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Endogenous Growth Factors and Economic Development: An In-depth Analysis of the Impact of Investments in R&D and Human Capital on Total Factor Productivity and Export Dynamics

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Investments in research and development (R&D) and human capital affect economic growth by influencing total factor productivity (TFP) and competitiveness (exports). The determinants of this influence were analysed on a cointegrated panel of seven large countries and separately on five medium-sized or small countries. The results show that TFP and exports per unit of R&D or per unit of human capital mainly depend on the interconnection of these two factors, but also on capital per employee, the control of inflation, the foreign trade share in GDP, oil prices, digitalisation, electrification, the concentration of development activity related to the share of military expenditures in GDP, energy efficiency and ecological protection in the national economy. In medium-sized or small countries, the influence of regulation is greater, while the effect of development activities related to military expenditures is much smaller than in the large countries.

Keywords: *Endogenous Growth; Research and Development; Human Capital; Total Factor Productivity; Exports.*

Introduction

In this article we deal with the effectiveness of investments in R&D and the engagement of human capital as key factors of endogenous growth (Romer, 1986; Grossman & Helpman, 1991) and their impact on both total factor productivity (TFP) and the export of goods and services as an indicator for competitiveness. TFP and export dynamics are part of the development process (Solow, 1956; Kaldor, 1985). It is a process of increasing prosperity which is influenced by changes in technology, the growth of trade with the increase in the division of labour and economies of scale, and the increase in the supply of production factors such as labour and capital.

In this article we analyse the dynamics of TFP and the dynamics of exports per unit of investment in R&D and per unit of human capital in two separate panels. The first includes seven large countries (the USA, Germany, France, the United Kingdom, Japan, China and South Korea) and the second deals with five medium-sized and small countries (Sweden, Denmark, Switzerland, Austria and Slovenia). The assessment was carried out on annual data for the period from 2000 to 2019, or, exactly, on growth rates from 2001 to 2019.

Our analysis showed that changes in TFP, or changes in exports per unit of R&D or per unit of human capital, i.e., the effectiveness of both endogenous factors of economic growth in promoting TFP and exports, are influenced by determinants in the following areas: knowledge, economic structure, economic and development policy and fields of energy and ecology.

We found that both endogenous factors of economic growth (investments in R&D and human capital) influence how TFP or exports change per unit of the other factor of endogenous growth. In the area of economic structure, capital per employee, exports or whole international trade to GDP, FDI to GDP, exports and imports of ICT per employee, mobile phones per capita, employee benefits to GDP, government expenditure to GDP and savings to GDP positively influence the dynamics of TFP or exports per R&D unit, or per unit of human capital. Economic and development policy works to change the dynamics of TFP, or exports per unit of R&D or human capital, through regulation, military expenditure to GDP, as well as through the influence on inflation and the exchange rate, or on price competitiveness. Inflation reduces TFP and exports per unit of R&D and per unit of human capital. When affecting exports, this similarly applies to exchange rate appreciation (price competitiveness). Energy consumption per capita, growth in oil prices and growth in CO_2 emissions per capita have also a negative impact on TPF, or exports per unit of R&D and per unit of human capital, while the impact of electricity production per capita is positive when affecting exports.

The results of our analysis show that the aforementioned determinants affect the dynamics of TFP and exports per unit of R&D or human capital in the short term with a somewhat stronger long-term impact. The effect is therefore distributed over a longer period.

For both analysed groups of countries, controlling inflation is considered to be an important economic and political lever for promoting TFP growth or export growth per unit of invested R&D or per unit of human capital. The analysis showed a statistical significance of the influence of the share of military expenditures in GDP on the growth of TFP, or on the growth of exports per unit of R&D or per unit of human capital. This characteristic is more important in larger countries. In the area of economic structure, our analysis for both groups of countries showed a considerable influence of the amount of capital per employee.

The structure of the article below is as follows: a review of the literature, a description of the collected data and the methodology used, a presentation of observed countries and a presentation of the results of the analysis. At the end there are conclusions and references.

Literature Review

While conceiving the neoclassical model of economic growth, TFP was defined as a constant in the Cobb-Douglas production function by Robert Solow (1956). Practically simultaneously, Moses Abramovitz (1956) also discovered the same relationship. The constant in the Cobb-Douglas production function shows those influences on output that are not explained by the inclusion of labour and capital. The first calculations already showed the great importance of TFP for economic growth (Metcalfe, 1991). Changing TFP explains long-term economic growth and its short-term fluctuations (Tsounis & Steedman, 2021). TFP changes with changes in economies of scale, with changes in the allocation of production factors and with technological progress (Akkaya & Guvercin, 2018; Kim & Loayza, 2019).

TFP and the economic development of a country intertwine. With economic development, the importance of TFP increases (Porter, 2003; Lopez-Carlos, 2009). In different countries TFP growth is divided into that associated with catching up and that at the level of the world production frontier. The farther the country is from the technological frontier, the greater the catch-up effect on its TFP. Additionally, countries in the catching up process have very few opportunities (low impact of innovation activity) to improve the world's development boundaries (Haider *et al.*, 2021). Before the establishment of a consistent theory of the factors influencing the growth of TFP, partial analyses showed a dependence on the quality of work (Denison, 1962) and that, in relation to capital, it acts as an embedded technological advancement (Cornwall, 1991; Hall, Lotti & Mairesse, 2009). Since the information revolution in the late 1970s, factors explaining TFP (determinants of TFP) have been incorporated into the endogenous growth theory (Romer, 1986; Grossman & Helpman, 1991). These determinants are, specifically, human capital (knowledge) and investment in R&D. Their engagement leads to technological advancement with increasing returns, learning by doing and a positive impact on the rest of the economy, i.e. positive externalities (Evenson & Westphal, 1995; Mazzucato, 2013). Econometric analysis, with the introduction of new or improved econometric techniques, showed that TFP is influenced by the following factors: domestic investments in R&D and investments in R&D by trading partners, human capital, the business cycle, infrastructure, openness of a given national economy to the world, direct foreign investments and institutions (Grossman & Helpman, 1991; Aghion & Howitt, 1992; Coe & Helpman, 1995; Coe, Helpman & Hoffmaister, 2008). Regarding institutions, important aspects are how business can be done in a given national economy (licenses, registrations, etc.), the quality of both tertiary education and intellectual property protection and the foundations of the legal system (Acemoglu *et al.,* 2006). The effects of current R&D are constantly transferred to future R&D as learning (Coe, Helpman & Hoffmaister, 2008). Analyses have also shown that the impact of R&D on TFP is time uneven, sometimes simply not occurring – so-called “dry holes” (Rouvinen, 2002).

