R&D in a post centrally-planned economy: The macroeconomic effects in Poland

R&D in a post centrally-planned economy: the macroeconomic effects in Poland

Katarzyna Zawalińska[a *], Nhi Tran[b], Adam Płoszaj[c]

[a] *IRWiR, Polish Academy of Sciences; ul. Nowy Świat 72, 00-330 Warsaw, Poland; email: kzawalinska@irwirpan.waw.pl (corresponding author)*
[b] *Centre of Policy Studies Victoria University; 10/300 Flinders Street, Melbourne, Australia; email: nhi.tran@vu.edu.au*
[c] *EUROREG, University of Warsaw; ul. Krakowskie Przedmieście 30, 00-927, Warsaw, Poland; email: a.ploszaj@uw.edu.pl*

Abstract

Half a century of centrally planned policy in the Central and Eastern European countries resulted in outdated technologies, inefficient allocation of resources and low productivity. Following the end of communism there was a fifteen year process of transition which ended in 2004 with eight post-communist countries joining the European Union (EU) of which Poland was the largest. As part of the EU these countries now face the challenge of the common EU strategy *Europe 2020*, which has set the target of achieving R&D expenditure to GDP ratio (called the R&D intensity) of 3% by 2020 for the Union as a whole in an effort to increase the competitiveness of the region. Poland, like the other post-communist countries, faces a lower target of R&D intensity, set at 1.7%. Nevertheless, the challenge is immense, since the country is still at only half that level and has little experience in developing policies to help achieve it. In this paper we tested two possible policy options to achieve the target: (1) to increase government expenditures on R&D and**;** (2) to provide tax relief on R&D to businesses. The method applied to assess the options is a recursive dynamic computable general equilibrium (CGE) model for Poland with an explicit link between productivity and R&D stock. The results show that achieving the R&D intensity target via the use of tax relief is 2.5 times more costly to the government budget, but it has a greater impact on the economy in terms of a higher GDP growth. Tax relief proved efficient in the short run while in the long run the government expenditure policy provides better value for money.

Keywords: R&D policy, productivity spillovers, stock of knowledge, CGE model, macroeconomic effects, post-communist countries.

JEL codes: O32, O38, O47, C68, P27

[*] Corresponding author Katarzyna Zawalińska. E-mail address: kzawalinska@irwirpan.waw.pl

1 Introduction

Half a century of central planning left the Central and Eastern European economies with outdated technologies and an inefficient allocation of resources. Following market reforms and structural changes during the 1990s, the situation in the region started to improve and in most countries significant productivity gains were observed (Kolasa, 2008). In 2004, eight ex-communist Central European economies (CE-8) joined the European Union (EU), marking a symbolic end to their period of transition. Since accession, the CE-8 have had to contribute to wider EU development as outlined in a range of strategic plans. The current EU strategy, Europe 2020, emphasizes that research, development and innovation are key policy components of economic growth and sets an average 3% target for R&D intensity[1] across the EU. In addition it establishes individual targets that each country has to meet so that the overall average is met (see Fig. 1).

Longer term members of the EU and non-transition countries usually have higher levels of R&D intensity than the EU average and hence also higher targets in this area. For example, Finland and Sweden have been assigned a target of 4%. Many studies have been published on R&D policy in those highly developed countries showing a positive impact of R&D on competitiveness (see for example Blomström et. al., 2002) and the productivity of companies (Ali-Yrkkö and Maliranta, 2006). The opposite is the case in post-communist countries. Their R&D intensity targets are smaller than the EU28 average (except Slovenia and Estonia) but at the same time there are greater challenges for these countries because they are further away from achieving them. According to the European Commission Europe 2020 targets, in 2011 Finland and Sweden required progress of only 6% and 19%, respectively (when expressed as percent of current R&D intensity value) in order to meet their R&D intensity targets. In contrast, for transition economies the figures to achieve their 2020 targets were: Romania, 315%: Bulgaria, 163%; Poland, 122%: Latvia, 115%; Lithuania, 107%; Croatia, 87%; Slovakia, 77% and; Hungary, 49%. Estonia (26% of progress required) and Slovenia (21% of progress required) were in a better situation (DG Research and Innovation). So on the one hand there is a big challenge ahead for many CE countries and on the other hand there are still only very few empirical studies on R&D in post-transition countries to shed a light on a prospectus impact of that increase in R&D. This paper therefore contributes to filling this important gap.

[1] R&D intensity is defined as R&D expenditure as a proportion of GDP.

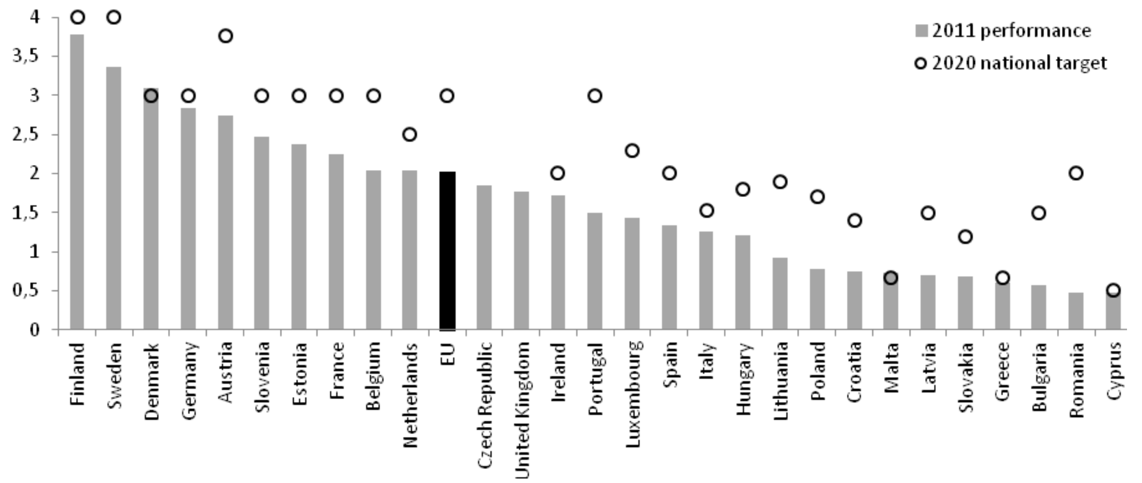


Fig. 1. R&D intensities in 2011 and targets for 2020

Source: European Commission: Europe 2020 Targets

In all post-communist countries (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovenia and Slovakia) Structural Funds from EU have become a significant, if not the main, source of public R&D funding In terms of policy instruments they are partly public expenditures (e.g. on research projects, patents and research institutions) and partly various types of government support (e.g. tax incentives, investment subsidies). The proper policy mix in order to achieve the intensity targets is the main policy challenge because there is usually a trade-off between the cost and the outcome of the policy, as we show in our paper.

Therefore, the paper investigates the impact on macroeconomic variables and differences in transmission mechanism (via price changes) in case of R&D expansion through two fiscal mechanisms: public R&D expenditures and government R&D tax relief, separately. The model simulations are designed so that the target for Poland of 1.7% of R&D in GDP is achieved by either of the two instruments. Then their impact on economy is compared. To our knowledge, R&D expenditures and R&D tax relief have not been explicitly compared in one paper for a transition economy yet. Therefore our paper provides useful information to assist the future planning of R&D expansion.

A further advantage of the paper is that R&D spillovers are modelled with an explicit link to productivity, which is often ignored in studies – either due to lack of data or due to choice of a method which does not allow for endogenous productivity changes. In our study the link between R&D and productivity is treated explicitly within a recursive dynamic Computable General Equilibrium (CGE) model, i.e. the growth rate of productivity is calculated as a ratio of return on R&D stock relative to output.

The specific case analyzed here is Poland, the largest post-communist economy in Europe. It is the first study on R&D for Poland which uses a country specific CGE model. The approach adopted has three distinct advantages over other methods. First, in contrast to the I-O model approach to R&D proposed by Brautzsch (2015), the applied CGE model brings in economic theory and allows the macroeconomic environment to be specified for the analyses by defining model closure. Second, in contrast to the system of models approach to R&D as proposed by Varga (2011) for studies at the regional and the EU macroeconomic levels, this paper keeps R&D within one model. Finally in contrast to the RHOMOLO approach (Brandsma and Kancs, 2015) which uses one model for all EU countries, this paper proposes a country specific model for Poland (POLTERM).

The main innovations of this paper lie in applying a recursive dynamic computable general equilibrium model specifically developed for Poland, taking into account its post-transition nature (in parameters and assumptions) with implicit links between R&D stock and productivity growth, and comparing economic effects of two separate policy instruments which would enable Poland to achieve its R&D intensity target by 2020.

