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A Comparative Analysis of the Diffusion of Mobile Technologies in the Visegrad Four Using an ECM Model

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ABSTRACT

Objective: The aim of the paper is to assess the size and rate of diffusion of mobile technologies in the processing industry, and to determine the nature and strength of the impact of investment specialisation (investment attractiveness) and industry export specialisation on this phenomenon in the four Visegrad Group countries.
Research Design & Methods: The occurrence of innovation diffusion and its dynamics were examined using an econometric model of the Gompertz function. To study the impact of specialisation according to foreign direct investments (FDI) located in V4 countries and their export specialisation on the process of innovation diffusion, an error correction model (ECM) estimated for selected industrial processing sectors was used. It was based on data for 2010–2021 from Eurostat, UNCTAD and the national statistical offices of individual V4 countries.
Findings: The phase of rapid increase in innovation diffusion calculated on the basis of the Gompertz function was significantly longer in high- and medium-high technology enterprises than in low- and medium-low technology enterprises. In the short term, the determinants of mobile technology diffusion in all V4 countries in industries with low and medium-low technology are both export specialisation and investment attractiveness.

Implications/Recommendations: The results lead to the conclusion that the diffusion of mobile technologies takes place in various industries in the V4, but its pace varies depending on the individual industry's technological development. The results indicate the need to develop industries with high technologies and sectors with high intensity of knowledge.
Contribution: A comparative analysis of the pace of diffusion of mobile technology innovations in the V4 was performed for the first time in this article. The combination of the Gompertz model with the ECM model can also be considered a pioneering solution in the analysis of innovation diffusion.
Article type: original article.

Keywords: diffusion of innovation, V4 countries, ECM, Gompertz function.

JEL Classification: O30, C22.

1. Introduction

Innovations combined with the knowledge-based economy play a pivotal role in shaping the competitive advantage of the modern economy, both on the macro- and microeconomic scales. Digital innovations developed in parallel with mobile technologies play a particularly important role. Recently, these technologies have become a common solution, an inseparable element of the lives of both individual users and the functioning of entire enterprises. The development of mobile technologies has been achieved thanks to numerous inventions and improvements regarding the portable nature of new devices, their intuitive and simple operation and the possibility of connecting them to the Internet. The low cost of buying and using this type of equipment also plays a meaningful role.

Mobile technologies are a key element of the digital economy and play an important role in increasing innovation and the competitiveness of organisations. Thanks to such technologies, the time needed to access information is shortened, while the communication process itself is improved. Mobile technologies enable the implementation of many digital innovations for social and business purposes. A large number of companies already widely use or even base their existence on available mobile technologies. They not only change the way traditional services such as transport and logistics function, but they are an invaluable improvement in processes such as the organisation of production, the provision of services, and the development of customer relationships. As a result, completely new business models are created, for example within the "sharing economy". Creating new mobile technology is generally expensive, and requires a large scientific and research base.

New mobile technology generally reaches the countries of Central and Eastern Europe through innovation diffusion. This term can be understood as the dissemination of innovation/technology through market and non-market channels, starting from their initial implementation anywhere in the world, and later spreading to other countries and regions and to other markets and companies (OECD/Eurostat, 2005). Such diffusion spreads new technological, organisational, and marketing solutions, as well as knowledge among enterprises-imitators and copycats (the spillover effect). An important feature of technological innovation diffusion is its variable rate of spread, which usually changes according to the S-shaped curve (e.g. logistic curve), which means that the rate of diffusion in its initial phase is slow, then increases more than proportionally and decreases again in the final phase.

The logistics curve is the most commonly used tool to study the diffusion of technological innovations. Other tools include the Bass model (Bass, 1969) and the wave and hierarchical model (Morrill & Manninen, 1975) among others. Technology diffusion occurs in both developed and developing economies and has been the subject of numerous empirical analyses. While the global literature offers no shortage of research on the diffusion of mobile technology using the above models, studies using econometric tools in Poland and in other Visegrad Group countries (Czech Republic, Hungary, Slovakia) are relatively rare. The existing research gap in this area makes it difficult to reliably assess the actual relationships between spillover processes and certain macroeconomic variables. This article attempts to fill this gap to some extent. The main objective of the present analysis is twofold: to assess the size and rate of diffusion of mobile technologies in the processing industry, and to determine the nature and strength of the impact of investment specialisation (investment attractiveness) and industry export specialisation on the diffusion of tech innovations in the four Visegrad Group countries (the Visegrad Four, V4). The occurrence of mobile technology diffusion and its rate was studied using the Gompertz function. Additionally, to determine the impact of the investment attractiveness of individual V4 countries and their specialisation in foreign trade on diffusion processes, dynamic error correction models (ECM) were used. These were estimated for industrial processing industries with various degrees of technological advancement. This research approach made it possible to determine how the technological progress of the industry affects the rate of innovation diffusion, and how the intensity of diffusion is affected by the revealed innovation advantage and investment attractiveness of the individual V4 countries.