The factors that influence TFP are represented by different variables. Innovation activity can be represented by investments in R&D, the number of patents, the number of publications in scientific and technical journals, as well as the share of intangible assets in total assets (Nadiri, 1993; Chen & Dahlman, 2004; Guellec *et al.,* 2004; Bistrova *et al.*, 2017; Matos & Neve, 2020). Human capital can be represented by the number of years of education of employees or the number of employees with secondary and tertiary education, as well as by the extent of public investment in education, the number of students per teacher and test results (Antonelli & Fassio, 2016; Kim & Loayza, 2019). In developing countries, human capital can be represented by the human development index, which in addition to education also includes the health and standard of living across demographics (Al-Shammari & Al-Rakhis, 2019).

Models that explain TFP can include variables in one or more equations. For example, Antonelli and Fasio (2016) used different factors to explain intellectual capital (patents per employee) and the share of knowledge-intensive business services in total employment. At the next level they used these variables together with investments in R&D and the share of students in tertiary education relative to the entire population to explain TFP. Vila, Cabrer and Pavia (2015) also explained TFP in several equations. They used TFP-weighted distance between regions to explain the cross-border effects of economic development. Competitiveness, or export growth as its indicator, is related to productivity based on economies of scale (Verdoorn, 1949). New trade theory and other modern theories of economic growth account for the same factors affecting TFP, especially the endogenous factors of economic growth that affect export dynamics. According to new trade theory, companies must lead a strategic policy by investing in R&D and engaging human capital, and the state must help them with this in various ways. The result is improved quality (including completely new goods), lower costs, greater exports and a further increase in competitiveness through economies of scale (Krugman, 1990; Helpman, 2011). Export-based growth has become the condition sine qua non of economic development (Rochon & Rossi, 2017).

Data and Methodology

The assessment of efficiency of investments in R&D and the efficiency of human capital by promoting TFP and exports was carried out separately on a panel of seven large economically developed or rapidly developing countries and on a panel of five medium-sized or small countries in Central and Northern Europe. We included the USA with a specific way of promoting technological progress through state demand, three Western European countries (Germany, France and the United Kingdom) with an institutional framework for promoting technological progress mainly through subsidies to companies, and three Asian countries (Japan, China and South Korea) with institutions promoting technological progress emphasising economy of scope. The panel of medium-sized and small countries included Sweden and Denmark from Northern Europe and Switzerland, Austria and Slovenia from Central Europe.

The growth rates of the variables were tested for unit root (Maddala & Wu, 1999; Levin *et al.*, 2002; Im *et al.*, 2003). We did not include series with a unit root in the equation. The cointegration (endogeneity) between the growth rates of the variables used was eliminated by using the procedure described in Phillips and Moon (1999), Kao and Chiang (2000), Pedroni (2000) and Mark and Sul (2003).

Relevant determinants taken into account in our analysis were knowledge, the economic structure, economic and development policy, energy and ecology. These determinants were represented by growth rates of different variables. Annual series of these variables from 2000 to 2019 were obtained from Penn World Table (PWT), 2022c (TFP, human capital, population, GDP, capital, employment, employee benefits, share of government expenditures in GDP, price competitiveness), from OECD.Stat (exports and imports of goods and services, share of savings in GDP, investments in R&D), from UNCTADstat (inflation, ICT exports and imports), from World Bank Open Data (number of mobile phone subscribers per 100 inhabitants, share of defence expenditure in GDP, CO_2 emissions per inhabitant), from the Statistical Review of World Energy – BP (primary energy consumption per capita, electricity production, crude oil prices) and from the Fraser Institute / Economic Freedom (regulation efficiency index – one of the components of the common Economic Freedom index). Penn World Table measures TFP from the Tornqvist quantity index based on GDP, capital and labour inputs (Penn World Table (PWT), 2022a), while the assessment of human capital is based on average years of schooling and the assumed return to education (Penn World Table (PWT), 2022b).

We estimated eight equations on the annual growth rates between 2001 and 2019. Four equations explain the dynamics of TFP and exports per unit of R&D or per unit of human capital in large countries, while the next four equations explain these dynamics in the group of medium-sized and small countries. Shown schematically:

a) Equations explaining TFP growth rates and exports per unit of R&D and per unit of human capital in large countries:

$r(TFP/R\&D) = b1{*}rHC + b2{*}r(E/GDP)_{-2} + b3{*}r(FDI/GDP)_{-1} + b4{*}r((E \text{ and } I \text{ of } ICT)/L)_{-1} + b5{*}drR_{-2} + b6{*}r(ME/BDP)_{-1} - b7{*}rP_{-1} + b8{*}r(EC/POP)_{-1} - b9{*}rP\_OIL + b10{*}r(TFP/R\&D)_{-1} + u$

$r(TFP/HC) = b1{*}\ rR\&D + b2{*}r(K/L)_{-1} + b3{*}r((E+I)/GDP)_{-3} + b4{*}r(W/GDP)_{-2} + b5{*}r(G/GDP)_{-3} + b6{*}r(FDI/GDP)_{-3} + b7{*}r((E \text{ and } I \text{ of } ICT)/L) + b8{*}(S/BDP) + b9{*}drR_{-1} - b10{*}rP_{-1} - b11{*}r(EC/POP)_{-1} + b12{*}r(TFP/HC)_{-1} + u$