The paper is structured as follows. The second section provides a conceptual framework, which describes the R&D policy of the European Union, gives a brief summary of Poland's situation in the R&D area and reviews previous studies on the links between R&D and productivity. The third section explains the model, data and simulation scenarios applied in the analysis whilst the fourth section presents the results and their robustness. In the fifth and final section we discuss the theoretical and practical conclusions from our findings and consider the pathways for further research.

2 Conceptual framework

2.1 European Union's R&D policy

The European Union's research and development (R&D) policy, like other EU policies, is based on objectives stated in the Treaties of the European Union which are the documents that create the EU's constitutional basis. In the last few decades R&D has grown considerably in importance and now receives significant political attention, due to its role in developing innovations and, as a result, in growth and socio-economic development. The main official documents in this area are two successive EU's strategies: the Lisbon Strategy (the Lisbon Agenda, the Lisbon Process) and Europe 2020. The Lisbon Strategy was a development plan adopted in 2000 with a 10-year perspective. Its aim was to make the European Union "the most competitive and dynamic knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion". One of the targets set by the Strategy was that average spending on R&D across the EU was to reach at least 3% of GDP by the end of 2010. This goal was not achieved: across the EU-27 the overall spending on R&D had increased but only from 1.8% cent in 2000 to about 2.0% in 2010. Under these circumstances another strategic 10-year document – Europe 2020 – was devised in 2010. Its main aim was "smart, sustainable, inclusive growth" for the EU. The strategy kept the target of at least 3% of GDP to be spent on research and development as set in the earlier Lisbon strategy. However, this time the European wide target was translated into national goals. The reasons for this differentiation were the fact that the EU member states were starting from very diverse points in terms of R&D expenditures levels and that their economic systems were highly differentiated. The 2020 national targets vary from 0.5% in the case of Cyprus up to 4% for Finland and Sweden. For Poland the target value of overall spending on R&D is 1.7% of GDP, nearly half that of the EU average.

2.2 State of R&D in Poland

Poland is still less economically developed than Western European countries. Despite the fact that in recent years Poland has performed remarkably well in terms of GDP growth (as compared to its European counterparts) it is commonly argued that the country faces the significant risk of the middle-income trap (Radło and Ciesielska, 2013). The main reason for this being the low levels of innovativeness within the Polish economy (Geodecki et al., 2012; Pruchnik and Toborowicz, 2014). The unsatisfactory level of Polish innovativeness is already well diagnosed (see e.g. Piekut, 2013) and has been targeted by public policy (mainly through EU programmes), but there has been no substantial improvement so far (European Union, 2015). The low innovativeness of the Polish economy has its roots far back into decades and even centuries (Sulmicki and Czyżewska, 2011; Hryniewicz, 2004) and is seen as a complex issue. The low R&D/GDP ratio can be seen as a manifestation of a low innovativeness. In 2013 total intramural R&D expenditures (GERD) constituted just 0.87%[2] of Polish GDP, far less than the EU28 average of almost 2%. There are many important factors influencing this disadvantageous situation of the Polish economy. Among others, these include : low private funding of R&D (in 2013 32.3% of GERD funds in Poland came from business enterprise sector, whereas the EU28 average was 55%); a low number of mid-tech and high-tech enterprises interested in developing their own technologies; relatively low FDI inflow into R&D as compared to for example the Czech Republic and Hungary (Owczarczuk 2013);

[2] According to the updated Polish IO tables this ratio was higher 1.02%.

under developed collaboration between science and industry (Łącka, 2012); thepoor state of technology transfer (Jasinski, 2009); insufficient human resources in R&D sector (Dąbrowa-Szefler, 2004) in part due to the 'brain drain' during the transition period (Jałowiecki and Gorzelak, 2004); low internationalization of scientific activities (Płoszaj and Olechnicka 2015) and; high regional disparities in R&D quantity and quality (Olechnicka and Płoszaj, 2010).

The Polish R&D sector has been constantly reformed since the early nineties, which is after the collapse of the communist bloc. The changes accelerated after Poland's accession to the European Union in 2004. The most important strategic decision was to transform the financial mechanism of public funding for research and development, from so-called statutory funds (earmarked subsidies) towards an increase in the number of open calls. Open competitions are managed mainly by two newly established institutions: National Center for Research and Development (2007) responsible for applied research and the National Science Centre (2011) responsible for basic research. The role of the Ministry of Science and Higher Education is mainly regulatory and strategic, however it also distributes limited resources via open competitions. The second important factor shaping the state of R&D sector in Poland is the large inflow of funding from European Union funds. The additional funds have been allocated in large part to build new infrastructure, including new buildings for universities and scientific institutes. The third essential feature of Polish R&D policy is the underuse of tax instruments by the firms. So called "relief on the acquisition of new Technologies" was in place from 2005 to 2015. The instrument provides an opportunity for the deduction from the income tax base of expenditures incurred due to the acquisition of new technologies. The effects of the measure were unsatisfactory mainly because of the low number of enterprises that took advantage of it. For example, in 2013 only 106 enterprises used the instrument (Kluzek 2015) and the tax reduction associated with their activities constituted only about 0.4% of total R&D expenditures in Poland. Part of the reason for the failure of the measure was a result of its low attractiveness for enterprises as compared to similar measures used in other countries (Kluzek 2013). This was due to too restrictive rules. One problematic rule was a requirement of acquisition of externally produced technology to get the tax relief, the other rule denied the costs associated with own R&D, such as wages of research personnel, to be deducted from the tax. Another reason may have been that the measure excluded costs associated with in-house R&D activities. Because of extremely low interest in that measure, the new one - R&D tax relief - was developed and it came into force in January 2016.

It is too early to evaluate the effectiveness of the reform and investments from EU funds. However, so far the effects have not been as large as expected (see e.g. Gorzelak 2014). There is still a need for a substantial increase in public investment in the R&D sector. There is an expectation in Poland that an increase in public spending should also boost private R&D investment. However the evidence supporting this contention is somewhat ambiguous – see e.g. Zúñiga-Vicente et al., 2014).

2.3 Approaches to analyze R&D

R&D activity is perceived as a key driver of technological advance, leading, therefore, to an increase in productivity which, in turn, translates into faster economic growth. As such, it is a topic of intensive research examining ways to measure and optimize its impact on economy. A comprehensive review of key concepts, issues and theories related to the quantitative analysis of R&D effects is provided by Shanks and Zheng (2006) in their study on modelling the link between R&D and Australia's productivity.

The first challenge faced by researchers is that the primary output of R&D is knowledge, an intangible asset that cannot be directly measured or valued. Sometimes they quantify it as a number of patents issued but from economical point of view this measure is far from ideal, since it says nothing about the value of knowledge produced. More common approach then is to use data on R&D expenditures as a rough equivalent of the outputs generated (Shanks and Zheng, 2006). However, this measure is accurate without any adjustments only if we assume that productivity of R&D is constant (Shanks and Zheng, 2006). Productivity may be analyzed in relation to absolute R&D expenditures or R&D intensity (proportion of expenditures to GDP).

Economists use a wide variety of models to analyze the relationships between knowledge development and economic growth. For example, neo-classical growth models assume that technological advance is an external factor which has no explicit link to knowledge development. The opposite approach is represented by evolutionary models that focus on technological trajectories and long cycles in technological opportunities. However, they are not well-established in terms of the empirical explanation of economic performance. Another important category comprises computable general equilibrium (CGE) models based on endogenous growth theory pioneered by Romer (1990). They are commonly used to assess the economic impact of different policy interventions. CGE models avoid a critique made by Garau and Lecca (2015) that typical Keynesian models with fixed nominal wage and excess labor supply, such as input–output models, are not well-suited for this type of analysis. For example, they would omit supply-side effects in the case of an exogenous increase in investment which is a supply-side policy. Hong et al. (2014) proved that R&D-based CGE models that include knowledge stock as an additional primary input factor and allows for changes in TFP explains the performance of the economy better than standard two-factor models. In transition economies the country-level analysis may overestimate the role of R&D in TFP growth, as aggregate productivity improvement due to fundamental structural changes may be erroneously ascribed to TFP growth from R&D (Mericul, Poltimae, Paas, 2013).