2. Literature Review

Innovation diffusion has been studied at length and for years. The classic approaches to this problem can be found in the works of Tarde (1895), Rogers (1962), and others. Researcher interest in the phenomenon is attributable to its key role in supporting the technical progress of many economies.

One research stream in the study of innovation diffusion involves analyses of the profitability of business ventures, pricing policy, distribution channels or, in a broader sense, the strategy policy of the company introducing products to other markets. Studies of this type look at the diffusion of digital innovation in general (e.g. Akçura & Altınkemer, 2010). As mobile technologies have developed, and devices such as smartphones and tablets emerged, researchers have also analysed the diffusion of innovation in this area. Another important research stream focuses on the analysis of innovation life cycles (Peres, Muller & Mahajan, 2010). As part of this research, mathematical models of innovation growth curves have been built to calculate and analyse a range of factors including inflection points and saturation levels. These studies aim to reflect the diffusion processes over time as accurately as possible, so that it is possible to create sales forecasts and develop effective commercial strategies (Mahajan, Muller & Bass, 1990).

Researchers have proposed many models that work well in specific socio-economic conditions (Meade & Islam, 1995). Much of the research on diffusion concerns innovations related to high-tech products such as mobile telephones, mobile technologies, digital technologies, and the Internet. One of the groundbreaking models in the study of this type of issue is the Bass model (Bass, 1969). There is research indicating that this model is not appropriate for the diffusion mapping of some more technologically advanced products. However, basic growth curve models, such as the Gompertz model, the logistic model, or a modified exponential model, accurately reflect these phenomena (Singh, 2008; Liu, Wu & Chu, 2009). The diffusion of mobile and digital innovations has been modelled widely in recent years. For example, in banking, Dos Santos and Peppers (1998) modelled the effectiveness of different diffusion models in analysing the spread of e-commerce applications. Singh (2008) studied the diffusion of mobile telephony in the Indian market using logistic curve models and the Gompertz function. The author showed that the latter function better reflects the diffusion in question. More recently, Roy, Dutta and Das (2019), Asongu (2021), and Skiti (2020) have studied the determinants of mobile technology diffusion processes.

In the Polish literature, studies of innovation diffusion have been done by Klincewicz (2011), Firlej and Żmija (2014), Wiśniewska (2004), and Gwarda-Gruszczyńska (2017). Empirical studies of the process of diffusion of innovation in the world literature have been conducted for years using econometric modelling (Bemmaor & Lee, 2002; Teng, Grover & Guttler, 2002; Desiraju, Nair & Chintagunta, 2004; Van den Bulte & Stremersch, 2004) or by means of simulation studies (Ramkumar *et al*., 2022), but the Polish literature offers few examples of the use of such tools (Kolarz, 2006, is one). There is a similar paucity in other Central and Eastern European countries (including the other V4 nations). Meanwhile, econometric modelling is already a well-established tool globally in the study of innovation diffusion. Models of this type allow for a real assessment of cause-and-effect relationships between spillover processes and macroeconomic variables, while also enabling forecasting of the diffusion process itself.

Thus, a research niche exists in this area, opening the field for in-depth analyses in the area of innovation diffusion, especially of innovations in dynamically developing mobile technologies, both in Poland and in other countries of Central and Eastern Europe. The research subject of this study is the proliferation of portable electronic devices enabling mobile access to the Internet, with which employers in enterprises of the processing industry equip their employees in the countries of the V4.

