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R&D and Economic Growth in Slovenia: A Dynamic General Equilibrium Approach with Endogenous Growth

Summary: In the article, we model R&D as a major endogenous growth element in a small open economy general equilibrium framework and consider several R&D policy scenarios for Slovenia. Increase of the share of sectoral investment in R&D that is deductible from the corporate income tax and increase of government spending on R&D turned out to be the most effective suggested policy measures. While the former policy measure is still followed in part by an undesired transfer of the tax relief to dividends, a moderate increase of government spending on R&D boosts long-run productivity in the economy, thus increasing the future value of firms, which is reflected in a desired dividend increase. The households that would gain more utility from such policy scenarios are those with more skilled and highly skilled labour, but not the very top earners in the economy.

Key words: Endogenous growth, General equilibrium modelling, R&D, Slovenia.

JEL: C68, D58, O38, O40.

The topic of economic growth is among the most essential issues in macroeconomics, as it directly affects the living standard of the population and the welfare level. As a result, the search for fundamental determinants behind the growth process is an ongoing research theme. There are broadly speaking two dominant theories; the neoclassical growth approach and the endogenous growth approach (*cf*. Robert J. Barro and Xavier Sala-i-Martin 2003). Neoclassical growth models assume that productivity growth is exogenous. This view has changed in the early 1980s. According to the new growth theory, the long-run economic growth is affected by deliberate economic behaviour and human actions.

Economists agree that the long-run growth potential in *per capita* growth is determined by advances in productivity. Production can to certain extent be expanded extensively through investment in factor inputs and through employment growth, but in the long run intensive improvements in productivity are required. By working in a more efficient way, more can be produced with given factor inputs. The major determinants of the productivity growth are investments in education and thus human capital, and in research and development (R&D). Along these lines, the theory of economic growth can be understood to have turned into the theory of productivity growth. On the other hand, the endogenous growth theory can be comprehended as an attempt to explain what can not be explained in the Robert M. Solow (1956) model, i.e. the rate of growth of total factor productivity or the so called Solow residual[1].

While these ideas have been tested in a number of empirical studies, they are struggling to find their way into general equilibrium modelling, which has led to a good deal of criticism. As Christian Ghiglino (2002) pointed out, endogenous growth theory has had some success in explaining the observed data related to the process of economic growth, but the results of the models are typically very sensitive to their microeconomic structure. Therefore, valuable insights can be gained by integrating endogenous growth theory into the framework of general equilibrium theory. The motivation behind our work is to construct and develop a dynamic general equilibrium model with endogenous growth, driven by investment in education and R&D, which will enable us to analyze the impact of these determinants on economic growth in the context of complex mutual activity of economic agents that is taking place in their socio-economic environment. Our contribution to the existing model literature is a focus on a small open economy case of Slovenia, where a large part of the technological change comes from abroad. In this article, we focus on integrating R&D as a major endogenous growth element into an inter-temporal general equilibrium framework, which has not been done before in the predominantly exogenous-based literature on economic growth in Slovenia[2].

R&D can be introduced either as a separate production factor, or through its impact on total productivity. R&D activity results in new goods, new ideas and new knowledge, which are non-rival (*cf.* Paul M. Romer 1990; Gene M. Grossman and Elhanan Helpman 1991; Philippe Aghion and Peter Howitt 1992). As such, it is a major source of sustained economic growth, both in terms of innovation and through adoption of existing technologies. Namely, the empirical studies stressing a strong and enduring link between R&D capital and output growth roughly suggest that a one per cent increase in the R&D capital stock is found to lead to a rise in output of between 0.05-0.1 per cent (Zvi Griliches 1992; David T. Coe and Elhanan Helpman 1995; Jeffrey I. Bernstein 1998; Steven Globerman 2000). The potential gains from improved efficiency can also be important, as innovation is increased. However, these relationships should also be dependent on the quality of institutions and its regulation (*cf.* Maja Klun and Renata Slabe-Erker 2009). Nonetheless, while increases in human capital, R&D, and product market competition can improve macroeconomic performance, it takes time before these benefits are realised.

On the other hand, investments in R&D are suboptimal as the private and social rates of returns diverge (Griliches 1988). This is because, in its R&D investment

[1] There is vast literature available on measuring total factor productivity. Thus, one could only point out here some comprehensive literature reviews on this topic, e.g. M. Ishaq Nadiri (1970), T. K. Rymes (1983), Renuka Mahadevan (2003), Richard G. Lipsey and Kenneth I. Carlaw (2004), and Tao Kong (2007).

[2] Readers are invited to consult Boris Majcen et al. (2005), Miroslav Verbič et al. (2006), Verbič (2007), Mitja Čok et al. (2009), Verbič (2009), and Majcen et al. (2009) in order to obtain an insight into the development of general equilibrium modelling of the Slovenian economy.

decision, a private investor does not account for the losses it imposes on previous innovators, as well as the inter-temporal knowledge spillovers and consumer surplus it creates. Existing literature suggests that in the absence of taxes and subsidies, the decentralized economy underinvests in R&D with the primary impetus coming from the surplus appropriability problem, arising from monopoly pricing of R&D output[3] (*cf*. Madanmohan Ghosh 2007). Thus, governments in many countries provide various incentives to stimulate R&D activities. Since most benefits of R&D are intangible, they are difficult to estimate econometrically and there is little empirical work that evaluates the relative merits of these incentives in a systematic way, such as using a dynamic general equilibrium framework.

The outline of the article is as follows. In Chapter 1 a current literature overview on R&D-driven endogenous growth models is presented. In Chapter 2 a broad description of the general equilibrium model of the Slovenian economy is provided, while in Chapter 3 we show in detail how the R&D sector is modelled in a dynamic general equilibrium framework. In Chapter 4 the scenarios are described and the results of simulations are presented, where we focus in particular on macroeconomic and welfare aspects. In the final chapter we summarize the main findings of the article.

1. Literature Overview on R&D-driven Endogenous Growth Models

The endogenous growth literature captures the insight that the crucial force behind positive growth rates is the elimination of the tendency of diminishing returns to investment in a broad class of capital goods, including R&D. Antecedents of this literature utilize theories of technological progress, innovation and imitation (Romer 1987; Grossman and Helpman 1991), learning by doing (Nancy L. Stokey 1991), and population change, fertility and human capital investment (Gary S. Becker and Barro 1988) in order to introduce increasing or constant returns to scale to the cumulative factor of production. Recent advances in the new growth theory identify, among many others, the investment in R&D as a crucial determinant of the long-run rate of economic growth (*cf*. Maria J. Alvarez-Pelaez and Christian Groth 2005; Ghosh 2007).