In 2008 the United Nations Statistical Commission (UNSC) introduced a new version of the System of National Accounts in which expenditures on R&D are treated as investments. This poses a challenge in estimating R&D stock depreciation rate – a parameter required to calculate the R&D stock by perpetual inventory method. As Nadiri and Prucha (1996) note, many researchers assume an arbitrary depreciation rate of 10 to 15% although several attempts have been made to determine this parameter in a scientific way. According to Schankerman and Pakes (1986) who examined data on patent renewal fees, the decay rate for knowledge capital in some European countries varies between 11 and 36%. Nadiri and Prucha (1996) measured the depreciation rate of the R&D stock using a factor requirements function and a restricted cost function which resulted in a figure of 12% for the total U.S. manufacturing sector. Bernstein and Mamuneas (2005) used an intertemporal cost minimization framework to conclude that R&D depreciation rates for four main U.S. industries varied between 18 and 29%. From this, it is possible to draw the general conclusion that R&D stock depreciation rates are at least two times higher than those of physical capital.

Another key parameter is the rate of return on R&D investments. The estimates of this rate of return are sensitive to the level of aggregation. A vast literature summarized by Griliches (1991) and Jones and Williams (1998) concerning mainly US industries at a relatively fine level of aggregation (four-digit) points to a rate of return to R&D of about 30%. Estimates by Griffith et al. (2004) on a panel of two-digit manufacturing industries covering OECD countries are more than twice as high as this. Econometric work undertaken by the Australian Industry Commission (1995) found that overall Australian R&D yielded a rate of return to the economy of between 50 and 60%. Attempts to assess the rate of return to R&D for developing or transition economies are relatively scarce and limited to firm-level studies, hence providing estimates on private rather than social rates of return to R&D. For example, Damijan, Jaklic and Rojec (2005) estimate the private rate of return to R&D in Slovenia at 24%. However, higher estimates, around 31%, were obtained by Kolasa (2008) for Poland.

Existing studies regarding the impact of R&D on productivity show inconsistent results. Shanks and Zheng (2006), in spite of applying various models, describe their empirical estimates of the effects of R&D on Australian productivity as unreliable. According to Botazzi and Peri (2007) the elasticity of domestic knowledge generation, measured by the number of patents issued, to R&D employment in 15 OECD countries varies between 0.304 and 0.786. Varga et al. (2011) presented a Geographic Macro and Regional model for NUTS-2 regions of the Euro zone (GMR-Europe) consisting of three sub-models and designed to assess policy instruments introduced to support the development of knowledge economies. Analysis based on this model suggests that the elasticity of patenting with respect to R&D exceeds one on average in the Euro zone. In attempting to explain factors that stimulated TFP growth in the Polish economy from 2005 to 2013 Świeczewska (2015) applied a neoclassical approach that starts with an aggregate two-factor production. She found that all explanatory variables were statistically significant with a TFP elasticity with respect to the stock of domestic knowledge estimated at 0.032.

There are many studies designed to evaluate the effects of R&D subsidies, especially those sourced from EU funds. Brautzsch et al. (2015), using a standard input-output model, came to the conclusion that R&D subsidies counteracted the effects of economic crises to some extent. However, they focused on Germany, so their findings may not be relevant to transition countries, such as Poland. To assess the European Union's R&D policies, Brandsma and Kancs (2015) developed a spatial computable general equilibrium (SCGE) approach called RHOMOLO. In their paper they refer to other, firm-level, studies in which the estimated elasticity of TFP with respect to R&D investments varied between 0.01 and 0.32. In the course of analysis covering 267 NUTS-2 EU regions they predicted potential policy-induced GDP growth effects of 0.01 to 2.75% above the baseline. They also show that the maximum estimated increase in productivity is larger than the maximum simulated GDP increase. Křístková (2012) estimated the impact of R&D activities, including external shocks, on the long-term economic growth of the Czech Republic within a recursively dynamic CGE framework. Her simulation shows that increasing foreign investment resources for R&D can lead to a higher GDP level at the end of the analyzed period but the gain is surprisingly small – only 1%.

These findings suggest that the relationship between R&D and productivity is highly context-sensitive making it difficult to generalize. Therefore, each new piece of research can make a valuable contribution to the existing stock of knowledge in this area.

3 Methodology and data

3.1 POLTERM model and R&D data

Computable General Equilibrium (CGE) models have proved, both in theory and in practice, to be a sophisticated and practical method for economic impact analyses of R&D. This is mainly due to their ability to link R&D with productivity and economic growth within a consistent theoretical framework and producing computable results. Hence we apply in our study POLTERM, an implementation of the standard TERM model (by Horridge et al., 2005) to the Polish economy (Zawalińska, Giesecke, Horridge, 2013) at the national level. The TERM model has gained its reputation over the years due to many scientific publications, policy applications and its detailed documentation (Horridge, 2012; Horridge and Wittwer, 2010)[3]. The theoretical structure of TERM follows the familiar neoclassical pattern common to many applied general equilibrium models. In this study we use the modernized, updated and recursive dynamic version of POLTERM. The dynamic mechanisms include equations relating investment to capital in year-to-year simulations; equations explaining the relationship between year-to-year capital growth and rate-of-return expectations; and equations explaining labor market adjustment. The theory is similar to that of the dynamic TERM model, which is described in detail in Wittwer (2012). In this paper we extend the model by treating R&D as investment into stock of knowledge and linking it to changes in productivity, as discussed in the next section.

The main data source for the POLTERM model is the latest version of the Polish Input-Output tables, especially the Supply and Use tables for 2010, issued by the Central Statistical Office of Poland in mid-2014 (GUS, 2014). Hence, the benchmark year for the model is 2010. For this study, the original I-O tables comprising 77 sectors were aggregated into 19 sectors[4]. The sectors are aggregated so as to coincide with the sections in the current European activity classification under the System of National Accounts (2008 SNA/NACE rev. 2). The only exception is that section M is disaggregated into two incorporating R&D and the rest of section M. By this process R&D is represented as a separate sector. It is important to note,

[3] Details on TERM are provided at the model's website: http://www.copsmodels.com/term.htm

[4]Their short names are: 1. Agriculture, forestry and fishing (section A), 2. Mining and quarrying (section B), 3. Manufacturing (section C), 4. Electricity, gas, steam (section D), 5. Water supply, sewerage, waste (section E), 6. Construction (section F), 7. Wholesale and retail trade (section G), 8. Transporting and storage (section H), 9. Accommodation and food (section I), 10. Information and communication (section J), 11. Financial and insurance activities (Section K), 12. Real estate activities (section L), 13. Professional, scientific and technical activities (Section M without R&D), 14. Scientific Research and Development services (part of Section M), 15. Administration (section N), 16. Public administration and defense; compulsory social security (section O), 17. Education (section P), 18. Human health and social work (section Q), 19. Rest of services (sections R, S, T, U).

that in the previous classification (1993 SNA) R&D spending was treated in the input-output tables as a current expenditure that is used up in the production process, so it was mainly present as intermediate consumption. In contrast, the new 2008 SNA expands the range of fixed assets and shifts R&D spending into fixed-capital formation. That is why in our analysis R&D sectors are treated mainly as an investment good in the input-output tables. This methodological change in treating R&D within input-output tables triggered new studies on modelling R&D within CGE models (Hong et al. 2014).

The database shows that in 2010 the R&D sector accounts for 0.48% of total production and 96.7% of total R&D expenditures in the economy. The sector sells about 66% of its output to other industries, 21.2% to government, 12.3% to exports, and 0.3% to households[5]. The country imports 3.3% of its R&D needs from abroad.

3.2 Modelling R&D in POLTERM

In POLTERM R&D expenditures by industry, government and households are treated as investment into the stock of knowledge. Following the method used by the American Bureau of Economic Analysis (Sliker, 2007; Bernat 2007), stock of knowledge is calculated using the perpetual inventory method. That is, for each agent and each year of the simulation period,

$$K_{R\&D,t} = K_{R\&D,t-1}(1 - D_{R\&D}) + I_{R\&D,t} \qquad (1)$$

where $K_{R\&D,t-1}$ and $K_{R\&D,t}$ are stock of R&D at the begininng and end of year *t* respectively, $D_{R\&D}$ is R&D depreciation rate, and $I_{R\&D,t}$ is R&D expenditure during year *t*.