3. Research Methodology

Innovation diffusion typically commences slowly before rapidly picking up speed. It then decreases and the level of innovation stabilises (the growth dynamics of innovation diffusion fades). Many studies have confirmed that changes in the innovation diffusion rate follow an S-shaped curve (Sharif & Kabir, 1976; Desiraju, Nair & Chintagunta, 2004). For this reason, in research on the dynamics of innovation diffusion, models are used that allow researchers to reproduce the behaviour of this phenomenon. These include, above all, the logistics model and the Gompertz model. This article applies the Gompertz model, which works well in similar analyses (Meade & Islam, 1995; Liu *et al*., 2014). The Gompertz curve shows the exponential rate of change of the phenomenon, which follows an asymmetric sigmoid path around the inflection point. This type of asymmetry is suitable primarily for describing cases in which maximum growth occurs relatively early (Meade & Islam, 1995, 2006). The Gompertz function is represented by the formula:

$$f(t) = A\exp(-\exp(-B(t-C))), \tag{1}$$

where:

A, B, C – parameters of the Gompertz function, where: A – the supremum of the values of the function, C – scale parameter,

t – time variable.

The rate of change in the Gompertz function is provided by the formula:

$$GRG = \frac{dy}{dt}\frac{1}{y} = B\exp(-B(t-C)). \tag{2}$$

In the course of the Gompertz function, several ranges can be distinguished, including the area where it has a clearly increasing growth rate and the area where it is characterised by a decreasing growth rate, aiming at the saturation level expressed by the asymptote $y = A$. The point separating the rapid growth rate of the curve from the decreasing growth rate is the inflection point with coordinates:

$$\frac{dy}{dt}\frac{1}{y}(C) = B. \tag{3}$$

Liu, Wu and Chu (2009) proved that the condition for an inflection point to appear is that approximately 37% of consumers accept the innovation.

The competitiveness of foreign trade was measured using the *RCA* (revealed comparative advantage) indicator (Balassa, 1965):

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

where:

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

Indicator (4) enables us to assess the relative comparative advantage of one country in exporting a specific commodity group over other countries. The higher the value it takes, the greater the advantage in exports the country under analysis has. Values greater than one are considered to indicate the existence of a comparative advantage, and values less than one indicate the absence of one. In the calculations of the *RCA* index, OECD countries were adopted as a reference group, due to the trade and investment relations of the V4 countries with these countries and their technological advancement, which makes it possible to seamlessly transmit innovation to the Visegrad countries.

As was done with indicator (2), the indicator of disclosed investment advantage is defined. This measure makes it possible to takie into account the country's investment attractiveness. This indicator is given by the formula (Salamaga, 2020):

$$RCAI_i = \frac{FDI_{ij}}{FDI_j} : \frac{FDI_i^R}{FDI^R}, \tag{5}$$

where:

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

The higher the investment attractiveness of a country, the higher the *RCAI*. Because foreign direct investment (FDI) suppliers to the Visegrad countries are also non-OECD countries, all countries in the world were assumed as reference countries when calculating the *RCAI*. The relationships between variables (3), (4) and (5) were analysed using a one-equation model with the error correction mechanism. The short-term relationship in the ECM model between logarithmic variables is described by the equation:

$$d\_lnGRG_t = \alpha_0 + \alpha_1 d\_lnRCA_t + \alpha_2 d\_lnRCAI_t + \alpha_3 ECM_{t-1} + \varepsilon_t, \tag{6}$$

where:

$\alpha_0, \alpha_1, \alpha_2, \alpha_3$ – model parameters,

d_lnGRG_t, d_lnRCA_t, d_lnRCAI_t – first differences of logarithmic variables: *GRG* (growth rate of the Gompertz function), *RCA* (revealed comparative advantage), *RCAI* (investment attractiveness of a country),

ECM_{t-1} – error correction mechanism,

ε_t – error term.

The ECM component represents the state of long-term equilibrium in the previous period (t – 1) in relation to period t. The cointegrating equation representing the long-term relationship is:

$$lnGRG_t = \gamma_0 + \gamma_1 lnRCA_t + \gamma_2 lnRCAI_t + u_t. \quad (7)$$

In the case of autocorrelation occurring in the model (6), lagged variables were also introduced. Before estimating the model, the internal structure of time series was studied, and their order of cointegration and autocorrelation was tested. In the study of time series stationarity, the augmented Dickey-Fuller test (ADF test) was used, while the Engle-Granger test was used in the time series cointegration study.