$r(E/R\&D) = b1{*}rHC_{-1} + b2{*}r(K/L)_{-1} + b3{*}r(W/GDP)_{-2} + b4{*}r(FDI/GDP)_{-1} + b5{*}r((E \text{ and } I \text{ of } ICT)/L) + b6{*}(S/BDP) + b7{*}drR_{-2} - b8{*}rRER_{-3} + b9{*}r(ELE/POP) - b10{*}r(ECO_2/POP) + b11{*}r(E/R\&D)_{-1} + u$

$r(E/HC) = b1{*}\ rR\&D + b2{*}r(K/L)_{-1} + r(E/HC) = b1{*}\ rR\&D + b2{*}r(K/L)_{-1} + b3{*}r((E+I)/GDP)_{-2} + b4{*}r(FDI/GDP)_{-1} + b5{*}r((E \text{ and } I \text{ of } ICT)/L)_{-1} + b6{*}(S/BDP) + b7{*}r(ME/BDP)_{-2} - b8{*}rP_{-1} - b9{*}r(EC/POP)_{31} - b10{*}rP\_OIL_{-1} + b11{*}r(E/R\&D)_{-1} + u$

b) Equations explaining TFP growth rates and exports per unit of R&D or per unit of human capital in medium-sized and small countries

$r(TFP/R\&D) = b1{*}rHC_{-1} + b2{*}r((E+I)/GDP)_{-3} + b3{*}r(FDI/GDP) + b4{*}rR + b5{*}dr(ME/BDP)_{-1} - b6{*}rP - b7{*}r(EC/POP)_{-3} - b8{*}rP\_OIL_{-3} - b9{*}r(ECO_2/POP) + b10{*}r(TFP/R\&D)_{-1} + u$

$r(TFP/HC) = b1{*}r(K/L)_{-1} + b2{*}r((E+I)/GDP)_{-3} + b3{*}r(FDI/GDP)_{-3} + b4{*}r((E \text{ and } I \text{ of } ICT)/L) + b5{*}(S/BDP) + b6{*}rR_{-2} - b7{*}rP_{-1} - b7{*}rP\_OIL_{-1} - b8{*}r(ECO_2/POP)_{-1} + b9{*}r(TFP/HC)_{-1} + u$

$r(E/R\&D) = b1{*}rHC_{-1} + b2{*}r((E+I)/GDP)_{-3} + b3{*}r(W/GDP)_{-3} + b4{*}r(FDI/GDP)_{-1} + b5{*}r((E \text{ and } I \text{ of } ICT)/L)_{-3} + b6{*}(S/BDP) + b7{*}rR_{-2} - b8{*}rP_{-1} + b9{*}r(ELE/POP)_{-3} - b10{*}rP\_OIL_{-3} + b11{*}r(E/R\&D)_{-1} + u$

$r(E/HC) = b1{*}r(K/L)_{-1} + b2{*}r(G/GDP)_{-2} + b3{*}r(FDI/GDP)_{-1} + b4{*}r((E \text{ and } I \text{ of } ICT)/L) + b5{*}r(MF/POP)_{-2} + b6{*}(S/BDP) + b7{*}rR_{-2} - b8{*}rRER_{-1} - b9{*}rP_{-1} + b10{*}r(ELE/POP)_{-2} + b11{*}r(E/R\&D)_{-1} + u$

Where: *r* is a sign for growth rate, *dr* is a sign for first differences of growth rates, *b1, b2,…* are regression coefficients, $_{-1,\,-2,\dots}$ are signs for time lag in years, *TFP* is total factor productivity, *HC* is human capital index, *L* is number of employees, *K* is capital, *E* is exports of goods and services, *I* is imports of goods and services, *GDP* is gross domestic product, *W* is employee benefits, *G* is government expenditure, *S* is savings, *FDI* is inflow of foreign direct investments, *E* and *I* of *ICT* is exports and imports of information and communication technology, *MF* is number of mobile phones, *R* is regulation index, *ME* is military expenditure, *P* is inflation, *RER* is real exchange rate, *EC* is energy consumption, *ELE* is electric power production , *P_OIL* is crude oil prices, *POP* is number of population, *ECO2* is *CO2* emissions and *u* is unexplained residual.The distribution of the impact of the independent variable on the dependent variable was estimated using a one-year lagged dependent variable. The long-term elasticity of the explained variable was calculated as:

(1) $DE = b / (1 - \lambda)$

Where DE represents long-term elasticity, b is the regression coefficient of short-term elasticity, and λ is the regression coefficient for the one-year lagged explained variable (Koyck 1954; Berndt 1991).

Presentation of Economic Development, Exports and Endogenous Growth Factors in the Observed Countries

The twelve countries included in our analysis accounted for 28% of the world's population and in 2019 generated 62% of global GDP (UNCTADstat). As seen in Table 1 from 2001 to 2019, among large countries GDP per capita grew fastest in China (average of 8.3% annually) and South Korea (average of 3.3% annually), and slowest in Japan and France (0.7% annually). In 2019, GDP per capita in this group of countries was highest in the USA ($60 thousand) and lowest in China ($10 thousand).

Among the large countries in the analysed period, TFP grew fastest in China (1.2% annually) and slowest in France (practically stagnated). In 2019, it was highest in the USA (factor of 1), followed by Germany with a factor of 0.91, and lowest in China with a factor of 0.4. Among medium-sized and small countries TFP grew fastest in Slovenia (1.1% annually) and slowest in Denmark and Austria (0.3% annually). In 2019, it was highest in Switzerland (factor of 0.92) and Denmark (factor of 0.91) and lowest in Slovenia (factor of 0.63).

Exports of goods and services in the observed period among large countries, measured in current dollars per employee, grew fastest in China (11.1% annually) and slowest in Japan (1% annually). In 2019, this factor was largest in Germany ($41 million) and smallest in China ($3 million). In medium-sized and small countries exports grew fastest in Slovenia (6.2% annually) and slowest in Sweden (2.4% annually). In 2019, they were largest in Switzerland ($96 million) and smallest in Slovenia ($43 million).