Following the method used by Bernstein and Mamuneas (2006), we calculated the initial R&D stock for the initial year ($K_{R\&D,0}$) as the ratio of R&D expenditure in the year ($I_{R\&D,o}$) to the sum of R&D depreciation rate and the average growth rate of R&D over some earlier period ($\dot{K}_{R\&D}$).

$$K_{R\&D,o} = \frac{I_{R\&D,o}}{D_{R\&D} + \dot{K}_{R\&D}} \qquad (2)$$

The value for the initial R&D expenditure ($I_{R\&D,o}$) is obtained directly from the input-output tables. We have adopted the value of 10% for the depreciation rate ($D_{R\&D}$) which is consistent with the value adopted by many studies on R&D (Garau and Lecca, 2015: Keller, 2004: Krammer, 2010). This value is higher than the average depreciation rate for physical capital in POLTERM (6.2%). This is however consistent with the finding from studies

[5] The household sector in the model includes non-profit institutions serving households (NPISH). This is these institutions that use R&D services.

directly estimating R&D depreciation rates (see, for example, Bernstein and Mamuneas 2006) that R&D stock depreciates faster than physical capital stock. The growth rate of R&D stock ($\dot{K}_{R\&D}$) is the average growth rate between 2005 and 2010, which is 10.3% according to OECD (2012).

The R&D stock is calculated as the sum of R&D stocks by industry, households and government[6].

We explicitly model the link between returns on R&D stock and total factor productivity. If we call $K_{R\&D}$ and $RoR_{R\&D}$ the stock and rate of return on R&D stock respectively, then the change in GDP at factor costs (Y) resulting from the returns on R&D would be:

$$\Delta Y = Y \times \dot{Y} = K_{R\&D} \times R_{R\&D} \qquad (3)$$

where $\dot{Y}$ the growth rate of GDP at factor costs. Representing GDP as a function of technology, labour and capital stock, i.e. Y=AF(L,K), the growth rate in GDP equals the growth rate of technology plus the share-weighted average of growth rates of labor and capital stock. That is:

$$\dot{Y} = \dot{A} + S_L\dot{L} + S_K\dot{K} \qquad (4)$$

where the dot above the variables represent their growth rates, and S_L and S_K are shares of labor and capital stock respectively in GDP at factor costs. When the change in GDP is due to the change in technology alone, we have $\dot{Y}=\dot{A}$, and the growth rate in TFP can be calculated from (3) as:

$$\dot{A} = \frac{K_{R\&D} \times R_{R\&D}}{Y} \qquad (5)$$

Estimates for the rate of return on R&D stock ($R_{R\&D}$) in the literature vary from 8.0 to 170.0% (Brandsma and Kancs, 2015: Mairesse and Sassenou M., 1991: Pakes and Schankerman, 1978). Kolasa (2008) estimated the private rate of return to R&D in Poland of above 30%, but as Meriküll et al. (2013) pointed out, in transition economies the country-level analysis may overestimate TFP growth and the role of R&D in it, as aggregate TFP growth due to changes in industry structure may be erroneously ascribed to TFP growth due to R&D. Therefore, we have adopted a more conservative value of 25%.

Studies linking R&D and productivity sometimes use the elasticity of TFP with regard to R&D stock instead of the returns on R&D stock used in this paper. For comparison, we have

[6] We do not count the exports of R&D services as investment in R&D stock. This is because R&D exports are likely to add to the stock of knowledge by foreign countries, and not directly to the stock of knowledge in the domestic economy.

calculated the elasticity resulting from our method. The elasticity is not constant, because in equation (5) above the numerator and denominator on the right hand side of the equation would change in different ways. R&D capital stock movements depend on the level of R&D investment, whereas GDP movements depend both on changes in the TFP itself and on changes in capital stock and employment, which in turn depend on many factors apart from changes in R&D stock. However, on average, our simulation results show that the elasticity varies between 0.02 to 0.06, which is within the estimated range in the studies by Świeczewska (2015) and Madden et al. (2001).

3.3 Simulation scenarios for R&D policies

The Europe 2020 strategy has set a target for R&D expenditures to GDP ratio for Poland of 1.7% by 2020. To reach this level from the 2014 level of 1.07%, the ratio will need to increase on average by 7.99% per annum over the period 2015 to 2020. Whilst in theory there are a number of ways to achieve the overall target, in this paper we explore just two possible policy instruments as these are the only two currently available in Poland. Policy 1 is to increase government demand for R&D services (e.g. research programs and grants available for public and private institutions). Policy 2 is to provide R&D tax relief for enterprises.

To compare the efficacy of these policies, two simulations with POLTERM for the period 2011-2025 were run. Going beyond the 2020 deadline enables investigation not only of the short-run but also the long-run impacts of the R&D targeting policies. The simulations are run in two stages. First, a baseline (business-as-usual) forecast was produced for the 2011-2025 period. This forecast includes available forecasts for the economy, but excludes the effects of the R&D targeting policies. The second stage involved the development of two policy forecasts for the same period, one for each of the policies listed above. Each policy forecast includes the shocks underpinning the aforementioned baseline forecast, but with the addition of a shock describing the R&D targeting policy. We report results for each of the policies as time paths of percentage deviations in the values of variables in each policy forecast away from their values in the baseline forecast.

In each of the policy simulations we exogenize the R&D/GDP ratio and shock it with the values calculated for each year during the period 2015-2020 at a constant growth rate of 7.94% discussed above so as to reach the target of 1.7% by 2020, and then maintain it at that level by 2025 (see Fig. 2). We endogenize the variable representing the policy under consideration so as to force the model to find the changes in the policy that are required to reach the R&D/GDP target. Specifically, for Policy 1 we endogenize government demand for

R&D services. For Policy 2 we endogenize the consumption tax on R&D uses by domestic businesses. Changes in those policy instruments are reported in Fig 2.

Simulation results show that by 2020 the government would have to increase its level of expenditures on domestic R&D by 300% compared with baseline. The share of R&D in total government consumption expenditures increases from 1.1% in 2014 to 4% in 2020. Afterwards, the expenditures change at a relatively low rate (see Fig.2).

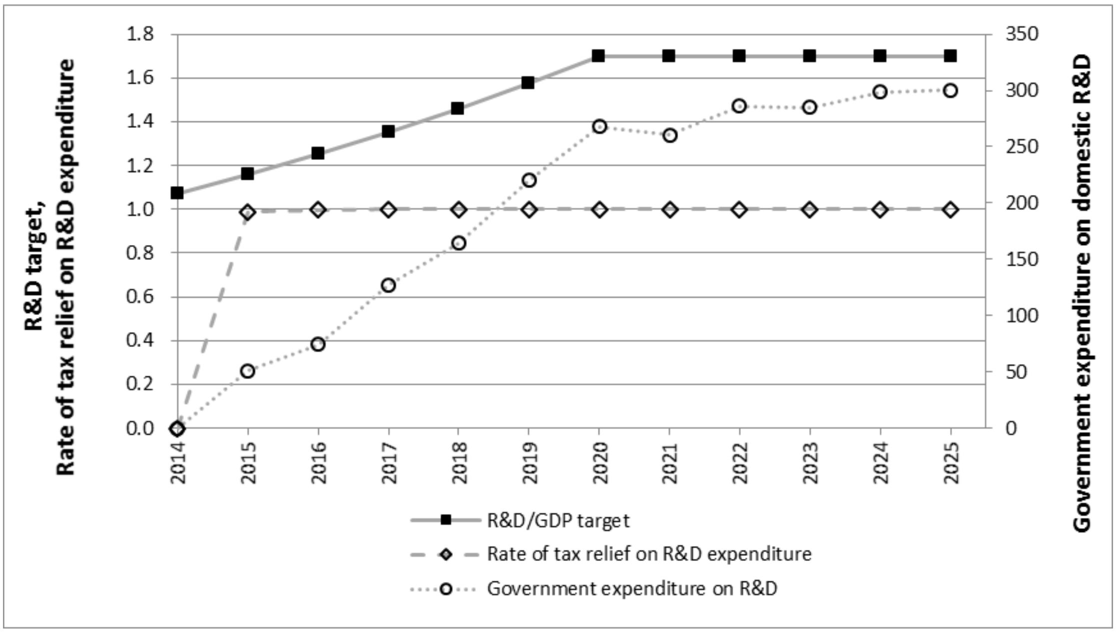


Fig. 2. Changes in R&D/GDP ratio and in policy instruments (Level for R&D/GDP target, % deviations from baseline for government expenditures; and deviations in the rate of tax relief for R&D expenditure)

Source: Authors' own calculations based on POLTERM model.

In the scenario where the government provide tax relief to businesses, simulation results show that the rate of tax relief on the production of R&D services will have to be from 98.9% in 2015 up to 100% by 2020 and then stay at that level in order to reach and maintain the target.

4 Results

This section discusses the results from our policy simulations. First we discuss the main impacts of each of the alternative policies, then we compare them in terms of their impacts on GDP and government budget.