At the beginning of 1990s, a first generation of endogenous R&D growth models appeared. The product-variety model by Romer (1990) and the quality-ladder model by Aghion and Howitt (1992) are pioneer models and the starting point for many later contributions. The idea was to assume that in order to set up production, a firm must incur a fixed cost in the form of an outlay on the final good; an outlay, which may be thought of as the R&D cost of developing its particular variety. The major policy questions of that time have been how an economy can sustain a positive growth rate and how innovation policy can enhance additional growth and welfare.

In Romer's (1990) model, growth was driven by technological change that arises from intentional investment decisions, made by profit-maximizing agents. The

[3] However, in some circumstances privately financed R&D may be too high as well (*cf*. Aghion and Howitt 1992; Charles I. Jones and John C. Williams 2000).

distinguishing feature of the technology as an input was that it is not a conventional or a public good; it is a non-rival, partially excludable good. Because of the non-convexity introduced by a non-rival good, price-taking competition cannot be supported. Instead, the equilibrium is one with monopolistic competition. The main conclusions were that the stock of human capital determines the rate of growth, that too little human capital is devoted to research in equilibrium, that integration into the world markets will increase growth rates, and that a large population is not sufficient to generate growth.

Aghion and Howitt (1992) developed a model of endogenous growth, in which growth is driven by vertical innovations that involve creative destruction. Equilibrium was determined by a forward-looking difference equation, according to which the amount of research in any period depends negatively upon the amount expected next period. They analyzed positive and normative properties of stationary equilibria, and showed conditions for the existence of cyclical equilibria and no-growth traps. They demonstrated that the growth rate may be more or less than optimal because a "business-stealing" effect counteracts the usual spillover and appropriability effects. In addition, innovations tend to be too small.

Lakshmi K. Raut and Thirukodikaval N. Srinivasan (1994) employed a model with endogenous population growth. According to this approach, the growth of population may induce technological change when certain resources, such as land, are fixed. As Ester Boserup (1981) and Julian L. Simon (1981; 1996) argued, population pressure gives agents incentives to develop new techniques of production. In that case, one would expect the resulting innovations to bring about changes in the technology, defined as the set of all efficient techniques, such that either the shape or the numbering of the contours that make up the isoquant map will depend on the size of the population.

Jones (1995) criticised R&D growth models with expanding variety or growing quality of intermediate inputs that have a scale effect of R&D employment on the productivity growth. His criticism was based on the ground that the prediction of such models is widely at variance with the facts of R&D employment and productivity growth in the advanced countries over the last fifty years. He suggested a model, which shares important features with Kenneth J. Arrow's (1962) seminal paper on learning by doing. He believed that growth *per se* is not endogenous, although if population is growing, *per capita* output may persistently increase because of purposeful research effort due to increasing returns to scale in the output sector.

While the aggregate models of Romer (1990) and descendants (Jones and Williams 2000; Alvarez-Pelaez and Groth 2005; Thomas M. Steger 2005) treated economies as closed, in a small open economy framework a large part of the technological change comes from abroad. These models take into account that technological change results from profit-maximising R&D firms' output of patents that are purchased by capital producers in order to supply new varieties of capital equipment. However, since the access to global knowledge is limited by its level of technical sophistication and capacity to absorb, domestic R&D is important both for its direct impact on long-run economic growth and enhancing absorptive capacity. Gerhard Glomm and B. Ravikumar (1994) modelled an infinite-horizon economy where the stock of technological knowledge enhances the productivity of all households and technological knowledge depends upon public sector investment in R&D. They established that public policy affects the growth rate of *per capita* income, but has no impact on income inequality.

More recently, a second generation of endogenous R&D growth models has appeared, in which the scale effect is eliminated and the simultaneous expansion of intermediate goods variety and quality occurs under conditions that make steady-state productivity growth dependant on the ratio between intensive R&D employment and total employment (*cf.* Alwyn Young 1998; Pietro F. Peretto 1998; Howitt 1999). Maria J. Freire-Serén (2001) introduced into an R&D-model a technology of innovation, based on expenditure that generates endogenous sustainable growth in absence of any scale effect. Daisuke Ikazaki (2006) constructed an endogenous growth model that incorporates the R&D sector, the education sector, and environmental issues. He suggested, similar to Jones (1995), that the population level does not affect the economic growth rate. Brita Bye et al. (2007) explored how innovation incentives in a small, open economy should be designed in order to achieve the highest welfare and growth by means of R&D-driven endogenous technological change, embodied in varieties of capital.

Ghosh (2007) utilized a general equilibrium R&D model of endogenous growth via increasing capital variety, similar to the one of Xinshen Diao et al. (1999), in order to examine the impact of alternative policies on productivity and economic growth. His findings reveal that direct incentives, such as subsidies to R&D activities, would have the highest productivity impact, that an increase in subsidies to the users of R&D capital would have a positive but smaller impact, and that trade liberalization would have minimal effects on productivity growth via its impact on international R&D spillovers.

2. Description of the General Equilibrium Model of the Slovenian Economy

The model SIDYN 2.0 is a dynamic endogenous-growth general equilibrium model of the Slovenian economy, based on social accounting matrix (SAM) for the base year, and parameter data on consumer preferences, production technologies, accumulation of human capital and composition of total factor productivity[4].

The model incorporates the following economic agents: (1) five households grouped into quintiles according to income level; (2) twenty production sectors of both goods and services; (3) investment sector; (4) national government; and (5) external sector. Each agent in the economy supplies and demands a range of goods, services and factors of production at prices defined by equilibrium on the corresponding markets. There are six types of production factors in the model; country-level human capital differentiated by three skill (education) levels, sector-specific physical capital, sector-specific R&D stock, and sector-specific human capital stock.

[4] This chapter provides a non-technical description of our general equilibrium model (except for modelling of R&D, which is provided in Chapter 4). For a technical description of the model the reader is invited to consult Verbič et al. (2009) or Majcen et al. (2011).

The output level of the aggregated commodity of each of the twenty sectors is determined by an optimal combination of these production factors.