The study of mobile technology diffusion was based on statistics regarding the number of mobile devices enabling mobile access to the Internet, such as laptops and smartphones companies distribute to employees. Models of Gompertz curves (1) of mobile technology diffusion were built and the growth rate of these functions (*GRG*) were calculated according to formula (2) for each year on the basis of data for 2010–2021 from Eurostat and the national statistical offices of individual V4 countries (Statistics Poland, the Czech Statistical Office, the Statistical Office of the Slovak Republic, and the Hungarian Central Statistical Office). Data on FDI holdings in the Visegrad countries (used to calculate the *RCAI*) were also taken from Eurostat and from the databases of national statistical offices. Export data used to calculate the *RCA* were taken from the Comext database available in Eurostat, which contains detailed statistics on the international trade of individual EU Member States. For calculations, data at a double-digit level of commodity disaggregation based on the Standard International Trade Classification (SITC) were used, as were data from the UNCTAD database. When selecting the parameters of the Gompertz function, the Gauss-Newton optimisation algorithm was applied. Gompertz function and ECM models were built on annual data, because only this frequency of data was available.

4. Empirical Results

The modelling of mobile technology diffusion was carried out using the Gompertz function among enterprises belonging to industries that utilise different levels of technology. Two business sectors were taken into account: those operating in low- and medium-low technology sectors and in sectors with high and medium technologies (Table 1).

Table 1. Results of the Estimation of Gompertz Regression Function Parameters among Enterprises Uutilising Different Levels of Technology

Specification	Sector					
	Low-tech and medium-low-tech			High-tech and medium-high-tech		
Czech Republic						
Parameter	A	B	C	A	B	C
Coefficient	2,291.965	0.579	2.900	5,679.211	0.521	4.188
Standard error	862.441	0.169	1.060	1,922.235	0.187	1.131
p-value	0.033	0.011	0.029	0.021	0.027	0.008
R^2	0.753			0.779		
Hungary						
Parameter	A	B	C	A	B	C
Coefficient	1,731.996	0.621	2.707	4,744.469	0.523	3.434
Standard error	330.395	0.081	0.431	2,714.591	0.282	2.427
p-value	0.001	0.000	0.000	0.124	0.106	0.200
R^2	0.743			0.752		
Poland						
Parameter	A	B	C	A	B	C
Coefficient	6,016.894	0.548	2.779	7,649.087	0.584	3.751
Standard error	1,451.276	0.150	0.766	1,666.511	0.192	1.942
p-value	0.004	0.008	0.008	0.003	0.019	0.095
R^2	0.591			0.626		
Slovakia						
Parameter	A	B	C	A	B	C
Coefficient	859.532	0.503	3.761	948.502	0.511	4.485
Standard error	245.330	0.058	0.412	883.507	0.192	1.954
p-value	0.010	0.000	0.000	0.319	0.033	0.055
R^2	0.702			0.784		

Source: the author's calculations.

Table 1 shows that the phase of rapid increase in innovation diffusion calculated on the basis of the Gompertz function was significantly longer in high- and medium-high technology enterprises than in low- and medium-low technology ones. The models built for low- and medium-low technology had statistically significant parameters, while some parameters in the models for high- and medium-high technology were not statistically significant (especially for Hungary). Among companies from the high- and medium-high technology sectors, companies operating in Slovakia had the longest phase of rapid mobile technology diffusion dynamics (about 54 months), and the shortest was experienced by Hungarian companies (about 41 months). Similarly, in low- and medium-low technology industries, Slovakian companies recorded the longest phase of rapid diffusion of mobile technology (about 45 months), and the shortest duration was among Hungarian companies (about 33 months). Companies from Poland operating in high- and medium-high technology industries achieved the highest growth rate of innovation diffusion (0.58), calculated at the inflection points of the Gompertz function, while companies from Slovakia (0.51) achieved the lowest. Slovak companies also had the lowest growth rate of innovation diffusion in low- and medium-low technology industries (approx. 0.50), while the highest growth dynamics were recorded in these industries by enterprises in Hungary (approx. 0.62).