4.1 R&D target achieved by government R&D expenditures (Policy 1)

The first impact of an increase in government expenditures on R&D is to increase demand for R&D services. This raises the price and output of R&D. As a back-of-the-envelope (BOTE) calculation, by 2020 government consumption of domestic R&D increases by 268% relative to the baseline. In 2014 the government consumes 20% of R&D output. The 268% increase in government consumption alone would cause R&D output to rise by about 53.6%. This almost entirely explains the 54.1% increase in R&D output.[7] Employment in the sector increases, while higher rates of return triggers investment, leading eventually to an increase in capital stock. The dominant impact of the policy is the increase in R&D stock, which leads to an increase in productivity for the whole economy. This, in turn, causes GDP to rise. By 2020 the deviation of real GDP from baseline is 0.38%. Fig. 3 reports simulation results for GDP income components. As can be seen from the figure, the increase in real GDP is mainly due to the increase in productivity induced by R&D stock accumulation.

During the 2015 to 2020 period the increase in real GDP is slightly lower than that of productivity. This is because there is a slight negative deviation in capital stock due to two main reasons. First, with a constant average propensity to consume, defined as a ratio of nominal final consumption (C+G) to nominal GDP, the rise in government consumption due to its increased expenditures on R&D causes a fall in private consumption. As private consumption is more capital intensive than government consumption, a fall in private consumption causes capital stock to fall relative to baseline. Second, we have assumed that aggregate employment stays at the baseline level. The expansion of the R&D sector attracts labor away from other industries, causing marginal products of capital in these industries to fall. This lowers their rates of return, and hence their investment, and subsequent capital stock fall. However, as can be seen from Fig. 3, these effects on capital stock are very small.

In the long run, after the R&D target has been reached, the above effects become much smaller, and the improvement in productivity raises the marginal product of capital stock and labour in all sectors, causing aggregate capital stock to increase. Together, the increase in capital stock and productivity, as well as in the wagebill-weighted employment, causes real GDP to continue to grow, reaching 3.1% higher than the baseline by 2025.

[7] As discussed earlier, simulation results for variables are deviations from their values in the baseline forecast. For brevity, we sometimes use a “rise” or an “increase” to indicate a positive deviation from baseline, and a “fall” or a “decline” to indicate a negative deviation from baseline.

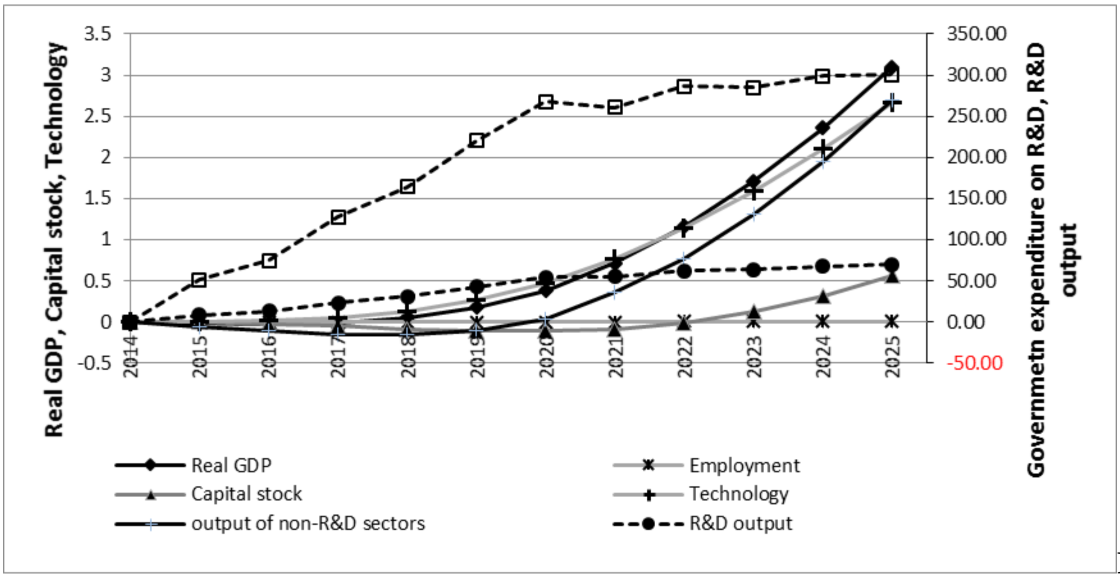


Fig. 3. Policy 1 – GDP income components, government expenditures on R&D and R&D output (% deviations from baseline)

Source: Authors' own calculations based on POLTERM model.

4.2 R&D target achieved by the provision of tax relief on R&D expenditure (Policy 2)

In this section we explore the impacts of a tax relief on the expenditure on R&D by domestic businesses. As discussed earlier, simulation results show that the tax relief rates will have to increase to approximately 100% by 2020 to reach the R&D intensity target. Fig. 4 reports the percentage deviations of R&D output and GDP and its income components from their baseline values.

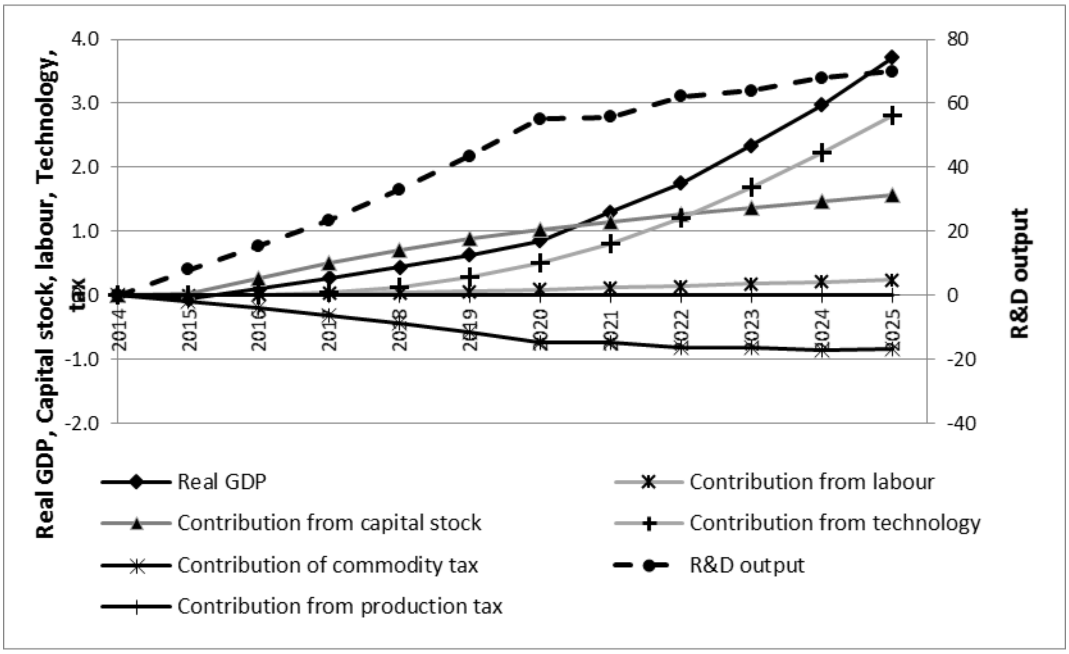


Fig. 4. Policy 2 – R&D output and contributions of GDP income components to GDP

(% deviations from baseline)