Both households and firms make their decisions under the assumption of an infinite horizon with perfect foresight (rational forward-looking expectations). All prices in the model are relative prices, which is the usual assumption of general equilibrium modelling. The inter-temporal problem is formulated in discrete time for the purpose of numerical implementation. To keep the derivation and calibration simple, all transactions are assumed to take place at the end of each period, while decisions are made or planned at the beginning of each period.

Households maximize their inter-temporal utility given the budget constraint. They decide how much time and money to invest into a particular type of human capital at each period of time. The consumers' decisions associated with spending of their money and time are independent of each other. The use of money positively influences consumer utility via an increase in consumption, whereas the use of time for education and work exerts a negative influence upon the consumers' utility level. Households do not invest in the sector-specific stocks. Different income categories in the economy correspond to different consumption patterns and governmental transfers.

Each type of labour is supplied by the households and the rest of the world. After domestic households decide upon the share of its labour endowment spent on work and education, the rest of the labour endowment is labelled as leisure activity and represents the level of voluntary unemployment in the economy. It is assumed that the labour flow from abroad does not choose to stay voluntarily unemployed. The human capital stock owned by the households is freely traded on the labour market and is mobile between the sectors. Sector-specific human capital is not mobile between the sectors and thus not traded. It represents sector-specific knowledge accumulated within the company, such as experience, reputation and contacts.

The firms choose investments into their physical capital, human capital and R&D stocks, as well as labour inputs such as to maximize its present discounted value. Investments made by the firms are financed using the total savings available in the economy. The stocks of sector-specific capital are accumulated over time via the new investments made by firms and the government. Gross prices for final goods are calculated as the sum of the producer price, transport and trade margins and various taxes and subsidies, where the transport and trade margins are the spending on transport and trade services, consumed in a certain proportion to the commodity itself.

Investments into physical capital are financed by the national investment agent with total savings and are used to buy different capital goods. The split of the total physical capital investment between the particular types of capital goods, such as machinery and buildings, is done so as to maximise the utility of the investment agent, which decides on how much of various capital goods are to be bought.

The public sector is represented by a national-level government, which collects a range of taxes, receives its share of dividends, and pays subsidies and transfers to households and firms, as well as transfers abroad. The revenues of the government consist of receipts from personal income tax, corporate income tax, VAT, payroll tax, social contributions, and import tariffs. The government subsidies support investment, production, intermediate consumption, household consumption, and exporting. The government also consumes a range of goods and services, and invests in national-level human capital and sector-specific R&D stocks.

The external sector incorporates the representation of exports and imports, as well as annual labour inflows from EU15, new member states and the rest of the world. Modelling of the external sector is based on the assumption of a small open economy, meaning that the prices of exports and imports are exogenously fixed in the model. Exports and imports are defined by Slovenian output and income levels, as well as by the ratio between the prices of domestic and exported goods and services, and elasticities of substitution between domestic and foreign goods. Inflows of labour to Slovenia are defined by the changes in domestic real after-tax wages and the elasticity of the labour supply, which is assumed to be higher for the rest of the world than for the EU15 and the new member states.

The model is build within the general algebraic modelling system (GAMS), which has become both most widely used programming language and most widespread computer software for construction and solving large and complex general equilibrium models. Within the GAMS framework, the dynamic general equilibrium model is written in Lars Mathiesen's (1985) formulation of the Arrow and Gerard Debreu (1954) equilibrium model, i.e. as a mixed complementarity problem (MCP). The key advantage of this formulation is the compact presentation of the general equilibrium problem, which is achieved by treating variables implicitly and thus significantly reducing the computation time for higher-dimensional problems. To solve the model, i.e. to achieve convergence, a recent version of the PATH solver (Michael C. Ferris and Todd S. Munson 2000) is used, which is renowned for its computational efficiency.

In contrast to simpler models, such a large-scale model enables one to consider simultaneous changes in a variety of policy instruments and provides ways to understand short-to-medium run responses by making it possible to observe the transition paths of the modelled economy from one steady state to possible-other. With assumptions of longer time-spans on the part of each agent, such a model provides a more realistic setup that points to the income distribution effects of permanent policy changes.

3. Modelling R&D in a Dynamic CGE Framework

Economic growth in the model is endogenously determined by the development of households' human capital stock, stock of sector-specific human capital and R&D, used as factors of production by the firms, as well as the development over time of the overall total factor productivity (TFP). With the higher levels of R&D stock one needs to invest more; the higher is technology development the more has to be invested in R&D in order to obtain new innovations and to further increase the R&D stock.

The development of overall TFP is described by the following regression equation and depends positively upon the share of nationally produced R&D in the GDP and the share of foreign trade in the GDP (*cf.* Erik Canton et al. 2005):

$$\log TFP_t = tfpr + e_{rd} \log\left(\frac{XD_{rd,t}}{GDP_t}\right) + e_M \log \sum_{sec}\left(\frac{MX_{sec,t}}{GDP_t}\right) \tag{1}$$

where *rd* is a subset of commodity types, consisting of R&D services; *tfpr* is the residual of the total factor productivity regression; e_{rd} is the partial elasticity of the total factor productivity with respect to the share of R&D in the GDP; e_M is the partial elasticity of the total factor productivity with respect to the share of foreign trade in the GDP; TFP_t is the total factor productivity level in the economy; GDP_t is the gross domestic product; $XD_{sec,t}$ is the total output of the domestic sector *sec*; and $MX_{sec,t}$ is the mean of total imports and exports of commodities. The latter is defined as:

$$\begin{aligned} MX_{sec,t} = \frac{1}{2}\big(& IMEU15_{sec,t} + IMEU9_{sec,t} + IMROW_{sec,t} + \\ & + EXEU15_{sec,t} + EXEU9_{sec,t} + EXROW_{sec,t} \big), \end{aligned} \tag{2}$$

where $IMEU15_{sec,t}$ is the import of commodities from EU15; $EXEU15_{sec,t}$ is the export of commodities to EU15; $IMEU9_{sec,t}$ is the import of commodities from the new EU member states; $EXEU9_{sec,t}$ is the export of commodities to the new EU member states; $IMROW_{sec,t}$ is the import of goods from the rest of the world (ROW); and $EXROW_{sec,t}$ is the export of goods to the rest of the world.

Expression (1) has been adopted in the current version of our general equilibrium model in order to account for the domestic and international spillover effects of the R&D activity. The total factor productivity, represented by the above regression equation is then applied to all production sectors of the economy through the sectoral production function $XD_{sec,t}$.