During the analysed period, among large countries R&D investments (in real terms and measured per employee) grew fastest in China (14.4% annually) and slowest in Japan (1.3% annually). The growth of these investments was also very fast in South Korea (8.2% annually). In 2019, they were the largest in the United States (almost $4,000) and the smallest in China ($644). In the observed medium-sized and small countries, investments in R&D per employee grew fastest in real terms per employee in Slovenia (4.6% annually) and slowest in Sweden (1.4% annually). In 2019, in this group of countries investments in R&D per employee were largest in Switzerland ($3,708) and smallest in Slovenia ($1,487).

In 2019, among the large countries human capital ranked highest in the United Kingdom (factor of 1.01) and lowest in China (factor of 0.72). From 2000 to 2019, it grew fastest in South Korea (0.9% annually) and slowest in the USA and Germany (0.2% annually). Among medium-sized and small countries, human capital was the highest in Switzerland (factor of 0.99) and lowest in Austria (factor of 0.95). From 2001 to 2019, it grew fastest in Slovenia as well as Denmark (0.5% annually) and slowest in Switzerland (0.3% annually).

From 2001 to 2019, the efficiency of R&D investments relative to the achieved TFP decreased in all twelve observed countries. Increasing TFP required increasingly more R&D investment per unit of TFP, or other factors affecting TFP deteriorated. The countries that increased investments in R&D the fastest, in fact, lowered the effectiveness of these investments in stimulating TFP growth (China, South Korea, Austria and Slovenia).

Conversely, in the analysis period the effectiveness of human capital investment in promoting TFP in both groups of countries was mainly increasing. TFP per unit of human capital grew fastest in China (0.4% annually), while it declined in the United Kingdom (-0.2% annually) and France (-0.6% annually). In the medium-sized and small countries TFP per unit of human capital grew fastest in Slovenia (0.6% annually), while in Denmark (-0.1% annually) and Austria (-0.2% annually) it declined.

Table 1

Economic Growth, Total Factor Productivity, Exports and Endogenous Growth Factors

The situation in 2019 and	**GDP per capita**	**Total factor productivity**	**Export of goods and services**	**R&D**	**Human capital**
Average annual growth 2001 to 2019	**$ thousand**	**Relative to the US**	**$ million per 1000 employees**	**$ per employee, constant prices**	**Relative to the US**
US	60	1.00	16	3997	1.00
(growth)	1.1%	0.6%	2.6%	3.0%	0.2%
China	10	0.40	3	644	0.72
(growth)	8.3%	1.2%	11.1%	14.4%	0.8%
Japan	42	0.63	13	2456	0.96
(growth)	0.7%	0.4%	1.0%	1.3%	0.4%
South Korea	42	0.60	24	3730	1.00
(growth)	3.3%	1.2%	4.6%	8.2%	0.9%
Germany	50	0.91	41	2946	0.98
(growth)	1.2%	0.4%	4.1%	2.7%	0.2%
France	43	0.89	30	2240	0.86
(growth)	0.7%	0.006%	2.4%	1.5%	0.6%
UK	45	0.77	27	1562	1.01
(growth)	1.0%	0.2%	2.1%	2.0%	0.4%
Sweden	51	0.81	51	3547	0.92
(growth)	1.4%	0.8%	2.4%	1.4%	0.4%
Denmark	53	0.91	68	2986	0.96
(growth)	0.8%	0.3%	3.6%	2.4%	0.5%
Switzerland	68	0.92	96	3708	0.99
(growth)	0.9%	0.6%	4.6%	3.7%	0.3%
Austria	53	0.80	54	3216	0.90
(growth)	1.0%	0.3%	3.8%	4.3%	0.4%
Slovenia	37	0.63	43	1487	0.95
(growth)	2.1%	1.1%	6.2%	4.6%	0.5%

Sources: OECD, Penn World Table, UNCTAD stat, own calculations

Among the large countries the exports per unit of investment in R&D grew fastest in Germany (1.5% annually) and worsened in South Korea (-2.9% annually) and in China (-3.4% annually). In medium-sized and small countries the export of goods and services per R&D unit grew the fastest in Slovenia (1.5% annually) and in Sweden (1.2% annually), while it declined in Austria (-0.2% annually).

The effectiveness of human capital in promoting the growth of exports among large countries increased fastest in China (9.6% annually) and slowest in Japan (0.8% annually). Among medium-sized and small countries it increased fastest in Slovenia (5.7% annually) and Switzerland (4.1% annually) and slowest in Sweden (2.2% annually).

Results

The factors that influence the effectiveness of R&D investments and human capital in promoting the growth of TFP and growth of exports are shown in Tables 2 to 9. We performed the assessment separately for the balanced panel of large countries and of the medium-sized and small countries. The analysis was carried out with variables mostly of growth rates and by eliminating the influence of the variables' endogeneity. In some cases, we avoided the unit root in a variable by including the first differences of the growth rates of that variable in the equation. The coefficient of determination (R^2) is between 35.4% and 76.6%.

Table 2

Determinants of Total Factor Productivity per Unit of R&D Investment in the Seven Large Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Human capital	0.5156 (2.1)	0.7638
	Exports to GDP (-2)	0.0388 (1.7)	0.0575
Economic structure	FDI to GDP (-1)	0.0359 (2.4)	0.0532
	Export and import of ICT per employee (-1)	0.0214 (1.9)	0.0316
Economic and development	Regulation[1] (-2)	0.0628[3] (1.6) [0.0013][2]	0.0930[3]
politics	Military expenditure to GDP (-1)	0.1573 (3.5)	0.2331
	Inflation (-1)	-0.5092 (-3.1)	-0.7542
Energy	Energy consumption per capita (-1)	-0.1356 (-2.0)	-0.2008
	Oil prices	-0.0279 (-4.2)	-0.0401
Dependent variable delayed by one period	TFP on R&D (-1)	0.3249 (4.9)	
R^2	76.6%		

Source: Own calculations

[1]First differences in growth rates, [2]Elasticity estimated by simulating the equation, [3]Estimated effect is not elasticity.

The first column in the tables sets out the determinants that, according to economic theory, affect the effectiveness of investments in R&D or human capital in promoting total factor productivity or exports. The second column shows the variables that represent these determinants. The parentheses under the variables' names in this column indicate the lag (how many years from a change in the independent variable are needed to produce the change in the dependent variable). The third column of the tables presents the coefficients showing the short-term influence of an independent variable on the dependent variable. In parentheses next to the coefficients is the t value. The last column of the tables shows the long-term influence of the dependent variable to a given explanatory variable.