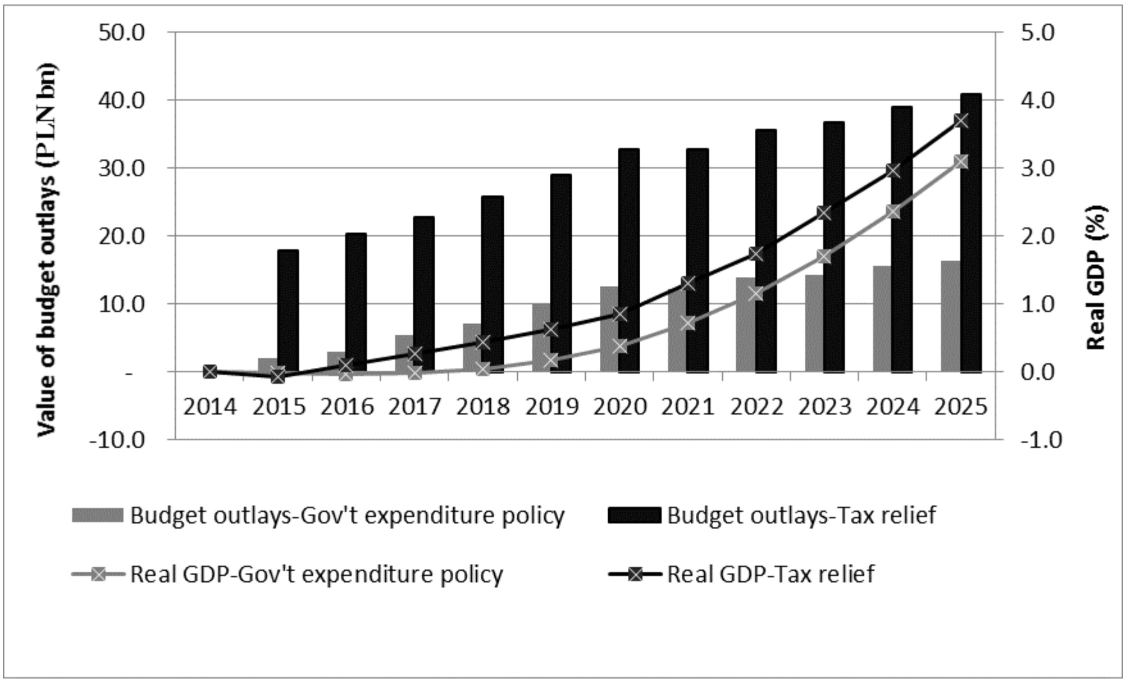
Source: Authors' calculations based on POLTERM model.

The first impact of the tax relief policy is to reduce the costs of R&D investment for industry. This increases industry demand for R&D services. This explains the large positive deviations in R&D output, which reaches 55.1% above the baseline by 2020. However, in the first year real GDP experiences a small negative deviation of -0.06% from baseline. This is mainly due to the decline in indirect tax revenues caused by the large tax relief. In 2015, indirect tax revenues falls 8.8% compared with baseline. Indirect taxes contribute about 12% of Poland's GDP. The fall of 8.8% in tax revenues should have led to a 1.1% decline in real GDP. However, real GDP declines by only 0.06%. This is due to the positive contribution from productivity, capital stock and labor. The increase in R&D expenditure increases the stock of knowledge and generates improvements in productivity. Productivity contributes directly to GDP, but also improves the marginal products of capital stock and labor, so capital stock increases. As employment levels are assumed to stay at the baseline level, its contribution to GDP growth occurs via the increase in the real wage, but the contribution is small. From 2016 onwards the positive contributions from technology, capital stock and employment become larger than the negative impact of indirect tax revenues. Real GDP deviations turn positive, reaching 0.85% higher than baseline by 2020 and 3.72% by 2025 respectively.

At the industry level, the results are quite similar to those found with Policy 1. The R&D sector expands the most (see Fig. 4), with output deviating 55% by 2020 and 70% by 2025 from the baseline. However, the impacts on other sectors are more positive than those in Policy 1. In aggregate, only in 2016 do they experience a small contraction of -0.06% in their outputs. From 2017 onwards the sectors grow, reaching deviations of 1.06% and 3.95% above baseline in 2020 and 2025, respectively. The reason for the more positive outcomes for other industries under Policy 2 is that, although they also experience resource-allocation impacts from the fast growth of the R&D sector as in Policy 1, they do not experience the negative impacts of an increase in R&D price as in Policy 1. On the contrary, they experience a fall in the price of R&D due to the tax relief policy.

4.3 Achieving R&D target by different policy instruments

Fig. 5 compares the impacts on real GDP and the impacts on government budget under the two policies. It is clear that the policy of tax relief leads to a higher positive GDP deviation from the baseline (0.85% in 2020 and 3.71% in 2025) than the policy of increasing government expenditures on R&D, where deviation from the baseline is respectively 0.38% in 2020 and 3.10% in 2025. However, the tax relief policy is also much more costly to the budget. In the government expenditures scenario the change in the value of government expenditures on R&D compared with that in the baseline increases almost linearly from PLN[8] 2bn in 2015 to PLN 12.6bn in 2020, and then up to PLN 16.4bn in 2025 at 2014 prices.



[8] PLN, is the abbreviation for the Polish national currency the Polish Zloty, where 4 PLN ≈ 1 EUR.

Fig. 5. Real GDP (% deviation from baseline) and government budget outlays (PLN billion change from baseline) under alternative policies

Source: Authors' calculations based on POLTERM model.

The total present value of the increase in government expenditures, discounted at 5% pa, is PLN 33.9bn for the period 2015-2020. At the same time, in the tax relief scenario the budgetary outlays increases from PLN 17.9bn in 2015 to PLN 32.8bn in 2020 and to PLN 40.9bn in 2025. The present value of the subsidies, discounted at 5% pa, is PLN 129.9bn for the period 2015-2020.

So the tax relief policy is superior to the government expenditure policy in terms of the impacts on GDP, both in the short run and the long run, but it is inferior in terms of the direct costs on the government budget. So in comparing the two policies, the question arises which of them is more efficient in terms of achieving the same R&D target with a lower output/input ratio, where output is measured as real GDP growth (above the baseline) and input as the budgetary cost of achieving it. In other words, which of the two policies buys the additional increase in GDP growth for less. Tab. 1 compares the ratio for the two policies over the time period considered in this study.

Table 1 Approximate efficiency of R&D policies

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1/ R&D target	1.16	1.25	1.35	1.46	1.57	1.70	1.70	1.70	1.70	1.70	1.70
2/ Budgetary outlays in billion PLN (above baseline) :											
Government expenditure (Policy 1)	2.0	2.9	5.4	7.1	10.0	12.6	12.2	14.0	14.3	15.6	16.4
Tax relief (Policy 2)	17.9	20.3	22.9	25.8	29.0	32.8	32.7	35.6	36.7	39.1	40.9
3/ Real GDP % change (above the baseline):											
Government expenditure (Policy 1)	-0.02	-0.02	-0.01	0.05	0.17	0.38	0.72	1.16	1.71	2.36	3.10
Tax relief (Policy 2)	-0.06	0.10	0.27	0.44	0.63	0.85	1.30	1.75	2.34	2.97	3.71
4/ Efficiency ratios (3 /2)											
Government expenditure (Policy 1)	-0.01	-0.01	0.00	0.01	0.02	**0.03**	0.06	0.08	0.12	0.15	**0.19**
Tax relief (Policy 2)	-0.003	0.005	0.01	0.02	0.02	**0.03**	0.04	0.05	0.06	0.08	**0.09**

Source: Authors' own calculations

Tab.2 shows that the efficiency ratio has been changing over time for both policies. At the beginning of the period the tax relief policy had a slightly higher efficiency. By 2020, however, the efficiency of the two policies was equal (0.03) and beyond 2020 (in the long run) the government expenditure policy brings greater value for money. By 2025 the efficiency ratio is quite markedly higher for the government expenditure policy being 0.19 compared to 0.09.

4.4 Robustness of the results

Since our analyses was based on some key assumptions on R&D taken from literature, such as the rate of return on R&D stock ($R_{R\&D}$) and the R&D depreciation rate ($D_{R\&D}$), a Systematic Sensitivity Analysis (SSA) was carried out with respect to those two parameters[9]. The confidence intervals were developed using Chebyshev's inequality, since it does not require any assumptions to be made about the distribution of the endogenous variables. Chebyshev's inequality says that, whatever the distribution of the variable in question, for each positive real number k, the probability that the value of Y does not lie within k standard deviations of the mean M is no more than 1/(k2). As a result, obtained confidence intervals are wider than they would be if we knew more about the distribution of the endogenous variables (or if we assume a normal distribution). So this is a cautious approach and the obtained intervals are probably wider than the actual ones.[10]

Gaussian quadrature - Stroud's quadrature of order 3 – are used for calculating estimates of the means and standard deviations of the endogenous variables produced by the software utilized for this study – GEMPACK. It uses a Gaussian quadrature to select a discrete approximation to the actual (continuous) distribution we have specified for the values of the varying parameters. The model is then solved only at the points of this discrete distribution, and the means and standard deviations reported are those for this discrete distribution. Hence the results reported are approximations to the true means and standard deviations. However, as examples in Arndt (1996) show, the results are often surprisingly accurate, given the relatively modest number of times the model is solved[11].

We undertook SSA for 30% of the variation in the parameter $R_{R\&D}$ (rate of return on R&D stock or RoR_RD) so it was varied between 17.5 and 32.5%, while our adopted value was 25%. Similarly, we carried out SSA for 30% range of variation in $D_{R\&D}$ (R&D depreciation rate or DEPR_RD) so it was varied between 7% and 13%, while our adopted

[9] See discussions on the SSA methodology and implementation in Channing (1996) and Channing and Pearson (2000).