The firms in the model are faced with the inter-temporal profit maximization problem and with the formulation of their investment decisions, related to R&D (*cf.* Stephen P. Cassou and Kevin J. Lansing 2004). In each period of time, the firms produce one commodity by sector, using physical capital, labour, sector-specific human capital and sector-specific R&D stock as inputs. It is assumed that the firms operate under the following constant returns to scale Cobb-Douglas technology function:

$$XD_{sec,t} = TFP_t aF_{sec} K_{sec,t}^{\alpha F_{sec}} L_{sec,t}^{\alpha FL_{sec}} HCS_{sec,t}^{\alpha FHC_{sec}} RDS_{sec,t}^{\alpha FRD_{sec}} \tag{3}$$

where aF_{sec} is the scale parameter of the Cobb-Douglas production function; $K_{sec,t}$ is the input of physical capital; $L_{sec,t}$ is the input of labour; $HCS_{sec,t}$ is the input of sector-specific human capital stock; $RDS_{sec,t}$ is the input of sector-specific R&D stock; αF_{sec} is the share parameter of the production function, associated with physical capital; αFL_{sec} is the share parameter of the production function, associated with labour; αFHC_{sec} is the share parameter of the production function, associated with human capital stock; and αFRD_{sec} is the share parameter of the production function, associated with R&D stock.

The stock of R&D knowledge, used as input by firms each period of time, is determined according to the following law of motion:

$$RDS_{sec,t} = ARDS_{sec} RDS_{sec,t-1}^{1-\delta RDs_{sec}} \left(RD_{sec,t-1} + RDG_{sec,t-1} \right)^{\delta RDs_{sec}} \quad (4)$$

where $ARDS_{sec}$ is the scaling parameter of the R&D stock accumulation function; δRDs_{sec} is the share parameter of the R&D stock accumulation function, associated with the new R&D investment[5]; $RD_{sec,t}$ are the R&D services bought by the sector *sec* for investment in its R&D stock; and $RDG_{sec,t}$ are the R&D services bought by the government for investment in the R&D stock of sector *sec*.

The firms choose investments in their physical capital, human capital and R&D knowledge stocks at each time period, as well as labour inputs such as to maximize the present discounted value of the firm, $VF_{sec,t}$. Given that the model has a finite simulation time horizon, {1, …, *T*}, where *T* is the last simulated time period[6], we obtain the following expression for the value of the firm:

$$VF_{sec} = \sum_{t=1}^{T-1} \left(\frac{1}{1+r} \right)^t DIV_{sec,t} + \left(\frac{1}{1+r} \right)^T \frac{1+r}{r-g} DIV_{sec,T} \quad (5)$$

where *r* is the steady state interest rate; *g* is the steady state growth rate; and $DIV_{sec,t}$ are the dividends paid by sector *sec*. It is assumed that the dividend payments are equal to the value of the commodity, reduced by the labour costs and the investments made by firms in physical capital, human capital and R&D stock. This leads to the following implicit expression for the firms' dividends, $DIV_{sec,t}$:

[5] Note that the share parameters of the laws of motion, associated with new investments, are interpreted as depreciation rates for different types of capital used as input by the firms.
[6] After time period *T* it is assumed that the economy will be on the steady-state path where all real economic variables grow with the same annual rate until infinity.

$$\begin{aligned}
&\left(1+spv_{sec,t}-\left(1-spv_{sec,t}\right)txdv_{sec,t}\right)PD_{sec,t}XD_{sec,t}=\left(1+tkv_{sec,t}\right)DIV_{sec,t}+I_{sec,t}PK_{t}+\\
&\quad+\left(1+tlev_{sec,t}+\left(1+tlev_{sec,t}\right)\left(tlv_{sec,t}+payrv_{sec,t}\right)\right)PL_{sec,t}L_{sec,t}+\\
&\quad+\sum_{secc\notin sechr}\Big[io_{secc,sec}XD_{sec,t+1}\left(P_{secc,t+1}+tmicv_{secc,t+1}PTM_{t+1}\right)\Big(1-sicv_{secc,t+1}+\\
&\quad\quad+\left(1-sicv_{secc,t+1}\right)\left(ticv_{secc,t+1}+vaticv_{secc,t+1}+exsticv_{secc,t+1}\right)\Big)\Big]+\\
&\quad+HC_{sec,t}\left(P_{edus,t}+tmicv_{edus,t}PTM_{t}\right)\Big[\left(1-sicv_{edus,t}-tkv_{sec,t}shareHCv_{t}+\right.\\
&\quad\quad\left.+\left(1-sicv_{edus,t}\right)\left(ticv_{edus,t}+vaticv_{edus,t}+exsticv_{edus,t}\right)\right)\Big]+\\
&\quad+RD_{sec,t}\left(P_{rd,t}+tmicv_{rd,t}PTM_{t}\right)\Big[\left(1-sicv_{rd,t}-tkv_{sec,t}shareRDv_{t}+\right.\\
&\quad\quad\left.+\left(1-sicv_{rd,t}\right)\left(ticv_{rd,t}+vaticv_{rd,t}+exsticv_{rd,t}\right)\right)\Big],
\end{aligned}\tag{6}$$

where *secc* is an alias of sector *sec*; *edus* is a subset of commodity types, consisting of education services; *sechr* is a subset of commodity types, consisting of education and R&D services; $spv_{sec,t}$ is the output subsidy rate; $txdv_{sec,t}$ is the output tax rate; $tkv_{sec,t}$ is the corporate income tax rate; $tlev_{sec,t}$ is the employees' social contribution rate; $tlv_{sec,t}$ is the employers' social contribution rate; $payrv_{sec,t}$ is the payroll tax rate; $I_{sec,t}$ is the private demand for investment goods; PK_t is the return to capital; $PL_{sec,t}$ is the wage; PTM_t is the composite price of trade and transport margin; $PD_{sec,t}$ is the domestic producer price; $P_{sec,t}$ is the domestic sales price; $HC_{sec,t}$ is the human capital spending; $io_{secc,sec}$ is an input-output coefficient of commodity *secc* used for production in the sector *sec*; $tmicv_{secc,t}$ is the intermediate consumption trade and transport margin; $sicv_{secc,t}$ is the intermediate consumption subsidy rate; $ticv_{secc,t}$ is the intermediate consumption tax rate; $vaticv_{secc,t}$ is the intermediate consumption VAT rate; $exsticv_{secc,t}$ is the intermediate consumption excise tax rate; $shareHCv_t$ is the share of sectoral investment in human capital stock, deductible from the corporate income tax; and $shareRDv_t$ is the share of sectoral investment in R&D, deductible from the corporate income tax.