The results (coefficients) mainly convey elasticities, that is, by how many percent the dependent variable changes if the independent variable changes by one percent. When the coefficients did not show elasticity (the independent variable is in absolute value or in the first differences of growth rates), short-run elasticity was estimated by simulating the equation. The result is presented in square brackets below the t-value. In such cases, we did not estimate the long-term elasticity.

Table 3

Determinants of Total Factor Productivity per Unit of Human Capital in the Seven Large Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Investments in R&D	0.1677 (5.7)	0.2556
	Capital per employee (-1)	0.2224 (2.0)	0.3390
Economic Structure	Exports and imports to GDP (-3)	0.032 (3.3)	0.0488
	Employee benefits to GDP (-2)	0.1452 (2)	0.2214
	Government expenditure to GDP (-3)	0.0371 (1.7)	0.0566
	FDI to GDP (-3)	0.0004 (2.3)	0.0007
	Export and import of ICT per employee	0.035 (6.5)	0.0534
	Savings to GDP[1]	0.0008[3] (1.7) [0.0002][2]	0.0013[3]
Economic and development politics	Regulation[4] (-1)	0.0427[3] (2.3) [0.0004][2]	0.0661[3]
	Inflation (-1)	-0.2199 (-2.8)	-0.3352

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Energy	Energy consumption per capita (-1)	-0.0880 (-2.5)	-0.1341
Dependent variable delayed by one period	TFP per human capital (-1)	0.3439 (5.2)	
R^2	53.2%		

Source: Own calculations

[1]Absolute value, [2]Elasticity estimated by simulating the equation, [3]Estimated effect is not elasticity, [4]First differences of growth rates.

Estimations for Large Countries

In Table 2, we see that the effectiveness of R&D investments in promoting TFP in the large countries is influenced most by the simultaneous engagement of human capital and low inflation. After the adaptation period, the elasticity of both is almost 0.8. A 1% increase in human capital or a 1% decrease in inflation results in a 0.8% increase in TFP per unit of R&D investment. Investment in human capital has a simultaneous effect on TFP with investment in R&D (Ziesemer, 2021), while changes in inflation are delayed by a year. Somewhat smaller, but still significant, are the impacts of defence spending and increased energy efficiency. Both operate in the short run with a lag year and a long run elasticity of 0.2. In both cases, it is the effect of increased, concentrated and stable investments in technologically demanding and knowledge-based activities. The results in Table 2 show that the effectiveness of R&D investments in promoting TFP is also influenced by the share of exports in GDP, it works through specialization and economies of scale (Helpman, 2011), the impact of the share of FDI in GDP (similar result as in Makieła *et al.*, 2021), Wojciechowski & Wach, 2021) and the impact of external exchanges of ICT technology per employee as an indicator of digitalization (similar result as in Jurado-González & Gómez-Barroso, 2022). The impact of changing the share of FDI in GDP and external trade in ICT technologies on the employee occurs after one year, and the impact of the share of exports in GDP after two years. The effectiveness of R&D investment in promoting TFP is also under a statistically significant but small influence of improved regulation (Wen *et al.*, 2021), while the rise in oil prices has a small negative effect, as it reduces the possibilities of economic adjustment (Kim & Vera, 2022).

Table 4

Determinants of Export per Unit of R&D Investment in the Seven Large Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Human capital (-1)	1.5368 (1.9)	1.8933
	Capital per employee (-1)	0.7906 (1.1)	0.9739
Economic structure	Employee benefits to GDP (-2)	0.5587 (1.7)	0.6883
	FDI to GDP (-1)	0.0485 (1.4)	0.0597
	Export and import of ICT per employee	0.1722 (5.8)	0.2122
	Savings to GDP[1]	0.0026[3] (1.1) [0.0003][2]	0.0035[3]
Economic and development politics	Regulation[4] (-2)	0.1330[5] (1.4) [0.0014][2]	0.1639[3]
	Real exchange rate (-3) (-3)	-0.0863 (-1.7)	-0.1063
Energy	Electricity production per capita	1.1031 (5.2)	1.3589
Ecology	CO_2 emissions per capita	-0.3305 (-2.0)	-0.4072
Dependent variable delayed by one period	Exports on R&D (-1)	0.1883 (3.4)	
R^2	54.5%		

Source: Own calculations

[1] Absolute value, [2] Elasticity estimated by simulating the equation, [3] Estimated effect is not elasticity, [4] First differences of growth rates.

The effect of human capital dynamics on changing TFP is simultaneously related to R&D investment with a long-term elasticity close to 0.3 (Table 3). The dynamics of capital per employee yield changes in TFP per unit of human capital one year after a change, and the long-term elasticity is 0.3. The development or assimilation of technology requires investments in both human and physical capital (Santos-Arteaga *et al.*, 2020). The growth of remuneration per employee influences the growth of TFP per unit of human capital with a lag of two years and- has a long-term elasticity of 0.2. Statistically significant but small here are also the influences of the dynamics of the share of exports and imports to GDP, the share of state spending to GDP as an indicator of changing potential for development policy (Kowalski, 2022), the share of FDI to GDP, the impact of the dynamics of foreign exchange of ICT technology on the employee and the impact of the share of savings to GDP as a basis for the efficient operation of the financial and especially the credit system, having a further impact on the introduction of new technologies and business approaches (Santos-Arteaga *et al.*, 2020). The dynamics of the share of savings in GDP and external trade with ICT technologies measured per employee affect simultaneously with the change in TFP on engaged human capital, while the share of external trade in GDP, the share of government spending in GDP and the share of FDI in GDP affect after three years. In the field of policy control, inflation has a strong (long-term elasticity of inflation is above -0.3) influence on TFP dynamics per unit of human capital. The lag of the impact is one year. The effect of improving regulation is statistically significant but small, and again with a one-year lag of influence.