[10] A proof of Chebyshev's inequality can be found in many statistics text books including Hogg and Craig (1970).

[11] In our case for rate of return on R&D stock ($R_{R\&D}$) the model was solved 736 times and for R&D depreciation rate ($D_{R\&D}$) it was solved 44 times.

value is 10%. We assumed triangular distribution, as the vales we have adopted have been chosen after careful considerations based on existing literature. We ran the SSA for both policy scenarios (R&D government expenditure and tax relief) and for each of the policies we varied the two parameters (RoR_RD and DEPR_RD) separately, and then also together to see the combined effect of our assumptions on the GDP results. The results of the SSA indicate that we can be 95% confident that the values of real GDP obtained in our simulations for the two policies are within the ranges reported in fig. 6.

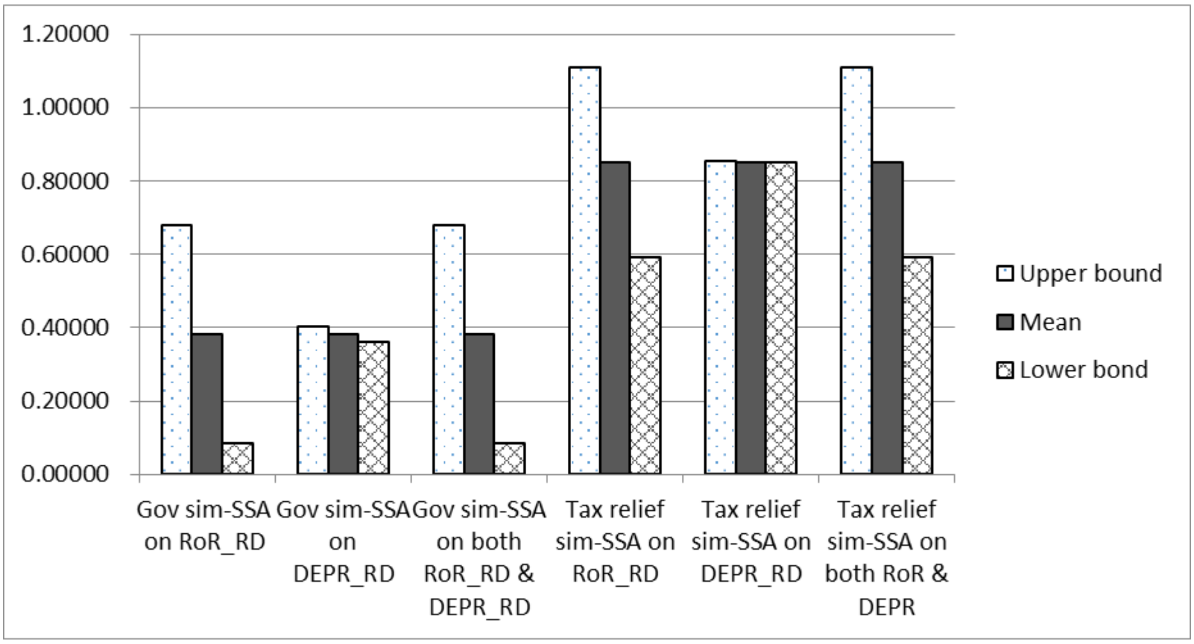


Figure 6 SSA results of 95% confidence intervals for real GDP in 2020 under two policy scenarios wrt changes in RoR_RD ($R_{R\&D}$) and DEPR_RD ($D_{R\&D}$)

Source: Authors' own calculations made in GEMPACK

Sensitivity analysis suggests that the results of the simulation are quite robust with regard to the assumed values of both parameters. The results are, however, more sensitive to changes in RoR_RD than in DEPR_RD. Despite some sensitivity to RoR variation, the SSA results indicate that the tax relief policy still brings higher real GDP effect to the economy than the government consumption policy.

5 Discussion of the results and conclusions

Poland has to achieve 1.7% level of R&D intensity by the year 2020 as required by the Europe 2020 strategy and then at least maintain this level into the future. However, this is a very challenging goal for a country which after about 50 years of communism was left with very outdated technologies and limited capacity for R&D absorption. There are only two policy instruments implemented in Poland: government expenditures on R&D - in the form of various publicly financed grants and research programs – and tax relief for business on use of R&D activities. So far R&D tax relief has not been much used in practice, due to restrictive rules in place hampering access to this instrument. However, a new reform of the R&D tax, introduced in January 2016, is less restrictive and broadly welcomed by the private sector. Therefore, there is an expectation that tax relief will be the main driver of increasing of R&D intensity in Poland.

However, benefits of policies must be considered in conjunction of their costs. Using a CGE framework, our paper consider costs and benefits of the two policies which are in place in Poland. Tax relief policy is indeed superior to the government expenditure policy in terms of the impacts on GDP, both in the short run and the long run, but it is inferior in terms of the direct costs on the government budget. The present value of estimated government outlays needed to meet the R&D intensity target in the tax relief scenario is about 2.5 times higher than in the government expenditure scenario. Moreover, allocating additional public funds to the purchase of R&D services brings direct effects while tax relief stimulate R&D indirectly via lower prices. In both scenarios, the resulting increase in R&D capital stock translates into substantial improvement of productivity across the whole economy. This, in turn, leads to faster GDP growth than in the baseline scenario, and in the case of tax relief policy the GDP growth is indeed higher comparing to the other one, i.e. 0.85% vs 0.38% in 2020 (or 3.71% vs. 3.1% in 2025). However, the results reveal that tax relief is more efficient (in the sense that it is brings a higher GDP growth per unit of public money) only in the short run, up to 2020. In the longer run government expenditure is more efficient, by 2025 it is even estimated to be twice as efficient as tax relief. It can be concluded therefore that an optimal policy is a matter of a proper policy mix over a given period of time.

The present work opens a number of possibilities for future research. First of all, more detailed analysis of the impacts of private versus public sources of R&D expenditures on actual productivity growth can shed a better light on the analysis of the two policy instruments. Second, an international comparison of the two measures analyzed with analogical methodology would be very informative, especially with respect to other post-transition economies. Third, the regional (sub-national) dimension could be brought into the analysis since R&D policy has growing importance for the development of regional economies.

Acknowledgements

The authors would like to primarily thank James Giesecke who provided valuable suggestions to the analyses in this paper. We also thank Mark Horridge and Glyn Wittwer who were involved in building the original TERM version for Poland. This work was supported by the Polish National Science Center under the grant " Regional input-output tables as a research tool for analyses of smart growth" (2012/07/B/HS4/03251).

References

Ali-Yrkkö, J., Maliranta, M., 2006. Impact of R&D on Productivity – Firm-level Evidence from Finland. Research Institute of the Finnish Economy Discussion Paper 1031.

Arndt, Ch., 1996. An Introduction to Systematic Sensitivity Analysis via Gaussian Quadrature, GTAP Technical Paper 2.

Bernat, G.A., 2007. Treatment of regional research and development as investment: Issues and estimates. Bureau of Economic Analysis/National Science Foundation R&D Satelite Account Background Paper.

Bernstein, J.I., Mamuneas, T.P., 2006. R&D depreciation, stocks, user costs and productivity growth for US R&D intensive industries. Structural Change and Economic Dynamics 17(1), 70-98.

Blomström, M., Kokko, A., Sjöholm, F., 2002. Growth and Innovation Policies for a Knowledge Economy: Experiences from Finland, Sweden, and Singapore. The European Institute of Japanese Studies Working Paper 156.

Bottazzi, L., Peri, G., 2007. The International Dynamics of R&D and Innovation in the Long Run and in The Short Run. The Economic Journal 117 (518), 486-511.

Brandsma, A., Kancs, D., 2015. RHOMOLO: A Dynamic General Equilibrium Modelling Approach to the Evaluation of the European Union's R&D Policies. Regional Studies 49, 1340-1359.

Brautzsch, H., Günther, J., Loose, B., Ludwig, U., Nulsch, N., 2015. Can R&D subsidies counteract the economic crisis? - Macroeconomic effects in Germany. Research Policy 44 (3), 623-633.

Channing, A. , 1996. An introduction to systematic sensitivty analysis via Gaussian quadrature. GTAP Technical Paper No. 02. Available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=305.

Channing, A., Pearson K.R., 2000. How to carry out systematic sensitivity analysis via Gaussain quadrature adn GEMPACK. GTAP Technical Paper No. 03. Available at https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=474.

Damijan, J., Jaklic, A., Rojec, M., 2005. Do External Knowledge Spillovers Induce Firms' Innovations? Evidence from Slovenia. LICOS Discussion Paper 156.