Investments made by the firms are financed using the total savings available in the economy, i.e. the savings of households, the government, retained profits of the firms and the savings from abroad. Investment level in the sector-specific R&D is thus chosen such that the firms' discounted profits resulting from these investments are equal to the costs of the investments. By maximizing the expression for the value of the firm (5) subject to the firms' output technology (3) and the law of motion (4), one obtains, after some simplification, the respective first-order condition:

$$
\begin{aligned}
&RD_{sec,t}\left(P_{rd,t}+tmicv_{rd,t}PTM_t\right)\left[\left(1-sicv_{rd,t}-tkv_{sec,t}shareRDv_t+\right.\right.\\
&\qquad\left.\left.+\left(1-sicv_{rd,t}\right)\left(ticv_{rd,t}+vaticv_{rd,t}+exsticv_{rd,t}\right)\right]=\\
&=\frac{1}{1+r}\left[\left(1+spv_{sec,t+1}-(1-spv_{sec,t+1})txdv_{sec,t+1}\right)PD_{sec,t+1}XD_{sec,t+1}-\right.\\
&-\sum_{secc\notin sechr}\left[io_{secc,sec}XD_{sec,t+1}\left(P_{secc,t+1}+tmicv_{secc,t+1}PTM_{t+1}\right)\left(1-sicv_{secc,t+1}+\right.\right.\\
&\left.\left.\left.+\left(1-sicv_{secc,t+1}\right)\left(ticv_{secc,t+1}+vaticv_{secc,t+1}+exsticv_{secc,t+1}\right)\right)\right]\right]\alpha FRD_{sec}\delta RDs_{sec}\,.
\end{aligned}
\tag{7}
$$

Left hand side of expression (7) represents the total cost of the investment in R&D, and is equal to the right hand side, which represents the additional discounted dividends of the firms, resulting from the investment in R&D. The value of additional dividends depends positively upon the Cobb-Douglas share of the R&D stock in the production function, $aFRD_{sec}$, and the Cobb-Douglas share that represents the contribution of new R&D investment to the total stock of sector-specific R&D, δRDs_{sec}.

In the government sector we model explicitly the tax revenues, the government subsidies and the government consumption of goods and services. The tax revenues of the government, associated with R&D, consist of the following expression:

$$\left(1-sicv_{rd,t}\right)\left(ticv_{rd,t}+vaticv_{rd,t}+exsticv_{rd,t}\right)\left(P_{rd,t}+tmicv_{rd,t}PTM_t\right)\sum_{secc}RD_{secc,t} \tag{8}$$

while the government subsidies, associated with R&D, have the following form:

$$\left(sicv_{rd,t}+tkv_{sec,t}shareRDv_t\right)\left(P_{rd,t}+tmicv_{rd,t}PTM_t\right)\sum_{sec}RD_{sec,t} \tag{9}$$

Finally, the equilibrium in the market for R&D services is determined by the following condition:

$$\sum_{sec}RD_{sec,t}+\sum_{sec}RDG_{sec,t}+I_{rd,t}+\sum_{secc\notin sechr}\left(io_{secc,sec}XD_{sec,t}\right)+SVX_{rd,t}+TMX_{rd,t}=X_{rd,t} \tag{10}$$

where $SVX_{sec,t}$ are the changes in stocks of sector *sec*; $TMX_{sec,t}$ is the consumption of sector *sec* for transport and trade margins; and $X_{sec,t}$ are domestic sales of the good of sector *sec* of domestic and foreign origin. Expression (10) thus reveals that the sum of firms' consumption of R&D services, government consumption of R&D services, consumption of the investment agent on R&D services, intermediate inputs in the production of R&D services, changes in the stocks of R&D services and transport and trade margins on R&D services is equal to the total domestic sales of R&D services.

4. Results of the Simulations

The groundwork for our analysis is the dynamic calibration of the model and consequently preparation of the reference solution. In the framework of performing the dynamic calibration of the model SIDYN 2.0, we follow the strategy of using the model to generate the entire dynamic path of endogenous variables in order to accurately reproduce the values of every endogenous variable in the base year. In this way we obtain the reference scenario, which represents the authentic state of the economy. Analysis of the Slovenian economy, where we take into account possible developments with respect to the R&D and other development policies, is then performed by forming counterfactual scenarios and comparing their outcomes to the results of the reference scenario. The counterfactual scenarios are based on varying the parameters of SIDYN 2.0, which are related to the modelling of R&D services.

For the purpose of our analysis we distinguish between model parameters and policy parameters; the former are of technical nature and subject to sensitivity analysis, while the latter are of economic nature and subject to policy analysis. In this article, we focus on the latter. Policy parameters, involved in modelling R&D decisions in a dynamic CGE framework, which are used in SIDYN 2.0, are the following: (1) the corporate income tax (CIT) rate in sector *sec*, $tkv_{sec,t}$; (2) the share of sectoral investment in R&D that is deductible from the CIT, $shareRDv_t$; and (3) government spending on R&D in sector *sec*, $RDG_{sec,t}$. There are also several policy parameters, involved directly in the production of R&D, which will not be examined here[7].