GRG values calculated for individual years of the period considered, together with *RCA* and *RCAI* indicators, were used to estimate dynamic econometric models. The variables were first logarithmised, and the construction of econometric models was preceded by a study of the stationarity of time series of variables using the ADF test. As a result, the use of this test was confirmed by the integration of time series in stage I(1) at a significance level of 0.05. The ADF test, applied to residuals calculated from the corresponding integrating equations (7), showed that their time series are integrated in order I(0). Due to the cointegration of the time series of variables *lnGRG*, *lnRCA*, *lnRCAI* in order I(1), dynamic econometric models for short-term relations containing an error correction mechanism were estimated.

Tables 2 and 3 present the results of estimates of the parameters of mobile diffusion rate models, which show the long- and short-term relationship for enterprises in low- and medium-low technology and high- and medium-high technology.

Based on the parameter assessments in Table 2, it can be concluded that in the short-term export specialisation and investment attractiveness are the determinants of mobile technology diffusion in all V4 countries in industries with low and medium--low technology. The first of these indicators had a particularly clear impact on the intensity of mobile technology diffusion in the industries under discussion in the Czech Republic, where an increase in the *RCA* index by 1% implies an increase in the rate of diffusion of innovation by an average of about 0.789 *ceteris paribus*. On the other hand, the strongest impact of investment attractiveness on the rate of mobile technology diffusion in low- and medium-low technology industries is visible in Hungary, where a one percent increase in the RCA index implies an increase in the rate of diffusion of innovation by an average of about 1.058% *ceteris paribus*. According to the results presented in Table 2, in industries with

Table 2. ECM Parameters in V4 Countries by Industries Utilising Different Levels of Technology

Variable	Sector							
	Low-tech and medium-low-tech				High-tech and medium-high-tech			
	Parameter	SE	*t*-Stat	*p*	Parameter	SE	*t*-Stat	*p*
Czech Republic								
const	–5.016	2.035	–2.465	0.069	–1.568	0.551	–2.849	0.046
d_lnGRG_1	1.285	0.175	7.362	0.002	1.076	0.492	2.187	0.094
d_lnRCA	0.789	0.183	4.317	0.012	0.279	0.336	0.829	0.454
d_lnRCAI	0.536	0.154	3.472	0.026	2.828	0.904	3.130	0.035
ECM_1	–0.267	0.181	–1.479	0.213	–0.037	0.008	–4.643	0.010
R^2	0.688				0.583			
Hungary								
const	–3.749	1.558	–2.406	0.074	–0.246	0.397	–0.619	0.569
d_lnGRG_1	1.355	0.212	6.384	0.003	1.356	0.546	2.484	0.068
d_lnRCA	0.475	0.118	4.030	0.016	–1.209	0.785	–1.541	0.198
d_lnRCAI	1.058	0.185	5.711	0.005	2.405	0.806	2.986	0.041
ECM_1	–0.088	0.211	–0.418	0.698	–0.040	0.012	–3.243	0.032
R^2	0.819				0.697			
Poland								
const	–0.063	0.017	–3.765	0.020	–0.183	0.054	–3.427	0.027
d_lnGRG_1	1.294	0.282	4.589	0.010	0.499	1.115	0.448	0.677
d_lnRCA	0.069	0.024	2.928	0.043	–1.213	0.406	–2.987	0.040
d_lnRCAI	0.128	0.033	3.889	0.018	1.241	0.634	1.956	0.122
ECM_1	–0.095	0.021	–4.494	0.011	–0.093	0.024	–3.852	0.018
R^2	0.620				0.583			
Slovakia								
const	–2.486	1.029	–2.416	0.073	–0.206	0.033	–6.157	0.004
d_lnGRG_1	1.321	0.238	5.555	0.005	0.771	0.251	3.080	0.037
d_lnRCA	0.945	0.309	3.058	0.038	–0.086	0.021	–4.054	0.015
d_lnRCAI	0.886	0.299	2.965	0.041	3.096	0.325	9.512	0.001
ECM_1	–0.141	0.106	–1.324	0.256	–0.061	0.021	–2.843	0.047
R^2	0.714				0.765			

Source: the author's calculations.