Table 5

Determinants of Exports per Unit of Human Capital in The Seven Large Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Investments in R&D	0.5411 (3.0)	0.7208
	Capital per employee (-1)	3.3312 (5.0)	4.4376
Economic structure	Exports and imports to GDP (-2)	0.3116 (4.6)	0.4151
	FDI to GDP (-1)	0.0818 (1.9)	0.1089
	Export and import of ICT per employee (-1)	0.1123 (3.1)	0.1496
	Savings to GDP[1]	0.0077[3] (2.7) [0.0013][2]	0.0102[3]
Economic and development	Military expenditure to GDP (-2)	0.3108 (2.5)	0.4140
politics	Inflation (-1)	-2.1730 (-3.8)	-2.8947
Energy	Energy consumption per capita (-3)	-0.3896 (-2.3)	-0.5190
	Oil prices (-1)	-0.0540 (-2.0)	-0.0720
Dependent variable delayed by one period	Exports per unit human capital (-1)	0.2493 (2.9)	
R^2	47.6%		

Source: Own calculations

[1] Absolute value, [2] Elasticity estimated by simulating the equation, [3] Estimated effect is not elasticity.

The effectiveness of human capital investment in stimulating TFP is also affected by improving energy efficiency. The impact occurs after one year with a long-term elasticity of 0.1.

Table 4 shows the effectiveness of R&D investment in promoting competitiveness and the resulting growth of exports in large countries. This efficiency, with a long-term elasticity of 1.9 and a year of operational lag, is most affected by the dynamics of human capital. Here, too, the simultaneous action of endogenous factors of economic growth is noticeable. With a long-term elasticity of almost 1.4, the effect of growth in electricity supply is also high, and it reflects the impact of accessibility to energy resources which are necessary for the introduction of new technologies or their assimilation (Şerban *et al*., 2022).

The dynamics of exports per unit of investment in R&D are influenced by changes in capital per employee (long-term elasticity is 1), as well as the dynamics of the share of employee benefits in GDP (long-term elasticity is 0.7) and the external exchange of ICT per employee (long-term elasticity is 0.2). The latter effect is simultaneous, the change of capital per employee is evident after one year, and the employee benefits after two years. The dynamics of exports per unit of investment in R&D is also statistically significantly related to the share of FDI in GDP and the share of savings in GDP, except that the influence in this case is small. The impact of the dynamics of savings on GDP occurs simultaneously, while the change in the share of FDI in GDP has an effect with a lag of one year.

Table 6

Determinants of Total Factor Productivity per Unit of R&D Investment in the Five Small and Medium-Sized Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Human capital (-1)	0.6599 (1.9)	0.7524
Economic structure	Exports and imports to GDP (-3)	0.2516 (2.4)	0.2869
	FDI to GDP	0.0371 (1.1)	0.0423
	Regulation	0.6598 (3.5)	0.7524
Economic and development politics	Military expenditure to GDP[1] (-1)	0.0941[3] (1.7) [0.0006][2]	0.1073[3]
	Inflation	-1.1381 (-2.5)	-1.2977
Energy	Energy consumption per capita (-3)	-0.2427 (-2.3)	-0.2767
	Oil prices (-3)	-0.0619 (-2.6)	-0.0705
Ecology	CO_2 emissions per capita	-0.2197 (-2.4)	-0.2506
Dependent variable delayed by one period	TFP on R&D (-1)	0.1230 (1.3)	
R^2	35.4%		

Source: Own calculations

[1] First differences in growth rates, [2] Elasticity estimated by simulating the equation, [3] Estimated effect is not elasticity.

Among the variables that show the conduct of economic policy there is a statistically significant, but small, influence of the dynamics of regulation, and a moderate influence of the real exchange rate. Here, the long-run elasticity is -0.1. Deterioration of price competitiveness reduces the effectiveness of R&D investment in promoting exports.

The effectiveness of investments in R&D in promoting exports is also related to protecting the environment

(Kowalski 2022). The long-term elasticity between the growth of CO_2 emissions per capita and the dynamics of exports per unit of investment in R&D is -0.4. The effect occurs in the current year.

In Table 5 we see a strong connection between the dynamics of exports per unit of human capital and investment in R&D. Their influence starts in the current year, and the long-term elasticity is 0.7. Among the economic structure variables, the dynamics of capital per employee has the greatest influence (long-term elasticity is 4.4), followed by the dynamics of involvement in international exchange (long-term elasticity is 0.4), the dynamics of exchange of ICT per employee (long-term elasticity is 0.15) and the dynamics of the share of FDI in GDP (long-term elasticity is 0.1). The effect begins one or, in the case of the share of external exchange in GDP, two years after the change in the independent variable. The influence of the share of savings in GDP is also statistically significant but small. Inflation control (long-term elasticity of inflation is -2.9) as well as the concentration and stability of research related to the share of defence expenditures in GDP (long-term elasticity is 0.4) have a strong influence on the efficiency of human capital in promoting exports in large countries. The effect of changing inflation occurs after one year, and the effect of changing the share of defence expenditures in GDP occurs after two years. In large countries the dynamics of exports per unit of human capital is also dependent on energy efficiency (long-term elasticity of change in energy consumption per capita is 0.5). The growth of energy efficiency increases the effectiveness of human capital in promoting competitiveness, and the impact occurs after three years. In the field of energy, the influence of oil price dynamics on export dynamics per unit of human capital is statistically significant but small (long-term elasticity is below -0.1). The effect occurs after one year.

Estimation for Medium-Sized and Small European Countries

The dynamics of TFP per unit of investment in R&D of the medium-sized and small countries is explained by the variables shown in Table 6. The strongest influence here belongs to the control of inflation (long-term elasticity of inflation is -1.3), and the effect is simultaneous. The same applies to the effect of regulation dynamics (long-term elasticity is 0.7). Among the policy variables the impact of changing the share of defence expenditures in GDP is also statistically significant but small. It occurs after one year. The effectiveness of R&D investments in promoting TFP growth with a lag year is also strongly influenced by the dynamics of human capital (the long-term elasticity is almost 0.8). TFP per unit of investment in R&D is additionally affected by the dynamics of integration into international trade (long-term elasticity is 0.3) and, to a lesser degree but still statistically significant, the share of FDI in GDP. The impact of the dynamics of foreign trade occurs within three years, while the effect of the dynamics of the FDI share in GDP is simultaneous. The dynamics of energy efficiency (long-term elasticity of change in energy consumption per capita is -0.3) and the dynamics of global crude oil prices (elasticity is small) affect the dynamics of TFP per unit of investment in R&D with a three-year lag. The effect of reducing CO_2 emissions is strong (long-term elasticity is close to -0.3) and occurs simultaneously.