Table 1 Scenarios for the Analysis of Impacts of R&D on Economic Growth

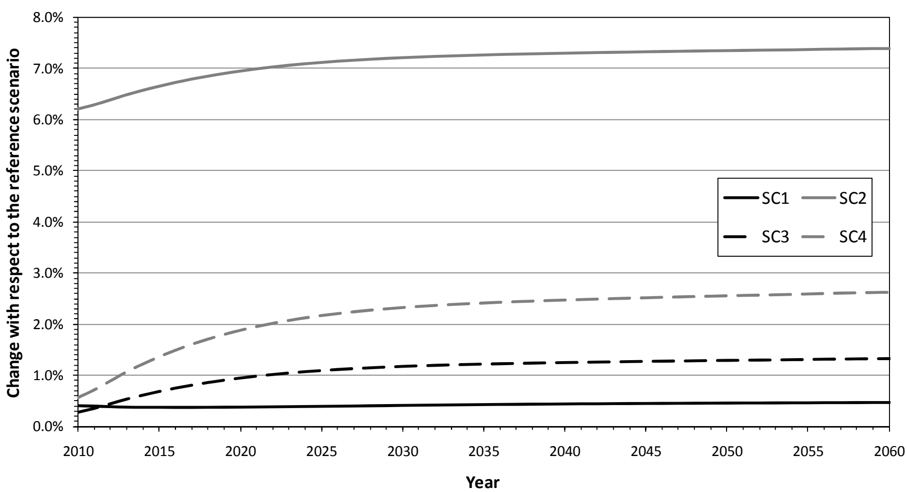
Scenario	Description of the scenario
SC1	Decrease of the corporate income tax rate, $tkv_{sec,t} = tkv_t$, by 25% from 2009
SC2	Increase of the share of sectoral investment in R&D that is deductible from the corporate income tax, *shareRDv,* by 25% from 2009
SC3	Increase of government spending on R&D, $RDG_{sec,t} = RDG_t$, by 10% *per annum* from 2009
SC4	Increase of government spending on R&D, $RDG_{sec,t} = RDG_t$, by 20% *per annum* from 2009

Source: Authors' simulations using SIDYN 2.0.

[7] These sector-specific policy parameters are: (1) the intermediate consumption tax rate, $ticv_{rd,t}$; (2) the intermediate consumption subsidy rate, $sicv_{rd,t}$; (3) the intermediate consumption VAT rate, $vaticv_{rd,t}$; (4) the intermediate consumption excise tax rate, $exsticv_{rd,t}$; and (5) the intermediate consumption trade and transport margin, $tmicv_{rd,t}$.

Description of the scenarios examined in this article is given in Table 1. We have chosen the scenarios in such a way that they reflect a combination of policy measures discussed in the Slovenian public debate and those proposed by Majcen et al. (2011).

Let us first examine the effects of these policy scenarios on R&D expenditure in Slovenia. As can be seen from Figure 1, scenario SC2 has a major effect on R&D expenditure of firms, while the effect of the remaining three scenarios is less profound, as it does not provide enough incentive to change the behaviour of firms. Namely, decreasing the CIT rate by 25% (SC1) increases on average the R&D expenditure of firms by modest 0.45% with respect to the reference scenario, while the impact of increasing the share of sectoral investment in R&D that is deductible from the CIT by 25% (SC2) amounts to 6.2-7.4%. It is thus rational for the firms to withheld realised profits for investment in R&D in order to increase future profits. The effect of increasing government spending on R&D with respect to the reference scenario is moderate; an increase of 10% *per annum* (SC3) increases the R&D expenditure of firms up to 1.3%, while an increase of 20% *per annum* (SC4) gives rise to an R&D expenditure increase of up to 2.6%.

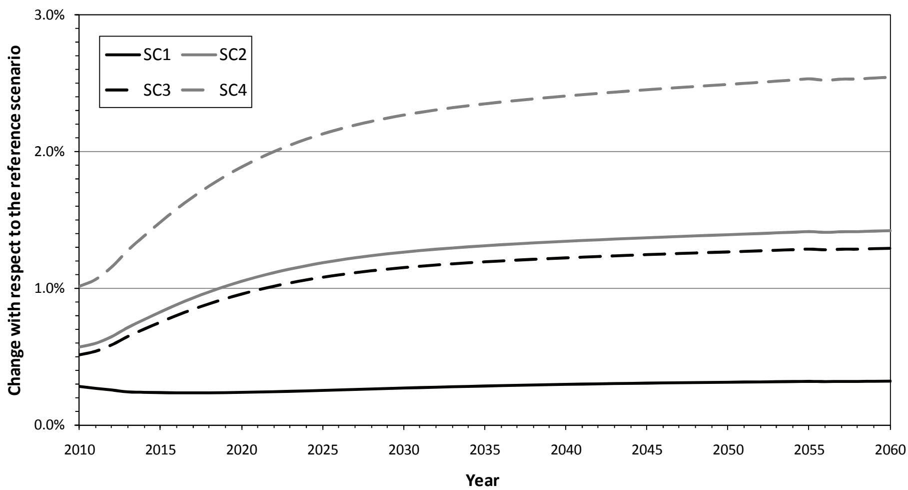


Source: Authors' simulations using SIDYN 2.0.

Figure 1 R&D Expenditure of Firms in Slovenia, 2010-2060

What is the rationale behind the dynamics presented in Figure 1 and how does it affect the rest of the economy? First, one needs to note that we only observe in Figure 1 the R&D expenditure change of firms with respect to the reference scenario, i.e. the response of the firms to economic policy, and not the total R&D expenditure change. Production of R&D services (not shown), which represents the total supply of R&D services in the economy, i.e. funded by the firms and the government, increases on average by 0.33% in scenario SC1, by up to 4.1% in scenarios SC2 and SC3, and by up to 7.9% in scenario SC4 with respect to the reference scenario. The latter scenario therefore demonstrates the dynamics of increasing the R&D expenditure on the Slovenian economy most distinctly.

In addition, investment in R&D services – be it by firms or the government – induces an accompanying investment in education services. R&D services and education services are to a certain extent complementary factors of production, which is necessary in order to consume additional R&D services efficiently in the production process. This phenomenon is obvious by looking at the effects of the policy scenarios on education expenditure of households (Figure 2) and on human capital expenditure of households and firms (not shown) in Slovenia.

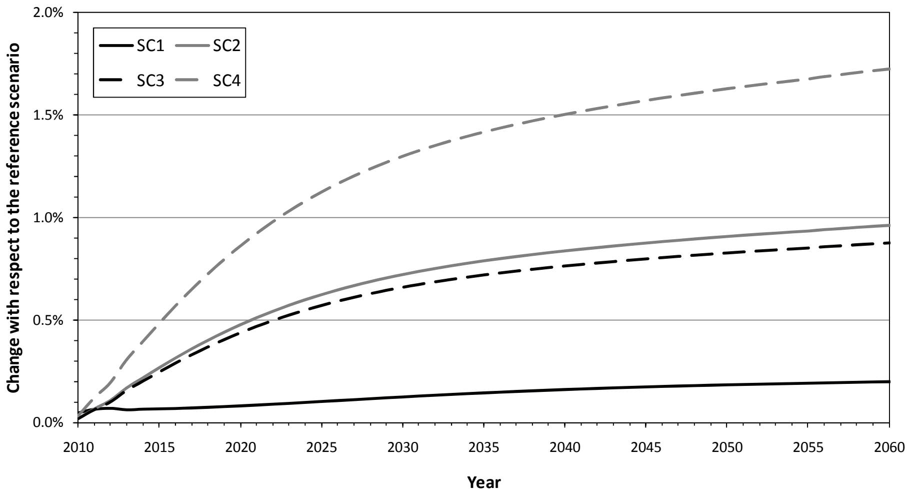


Source: Authors' simulations using SIDYN 2.0.