high and medium-high technology, the statistically significant impact of both export competitiveness and investment attractiveness on mobile technology diffusion is visible only in Slovakia, with the first of these factors being a destimulant and the second being a stimulant: an increase in the *RCA* index by 1% causes a decrease in the rate of diffusion of innovation by an average of approx. 0.086% *ceteris paribus*, and the same increase in *RCAI* implies an increase in *RCA* by approx. 3.096% *ceteris paribus*. In addition, in these industries, competitiveness in foreign trade is also an important destimulant to the intensity of innovation diffusion among Polish enterprises, while investment attractiveness significantly accelerates the pace of diffusion of mobile technologies in the Czech Republic and Hungary. The calculations show that, in the short term, in low- and medium-low technology industries, both foreign trade and foreign direct investment are important transmission channels for innovation diffusion, while in the case of high-tech and medium-high technology industries, foreign direct investments are such a channel. Assessments of the parameters of the error correction mechanism are generally negative, which indicates an adjustment of short-term changes to the long-term equilibrium in the Visegrad Group countries. Table 3 presents the parameters of cointegration equations for enterprises belonging to industries that utilise different levels of technology. The coefficients of determination show that the fit of the models to the data is usually average, and in some cases the R^2 is even less than 50% (for high- and medium-high technology in Czech Republic and Slovakia).

In terms of the long-term relationship in low- and medium-low technology industries (see Table 3), the positive impact of *RCA* and *RCAI* indicators on the rate of change of innovation diffusion as measured by the *GRG* indicator is also confirmed. However, here the impact of the investment attractiveness index is generally stronger (with the exception of Poland) than that of the export competitiveness index. The strongest long-term impact of export advantage in these industries on the rate of innovation diffusion occurs in Slovakia, where a one percent increase in the *RCA* indicator causes an increase in the rate of mobile technology diffusion by an average of approx. 2.914% *ceteris paribus*. On the other hand, the most pronounced impact of investment attractiveness on the speed of innovation diffusion is visible in the Czech Republic – where an increase in the *RCAI* by 1% results in an increase in the *GRG* index by an average of approx. 3.726% *ceteris paribus*.

Thus, it can be argued that foreign investment is a more effective transmission channel for innovation diffusion than foreign trade. The situation is slightly different in industries with high and medium-high technologies where, although investment attractiveness is generally a factor that significantly supports the diffusion of mobile technology, competitiveness in exports more often limits this diffusion or does not significantly affect it. According to the results in Table 3, the strongest impact of innovation advantage in these industries on the rate of diffusion of innovation can be observed in Poland, where a one percent increase in the *RCAI* causes an increase in the *GRG* index by an average of approx. 4.381%. At the same time, the most inhibiting impact of the dominance in foreign trade on the diffusion rate is visible in Hungary, where an increase in the *RCA* index by 1% results in a decrease in the

Table 3. Parameters of Cointegration Equations for Enterprises Belonging to Industries That Utilise Different Levels of Technology

Variable	Sector							
	Low-tech and medium-low-tech				High-tech and medium-high-tech			
	Parameter	SE	*t*-Stat	*p*	Parameter	SE	*t*-Stat	*p*
Czech Republic								
const	–7.499	0.922	–8.136	0.000	–1.509	1.258	–1.199	0.265
lnRCA	2.760	3.256	0.848	0.421	–0.278	0.115	–2.411	0.042
lnRCAI	3.726	0.742	5.021	0.001	3.087	0.853	3.620	0.007
R^2	0.935				0.416			
Hungary								
const	–6.581	1.057	–6.228	0.000	–3.427	1.784	–1.921	0.091
lnRCA	1.450	0.455	3.191	0.013	–4.153	1.240	–3.349	0.010
lnRCAI	1.492	0.441	3.382	0.010	2.288	0.513	4.458	0.002
R^2	0.614				0.506			
Poland								
const	–3.846	1.363	–2.821	0.022	–3.866	1.411	–2.740	0.025
lnRCA	2.882	1.073	2.684	0.028	2.761	0.890	3.102	0.015
lnRCAI	2.576	1.083	2.378	0.045	4.381	1.856	2.360	0.046
R^2	0.548				0.678			
Slovakia								
const	–5.797	1.144	–5.067	0.001	0.345	0.110	3.148	0.014
lnRCA	2.914	1.118	2.606	0.031	3.484	1.783	1.954	0.086
lnRCAI	2.080	0.720	2.890	0.020	3.828	0.908	4.215	0.003
R^2	0.533				0.401			

Source: the author's calculations.

rate of diffusion of mobile technology by an average of about 4.153%. The negative impact of the comparative advantage on the *GRG* index in some V4 countries may be a consequence of the fact that the share of technologically advanced goods constitutes only a small part of the foreign trade of the V4 countries (at most a dozen or so percent). In addition, having an advantage in foreign trade in high-tech industries can demotivate the propensity of local producers to innovate. Only the increase of foreign competitiveness in trade stimulates domestic companies, "forcing" them to innovate and thus also activating the processes of innovation diffusion. In turn, the inflow of FDI to the V4 countries is still growing and has recently achieved significant dynamics despite the worldwide economic crisis caused by the COVID-19 pandemic. The Visegrad countries have effectively taken advantage of the global trend of shortening supply chains due to the pandemic and have become attractive locations to foreign investors.