Table 7 shows that TFP per unit of human capital is strongly influenced by control of inflation (long-term elasticity of inflation is -1) and to certain extend also by regulation (long-term elasticity is 0.2). The first effect appears after one year, and the second after two. The next influential factor of TFP per unit of human capital is the dynamics of capital per employee (long-term elasticity is 0.5) and to some extent both the dynamics of the external exchange of ICT per employee and the dynamics of the country's inclusion in international trade. Long-term elasticity here is slightly below 0.1. The dynamics of digitalization already take effect in the current year, and the dynamics of capital per employee and the share of foreign trade in GDP follow one year after the change. The influence of the share of savings in GDP as well as the share of FDI in GDP are statistically significant but small. The influence of the dynamics of the share of savings in GDP occurs simultaneously, while changes in the share of FDI in GDP have an effect with a three-year lag.

Table 7

Determinants of Total Factor Productivity per Unit of Human Capital in the Five Small and Medium-Sized Countries

Growth rates Period: 2001–2019	Variables (lag in years)	Coefficient (t-statistics)	Long-term elasticity
	Capital per employee (-1)	0.3812 (3.2)	0.5019
	Exports and imports to GDP (-1)	0.0484 (1.3)	0.0637
Economic structure	FDI to GDP (-3)	0.0185 (1.8)	0.0244
	Export and import of ICT per employee	0.0645 (4.2)	0.0850
	Savings to GDP[1]	0.0012[3] (2.3) [0.0001][2]	0.0016[3]
Economic and development	Regulation (-2)	0.2445 (3.0)	0.1902
politics	Inflation (-1)	-0.7571 (-4.8)	-0.9969
Energy	Oil prices (-1)	-0.0085 (-1.1)	-0.0519
Ecology	CO_2 emissions per capita (-1)	-0.0514 (-1.9)	-0.0677
Dependent variable delayed by one period	TFP per unit of human capital (-1)	0.2406 (2.5)	
R^2	67.6%		

Source: Own calculations

[1] *Absolute value,* [2] *Elasticity estimated by simulating the equation,* [3] *Estimated effect is not elasticity.*

The effectiveness of human capital in stimulating TFP is negatively affected by the dynamics of crude oil prices and the growth of CO_2 emissions. The long-term elasticity for both is slightly below 0.1, and the lag is one year.

In Table 8, we see that the effectiveness of R&D investments in promoting exports is influenced most by the simultaneous operation of human capital (the long-term elasticity is as much as 4.9). There is also a strong influence of inflation control (long-term elasticity of inflation is -2.7) and regulation dynamics (long-term elasticity is 1.2). The effect of inflation dynamics appears after one year, and the effect of regulation dynamics after two years.

The effectiveness of R&D investments in promoting exports is then influenced by the dynamics of the share of employee benefits in GDP (long-term elasticity is 1), the dynamics of the share of foreign trade in GDP (long-term elasticity is 0.7), the dynamics of the share of FDI in GDP (long-term elasticity is 0.3) and the dynamics of external exchange of ICT per employee (long-term elasticity is 0.2). The influence of the dynamics of the share of FDI in GDP occurs in one year, and the influence of the other three variables in three years. The efficiency of investments in R&D in promoting TFP is also statistically significant, simultaneously but slightly influenced by the share of savings in GDP.

Exports per unit of R&D investment also depends on the supply of electricity. The long-term elasticity is 0.2, and the lag is three years. A negative effect has global crude oil price dynamics with long-term elasticity slightly above 0.1 and with a lag of three years.

Table 8

Determinants of Exports per Unit of Investment in R&D in the Five Small and Medium-Sized Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
Knowledge	Human capital (-1)	3.0495 (4.9)	4.9150
	Exports and imports to GDP (-3)	0.4305 (2.4)	0.6939
Economic structure	Employee benefits to GDP (-3)	0.6327 (1.2)	1.0197
	FDI to GDP (-1)	0.1729 (3.3)	0.2787
	Export and import of ICT per employee (-3)	0.1162 (1.5)	0.1874
	Savings to GDP[1]	0.0078[3] (2.9) [0.0008][2]	0.0125[3]
Economic and development	Regulation (-2)	0.7410 (2.7)	1.1943
politics	Inflation (-1)	-1.6721 (-2.5)	-2.6949
Energy	Electricity production per capita (-3)	0.1253 (1.4)	0.2019
	Oil prices (-3)	-0.0806 (-2.1)	-0.1299
Dependent variable delayed by one period	Exports on R&D (-1)	0.3786 (4.1)	
R^2	54.2%		

Source: Own calculations

[1] Absolute value, [2] Elasticity estimated by simulating the equation, [3] Estimated effect is not elasticity.

The results in Table 9 show a strong influence of the controlling of inflation on exports per unit of human capital. The long-term elasticity of inflation is as much as -2, and the effect appears after one year. Among the political variables, regulation (long-term elasticity is 0.7 with two years lag) and real exchange rate (long-term elasticity is -0.2 with one year lag) are also statistically significant.

The dynamics of capital per employee impacts exports per unit of human capital with long-term elasticity of 1.9 with two years lag. Digitalization also plays a significant role here. For export and import of ICT per employee, the long-term elasticity is 0.5 and takes effect in the current year, while considering the number of mobile phones per capita, the long-term elasticity is 0.3, and the lag is two years. Changing the share of government expenditure in GDP affects the effectiveness of human capital in promoting exports with a two-year lag and a long-term elasticity of 0.3, and the share of FDI in GDP has a one-year lag and a long-term elasticity of 0.1. The influence of the share of savings in GDP is, again, statistically significant but small.