Figure 2 Education Expenditure of Households in Slovenia, 2010-2060

Namely, scenario SC1 induces on average an increase of education expenditure of households with respect to the reference scenario of 0.3%, scenario SC2 of up to 1.4%, scenario SC3 of up to 1.3%, and scenario SC4 of up to 2.5% (see Figure 2). Human capital expenditure change deviates from the education expenditure change (not shown) only in scenario SC1, where the human capital expenditure increases on average with respect to the reference scenario by 0.45%. This indicates that only scenario SC1 induces significant firm-funded human capital investment, while additional human capital change, induced by the other three policy scenarios, originates mainly from household-funded education expenditure investment.

Because of additional investment in R&D and the induced investment in human capital, the labour demand of firms in the economy increases and the labour supply of households adjusts (Figure 3). The adjustment is again least distinct in case of scenario SC1 (up to 0.2% increase) and most evident in case of scenario SC4 (up to 1.7% increase with respect to the reference scenario).



Source: Authors' simulations using SIDYN 2.0.

Figure 3 Labour Supply of Households in Slovenia, 2010-2060

Let us now examine in more detail the effect of increasing government spending on R&D by 20% *per annum* (SC4) on household investment in education. Figure 4 presents the dynamic of this effect by labour type. It turns out that households with unskilled labour increase its spending on education the least, while households with highly skilled labour increase its spending on education the most. This follows naturally by: (1) keeping in mind the nature of R&D investment; and (2) observing the dynamic of household income (not shown, but follows closely the dynamic of GDP in Figure 7). Namely, R&D investment – a key driver of economic growth – yields new product innovations and adds to the knowledge base of industry and the marketplace as a whole. As such, additional R&D expenditure employs more highly skilled labour, but also needs the support of skilled and unskilled labour in order to transform R&D investment into higher long-term growth. As can be inferred from Figure 4, implementing scenario SC4 employs on average 0.44 percentage points more highly skilled labour in comparison to skilled labour, and 0.64 percentage points more highly skilled labour in comparison to unskilled labour.

Additionally, by withdrawing labour from the production process the households lose income. Households with unskilled labour, which are on average also lower-income households, use higher share of their income for existential needs and are less able to invest its own funds in education. On the other hand, more investment in education reduces current labour supply. Figure 5, which presents the dynamic of labour supply by labour type, reveals this phenomenon. Labour type depends primarily on years of schooling. Investment in education of unskilled and skilled labour causes no initial decrease in labour supply with respect to the reference scenario, but leads to lower long-term growth change. Conversely, investment in education of highly skilled labour pulls the (potential) labour force out of the production process for a longer period of time, but leads to highest long-term growth change.

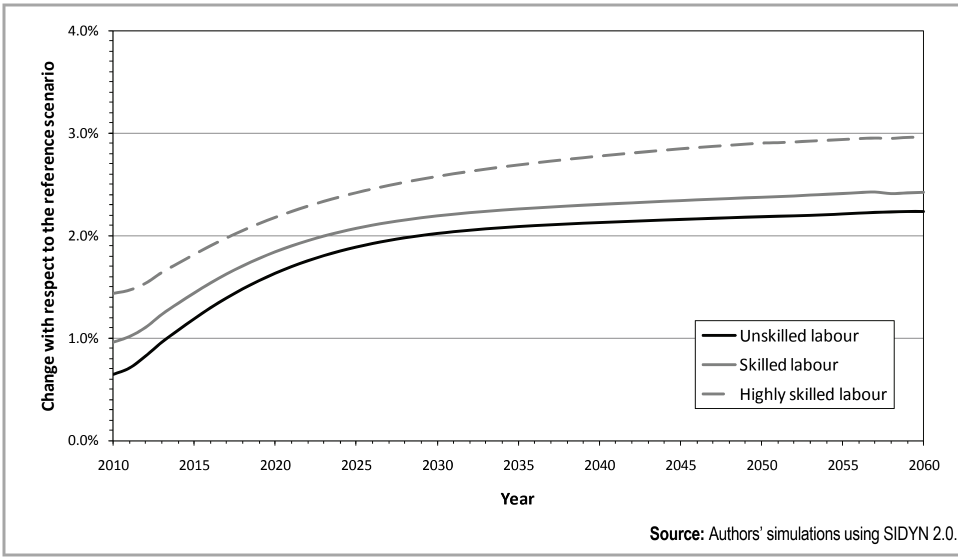


Figure 4 Education Expenditure of Households in Slovenia in Case of Increasing Government Spending on R&D by 20%, by Labour Type, 2010-2060

