new product diffusion: A meta-analytic test. *Marketing Science*, 23 (4), 530-544.

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