It can be concluded that industries with low- and medium-low technologies currently provide better conditions for the absorption of mobile technology compared to high and medium technology industries. One of the reasons for this may be that the Visegrad economies still have a small share of industries with very advanced technologies compared to industries with less advanced technologies.

5. Conclusions

The results confirm that the choice of the Gompertz function was appropriate for modelling the diffusion of mobile technologies. This choice is consistent with the results obtained by other researchers in similar analyses conducted for other European (Meade & Islam, 1995) and non-European countries (Liu, Wu & Chu, 2009; Liu *et al*., 2014).

The research shows that the diffusion of mobile technologies in the Visegrad four countries takes place in different industries, but its speed varies depending on the technological advancement of the industry.

The research done for this paper has also shown that the phases of increasing rates of innovation diffusion are clearly longer in high- and medium-high technology industries than in low- and medium-low technology ones. Lower dynamics of diffusion of mobile technology in high- and medium-high technology industries in Poland and Hungary (compared to low- and medium-low technology industries) may indicate the existence of barriers to the diffusion process in some high-tech industries or the possibility of developing innovation through channels other than diffusion. The study shows that in industries with low- and medium-low technology, both export specialisation and investment attractiveness support the diffusion of mobile technology in V4 countries. In the short term, in low- and medium-low technology industries, both foreign trade and foreign direct investment are important transmission channels for innovation diffusion, while in the case of high-tech and medium-high technology industries, foreign direct investments are such a channel. Therefore, strengthening the competitive position of companies on foreign markets as well as introducing support systems for foreign investors on the domestic market are conducive to the diffusion of innovation.

In high- and medium-tech industries, comparative advantage in exports inhibits the diffusion of innovation. Thus, in these industries, the weakening position of domestic enterprises on foreign markets and their displacement by external competition may be a motivating factor for strengthening the innovation process in enterprises. The obtained results indicate the need to develop industries with high technologies and sectors with a high intensity of knowledge, whose share in the economy is still giving way to less technologically advanced industries.

Lastly, one limitation of this research is that the models presented here were built on the basis of a small amount of data (relatively short time series). In future research, using longer time series will make it possible to produce models that better fit the empirical data.

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Conflict of Interest

The author declares no conflict of interest.

References

Akçura, M., & Altınkemer, K. (2010). Digital Bundling. *Information Systems and E-Business Management*, *8*(4), 337–335. https://doi.org/10.1007/s10257-009-0117-5

Asongu, S. A. (2021). The Effects of Mobile Phone Technology, Knowledge Creation and Diffusion on Inclusive Human Development in Sub-Saharan Africa. *Journal of Knowledge Economy*, *12*(3), 1367–1398. https://doi.org/10.2139/ssrn.3623840

Balassa, B. (1965). Trade Liberalisation and "Revealed" Comparative Advantage. *The Manchester School of Economic and Social Studies*, *33*(2), 99–123. https://doi.org/10.1111/j.1467-9957.1965.tb00050.x

Bass, F. M. (1969). A New Product Growth Model for Consumer Durables. *Management Science*, *15*(5), 215–227. https://doi.org/10.1287/mnsc.15.5.215

Bemmaor, A. C., & Lee, J. (2002). The Impact of Heterogeneity and Ill-conditioning on Diffusion Model Parameter Estimates. *Marketing Science*, *21*(2), 209–220. https://doi.org/10.1287/mksc.21.2.209.151

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. https://doi.org/10.1016/j.ijresmar.2004.05.001

Dos Santos, B. L., & Peffers, K. (1998). Competitor and Vendor Influence on the Adoption of Innovative Applications in Electronic Commerce. *Information & Management*, *34*(3), 175–184. https://doi.org/10.1016/S0378-7206(98)00053-6

Firlej, K., & Żmija, D. (2014). *Knowledge Transfer and Diffusion of Innovation as a Source of Competitiveness of Food Industry Enterprises in Poland*. Foundation of the Cracow University of Economics.