Table 9

Determinants of Exports per Unit of Human Capital in the Five Small and Medium-Sized Countries

Growth rates Period: 2001–2019	**Variables (lag in years)**	**Coefficient (t-statistics)**	**Long-term elasticity**
	Capital per employee (-2)	1.4038 (3.2)	1.9189
	Government expenditure to GDP (-2)	0.2109 (1.5)	0.2883
Economic structure	FDI to GDP (-1)	0.0634 (1.5)	0.0866
	Export and import of ICT per employee	0.3934 (6.7)	0.5377
	Mobile phones per capita (-2)	0.2547 (2.4)	0.3481
	Savings to GDP[1]	0.0055[3] (2.7) [0.0005][2]	0.0075[3]
Economic and development	Regulation (-2)	0.5104 (2.9)	0.6977
politics	Real exchange rate (-1)	-0.1528 (-1.9)	-0.2088
	Inflation (-1)	-1.4750 (-3.0)	-2.0162
Energy	Electricity production per capita (-2)	0.2063 (3.2)	0.2819

Growth rates Period: 2001–2019	Variables (lag in years)	Coefficient (t-statistics)	Long-term elasticity
Dependent variable delayed by one period	Exports per unit of human capital (-1)	0.2684 (3.1)	
R^2	74.8%		

Source: Own calculations
[1] Absolute value, [2] Elasticity estimated by simulating the equation, [3] Estimated effect is not elasticity.

The dynamics of exports per unit of human capital is also influenced by the dynamics of electricity supply, as shown by changes in its production per capita. The long-term elasticity is 0.3, and the effect starts after three years.

Conclusions

The results of our analysis confirmed that the influence of endogenous growth factors on TFP and competitiveness (as shown by export dynamics) are complementary. Here, human capital influences the efficiency of investments in R&D and vice versa. This is especially true for large countries, while the impact of human capital efficiency in medium-sized and small countries in stimulating TFP and exports does not depend on investments in R&D.

Among the variables that show changes in the economic structure, the dynamics of capital per employee has the strongest positive influence on the effectiveness of investments in R&D and human capital in promoting TFP and exports. This effect is especially strong when promoting exports in large countries and when influencing the efficiency of human capital in promoting exports in medium-sized and small countries. The moderate positive influence of the dynamics of the share of FDI in GDP can be detected on the effectiveness of investment in R&D and human capital in promoting TFP and in promoting exports in both the group of large countries and the group of medium-sized and small countries.

The dynamics of the share of employees' remuneration in GDP in both groups of countries has the strongest positive influence on the effectiveness of R&D investments in promoting the dynamics of exports. This influence is also noticeable in explaining the dynamics of TFP per unit of human capital in the group of large countries. On the other hand, the dynamics of the share of state expenditures in GDP has a positive but small impact on the efficiency of human capital in promoting TFP in the large countries and in promoting exports in the medium-sized and small countries. The same applies to the influence of the dynamics of the share of foreign trade in GDP. This impact generally has a significant lag. The share of savings in GDP affects the effectiveness of investments in R&D and human capital in promoting TFP and exports simultaneously within the current year, but the impact is small. It is, in fact, negligible in terms of effectiveness of investments in R&D in promoting TFP dynamics.

Digitalization, as shown by the real export and import of ICT per employee, affects the effectiveness of investments in R&D and the effectiveness of human capital in promoting TFP and in promoting exports. The impact is small but principally very fast. This effect was not detected only when assessing the dynamics of TFP per unit of investment in R&D in medium-sized and small countries. The dynamics of exports per unit of human capital in these countries is also influenced by level of mobile phone ownership.

Among economic policy variables, inflation has the greatest impact on the effectiveness of investments in R&D and human capital in promoting TFP and exports. In the medium-sized and small countries, long-term elasticities of inflation are equal to or higher than 1 across all factors. The same is true for the export dynamics per unit of human capital in large countries. The lag is generally one year. The impact of inflation on the effectiveness of investments in R&D and human capital in promoting TFP and exports was also assessed through the impact of the dynamics of real exchange rate (the impact of exchange rate policy is also included here). This effect was detected when evaluating the dynamics of exports per unit of R&D investment in large countries and exports per unit of human capital in medium-sized and small countries. Taken as a whole, we can conclude that the control of inflation strongly influences the productivity and competitiveness of a given national economy.

Regulation generally influences the effectiveness of investments in R&D and human capital in promoting TFP as well as in promoting exports. This influence was detected in explaining the dynamics of TFP per unit of human capital and exports per unit of investment in R&D in large countries, on the other hand, the effect of regulation is clearly general and very strong.

In large countries, TFP per unit of investment in R&D and exports per unit of human capital are also positively affected by changes in the share of defence expenditures in GDP. The onset of this impact comes one to two years after the change. In medium-sized and small countries, we found this effect when explaining TFP per unit of R&D investment.

The improvement of energy efficiency or the decrease of primary energy consumption per inhabitant mainly affects the growth of the impact of investments in R&D and human capital in promoting TFP or exports in large countries. Here, we did not perceive the effect only in the assessment of exports per unit of investment in R&D. In the medium-sized and small countries this effect was detected in the assessment of TFP per unit of investment in R&D. In this group of countries, the increase in global crude oil prices has a negative effect on the efficiency of investments in R&D and human capital, in promoting TFP and on the efficiency of investments in R&D in promoting exports. Oil prices also negatively affect the efficiency of R&D investment in promoting TFP and the efficiency of human capital in promoting exports in large countries. In the large countries, electrification (ensuring a stable supply of electricity) strongly influences the effectiveness of human capital in promoting exports. In the medium-sized and small countries, this effect can be detected in the exports per unit of investment in R&D and per unit of human capital.

Threats to the environment or air pollution (CO_2 emissions) have a negative impact on the effectiveness of R&D investments in promoting TFP in medium-sized and small countries and in promoting exports in large countries. The growth of CO_2 emissions also negatively affects the dynamics of TFP per unit of human capital in medium-sized and small countries. The impact is strong (the exception is the relatively small effect on TFP per unit of human capital in medium-sized and small countries) and generally occurs simultaneously.

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