Dąbrowa-Szefler, M., 2004. Basic Demand and Supply Problems Concerning Research Personnel in Poland. Higher Education Policy, 17(1), 39-48.

European Union, 2015. Innovation union scoreboard 2013.

European Commission Europe 2020 targets. Internet source (available as of 27.04.2016): http://ec.europa.eu/europe2020/pdf/themes/15_research__development.pdf

Garau, G., Lecca, P., 2015. The Impact of Regional R&D Subsidy in a Computable General Equilibrium Model. International Regional Science Review 38(4), 319-357.

Geodecki, T., Gorzelak, G., Górniak, J., Hausner, J., Mazur, S., Szlachta, J., Zaleski, J., 2012. Kurs na innowacje. Jak wyprowadzić Polskę z rozwojowego dryfu. Fundacja Gospodarki i Administracji Publicznej, Kraków.

Gorzelak, G., 2014. Wykorzystanie środków Unii Europejskiej dla rozwoju kraju – wstępne analizy. Studia Regionalne i Lokalne 3 (57), 5-25.

Griffith, R., Redding, S., Reenen, J., 2004. Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries. The Review of Economics and Statistics 86 (4), 883-895.

Griliches, Z., 1991. The Search for R&D Spillovers. National Bureau of Economic Research, Working Paper 3768.

GUS. Bank Danych Lokalnych. http://stat.gov.pl/bdl/app/dane_podgrup.hier?p_id=994892&p_token=-1741628568.

GUS, 2014. Input–output tables at basic prices in 2010.

Hogg, R.V., Craig, A.T., 1970. Introduction to Mathematical Statistics. MacMillan Publishing Co, New York.

Hong, C., Yang, H., Hwang, W., Lee, J., 2014. Validation of an R&D-based computable general equilibrium model. *Economic Modelling* 42, 454-463. DOI: 10.1016/j.econmod.2014.07.014.

Horridge, J.M., 2012. The TERM model and its data base. In: Wittwer, G. (Ed.), Economic Modelling of Water: The Australian CGE Experience. Springer, Dordrecht, Netherlands.

Horridge, M., Madden, J., Wittwer, G., 2005. The impact of the 2002-2003 drought on Australia. Journal of Policy Modeling 27 (3), 285-308.

Horridge, J.M., Wittwer, G., 2010. Bringing regional detail to a CGE model using census data. Spatial Economic Analysis 5 (2), 229-255.

Hryniewicz J., 2004. Polityczny i kulturowy kontekst rozwoju gospodarczego. Wydawnictwo Naukowe Scholar, Warszawa.

IMF, 2015. World Economic Outlook Database October 2015 Edition. Accessed 2 November 2015 at https://www.imf.org/external/pubs/ft/weo/2015/02/weodata/index.aspx.

Industry Commission, 1995. Research and Development. Report No 44.

Jałowiecki, B., Gorzelak, G.J., 2004. Brain drain, brain gain, and mobility: Theories and prospective methods. Higher Education in Europe 29 (3), 299-308.

Jasinski, A.H., 2009. Barriers for technology transfer: The case of a country in transition. Journal of Technology Management in China 4 (2), 119-131. DOI: http://dx.doi.org/10.1108/17468770910964984

Jones, C., Williams, J., 1998. Measuring the social return to R&D. The Quarterly Journal of Economics 113 (4), 1119-1135 .

Keller, W., 2004. International Technology Diffusion. Journal of Economic Literature 42 (3), 752-782. DOI: 10.1257/0022051042177685.

Kluzek, M. (2015). Efektywność ulg podatkowych sprzyjających innowacyjności w Polsce. Research Papers of the Wroclaw University of Economics/Prace Naukowe Uniwersytetu Ekonomicznego we Wroclawiu, (386).

Kluzek M., 2013, Rozwiązania podatkowe wspierające innowacyjność, Zarządzanie i Finanse, nr 2, z.2, 149-160.

Kolasa, M., 2008. Productivity, innovation and convergence in Poland. Economics of Transition 16 (3), 467-501.

Krammer, S., 2010. International R&D spillovers in emerging markets: The impact of trade and foreign direct investment. The Journal of International Trade & Economic Development 19 (4), 591-623.

Křístková, Z., 2012. Impact of R&D Investment on Economic Growth of the Czech Republic – A Recursively Dynamic CGE Approach. Prague Economic Papers 21 (4). DOI: 10.18267/j.pep.432.

Łącka, I., 2012. The state of linkages between the science and industry in Poland before the reform of the sector of science and research. Advances In Management & Applied Economics 2 (4), 57-70.

Madden, G.G, Savage, S.J., Bloxham, P., 2001. Asian and OECD international R&D spillovers. Applied Economics Letters 8 (7).

Mairesse, J., Sassenou, M., 1991. R&D Productivity: A Survey of Econometric Studies at the Firm Level. National Bureau of Economic Research, Working Paper 3666. DOI: 10.3386/w3666.

Meriküll, J., Poltimäe, H., Paas, T., 2013. International Technology Diffusion: The Case of Central and Eastern European Countries. Eastern European Economics 51, 21-138.

Nadiri, M.I., Prucha, I.R., 1996. Estimation of the depreciation rate of physical and R&D capital in the US total manufacturing sector. Economic Inquiry 34, 43-56.

OECD, 2012. STI e-Outlook 2012: STI country profiles: Poland. Accessed 10 July 2015 at http://www.oecd.org/sti/outlook/e-outlook/sticountryprofiles/poland.htm

Olechnicka, A., Płoszaj, A., 2010. Mapping the regional science performance. Evidence from Poland. Collnet Journal of Scientometrics and Information Management, 4(1), 21-27.

Owczarczuk, M., 2013. Government Incentives and FDI inflow into R&D: The Case of Visegrad Countries. Entrepreneurial Business and Economics Review 1 (2), 73-86.

Pakes, A., Schankerman, M. 1979. The Rate of Obsolescence of Knowledge, Research Gestation Lags, and the Private Rate of Return to Research Resources. National Bureau of Economic Research Working Paper 0346.

Piekut, M., 2013. Comparison of R&D Expenditures in Selected Countries. Comparative Economic Research 16(3), 107-126.

Płoszaj A., Olechnicka A., 2015. Running faster or measuring better? How is the R&D sector in Central and Eastern Europe catching up with Western Europe? GRINCOH Working Paper 3.06.

Pruchnik, K., Toborowicz, J., 2014. Low Level of Innovativeness and the Middle Income Trap – Polish Case Study. Journal of Entrepreneurship. Management and Innovation 10 (2), 141-157.

Radło, J., Ciesielska, D., 2013. Polska w pułapce średniego dochodu? Perspektywy konkurencyjności polskiej gospodarki regionów. Difin, Warszawa.

Romer, P., 1990. Endogenous Technological Change. Journal of Political Economy 98 (S5), S71.

Schankerman, M., Pakes, A., 1986. Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period. Economic Journal 96, 1052-1076.

Shanks, S., Zheng, S., 2006. Econometric Modelling of R&D and Australia's Productivity. Productivity Commission, Staff Working Paper.

Sliker, B., 2007. 2007 R&D Satellite Account Methodologies: R&D Capital Stocks and Net Rates of Return. Bureau of Economic Analysis/National Science Foundation R&D Satellite Account Background Paper.

Sulmicki, J., Czyżewska, M. (eds.), 2011. Uwarunkowania rozwoju innowacyjności przedsiębiorstw. Wydawnictwo IPIS, Warszawa.

Świeczewska, I., 2015. Labour productivity in Polish economy. A sectoral perspective. Paper presented at 23th International Conference INFORUM.

Varga, A., 2011. Modelling the economic impacts of regional R&D subsidies: The GMR-Europe model and its application for EU Framework Program policy impact simulations. Paper presented at 6th International Seminar on Regional Innovation Policies, University of Lund, Lund, Sweden.

Wittwer G. (Ed.), 2012. Economic Modeling of Water: The Australian CGE Experience. Springer.

Zawalińska, K., Giesecke, J., Horridge, M., 2013. The consequences of Less Favoured Area support: a multi-regional CGE analysis for Poland. Agricultural and Food Science Vol 22, No 2 (2013) http://ojs.tsv.fi/index.php/AFS/article/view/7754/6305 .

Zúñiga-Vicente, J. Á., Alonso-Borrego, C., Forcadell, F. J., Galán, J. I., 2014. Assessing the effect of public subsidies on firm R&D investment: a survey. Journal of Economic Surveys 28 (1), 36-67.