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

Klincewicz, K. (2011). *Dyfuzja innowacji. Jak odnieść suckes w komercjalizacji nowych produktów i usług*. Wydawnictwo Naukowe Wydziału Zarządzania Uniwersytetu Warszawskiego.

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

Liu, A. X., Wang, Y., Chen, X., & Jiang, X. (2014). Understanding the Diffusion of Mobile Digital Content: A Growth Curve Modelling Approach. *Information Systems and E-Business Management*, *12*(2), 239–258. https://doi.org/10.1007/s10257-013-0224-1

Liu, X., Wu, F.-S., & Chu W.-L. (2009). Innovation Diffusion: Mobile Telephony Adoption in China. *International Journal of Innovation Management*, *13*(2), 245–271. https://doi.org/10.1142/S1363919609002285

Mahajan, V., Muller, E., & Bass, F. M. (1990). New Product Diffusion Models in Marketing: A Review and Directions for Research. *Journal of Marketing*, *54*(1), 1–26. https://doi.org/10.2307/1252170

Meade, N., & Islam, T. (1995). Forecasting with Growth Curves: An Empirical Comparison. *International Journal of Forecasting*, *11*(2), 199–215. https://doi.org/10.1016/0169-2070(94)00556-R

Meade, N., & Islam, T. (2006). Modelling and Forecasting the Diffusion of Innovation – a 25-year Review. *International Journal of Forecasting*, *22*(3), 519–545. https://doi.org/10.1016/j.ijforecast.2006.01.005

Morrill, R. L., & Manninen, D. (1975). Critical Parameters of Spatial Diffusion Processes. *Economic Geography*, *51*(3), 269–277. https://doi.org/10.2307/143121

OECD/Eurostat. (2005). *Oslo Manual. Guidelines for Collecting and Interpreting Innovation Data* (3rd ed.). OECD Publishing. https://doi.org/10.1787/9789264013100-en

Peres, R., Muller, E., & Mahajan, V. (2010). Innovation Diffusion and New Product Growth Models: A Critical Review and Research Directions. *International Journal of Research in Marketing*, *27*(2), 91–106. https://doi.org/10.1016/j.ijresmar.2009.12.012

Ramkumar, S., Mueller, M., Pyka, A., & Squazzoni, F. (2022). Diffusion of Eco-innovation through Inter-firm Network Targeting: An Agent-based Model. *Journal of Cleaner Production*, *335*, 130298. https://doi.org/10.1016/j.jclepro.2021.130298

Rogers, E. M. (1962). *Diffusion of Innovations*. The Free Press.

Roy, A., Dutta, G., & Das, P. K. (2019). Exploring the Determinants of Mobile-based Services Diffusion: Past Determinants, Emergent Pattern and a Proposed Framework. *International Journal of Business Innovation and Research*, *18*(4), 429–452. https://doi.org/10.1504/IJBIR.2019.098759

Salamaga, M. (2020). Econometric Analysis of the Relationship between Innovation and Foreign Trade Distance in Central and Eastern Europe Countries. *Folia Oeconomica Stetinensia*, *20*(1), 360–372. https://doi.org/10.2478/foli-2020-0021

Sharif, M. N., & Kabir, C. (1976). System Dynamics Modelling for Forecasting Multilevel Technological Substitution. *Technological Forecasting and Social Change*, *9*(1–2), 89–112. https://doi.org/10.1016/0040-1625(76)90046-9

Singh, S. K. (2008). The Diffusion of Mobile Phones in India. *Telecommunications Policy*, *32*(9–10), 642–651. https://doi.org/10.1016/j.telpol.2008.07.005

Skiti, T. (2020). Institutional Entry Barriers and Spatial Technology Diffusion: Evidence from the Broadband Industry. *Strategic Management Journal*, *41*(7), 1336–1361. https://doi.org/10.1002/smj.3146

Tarde, G. (1895). *Les lois de l'imitation*. G. Baillière & C.

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. https://doi.org/10.1109/17.985744

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. https://doi.org/10.1287/mksc.1040.0054

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