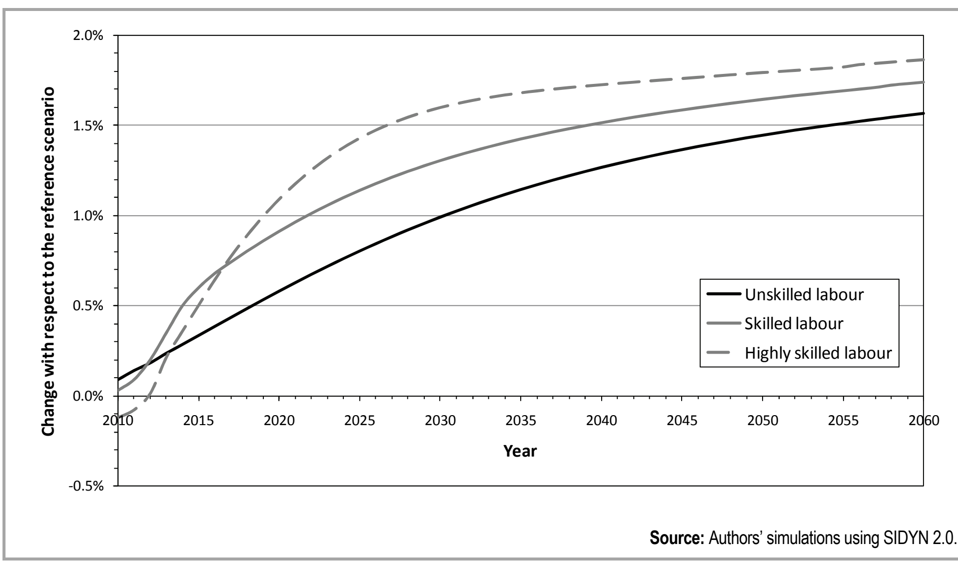
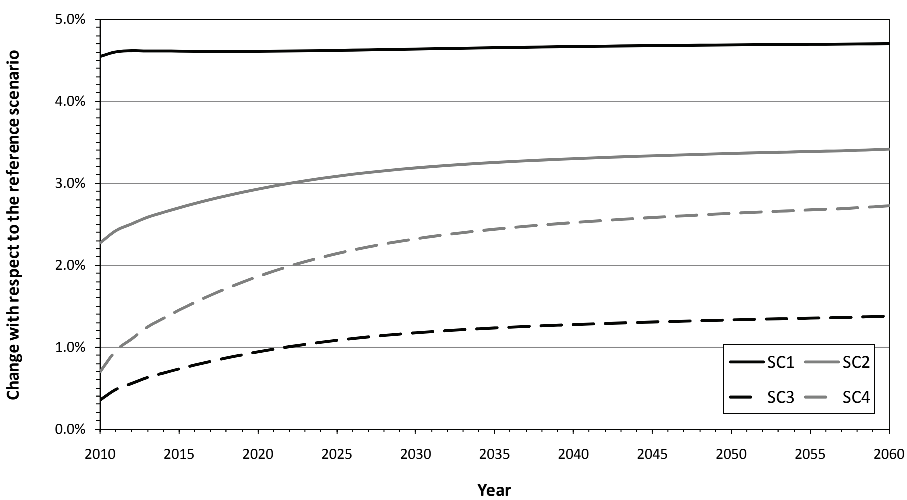


Figure 5 Labour Supply of Households in Slovenia in Case of Increasing Government Spending on R&D by 20%, by Labour Type, 2010-2060

Investment in R&D (Figure 1) and the induced investment in education and thus human capital (see Figures 2 and 4) are followed also by additional capital input (not shown). This is most evident in scenario SC4, where capital input increases with respect to the reference scenario by 3.75% in the long run, but also in scenarios SC2 and SC3, where we observe an increase of up to 1.5% and 1.4%, respectively. Capital input change is even more manifest in the R&D services sector, where it amounts up to 4.1% in scenario SC3, up to 4.2% in scenario SC2, and up to 8.1% in scenario SC4 with respect to the reference scenario.

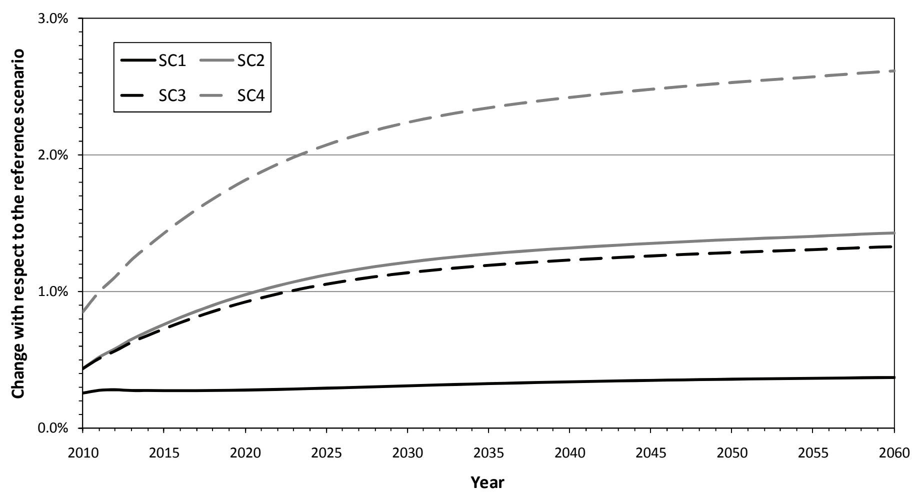
Diverse policy measures obviously affect different incomes to a different extent, which is most distinct in the case of real dividends (Figure 6). Namely, real dividends increase with respect to the reference scenario on average by 4.6% in scenario SC1, by up to 3.4% in scenario SC2, by up to 1.4% in scenario SC3, and by up to 2.7% in scenario SC4. Obviously, decreasing the CIT rate (scenario SC1) not only provides more funds in the profit optimization process for investment, but also leaves the firm with more profit for sharing, which appears to be an attractive option. On the other hand, by increasing the share of sectoral investment in R&D that is deductible from the CIT (scenario SC2), it becomes rational for the firm to redistribute some profit from sharing to investing in order to increase future profits. In these two scenarios, the dividend increase is still primarily a direct effect (an undesired effect) of the policy measures. Increasing government spending on R&D (scenarios SC3 and SC4) boosts long-run productivity in the economy, thus increasing future profits and the future value of firms, which is reflected in the dividend increase. The latter thus becomes a side effect (a desired effect) of the policy measures.



Source: Authors' simulations using SIDYN 2.0.

Figure 6 Real Dividends in Slovenia, 2010-2060

As already indicated, the dynamics of real household income change (not shown) and real GDP change (Figure 7) are similar, but with different levels. Real household income increases noticeably with respect to the reference scenario in scenarios SC2 and SC3 (on average by 1.0% in the long run) and scenario SC4 (by 1.9% in the long run). Real consumption (not shown) and real saving (also not shown) increase accordingly in the same three scenarios. Real GDP increases markedly in scenarios SC2 and SC3 (on average by 1.4% in the long run) and scenario SC4 (by 2.6% in the long run). This would indicate that increasing the government spending on R&D by 20% *per annum* is the most efficient policy measures with respect to the long-term economic growth, while decreasing the CIT rate by 25% and increasing the government spending on R&D by 10% *per annum* are roughly equivalent (though inferior) policy measures. However, even if one neglects the problem of comparability of the analyzed policy measures, it is necessary to compare other measures of well-being as well.



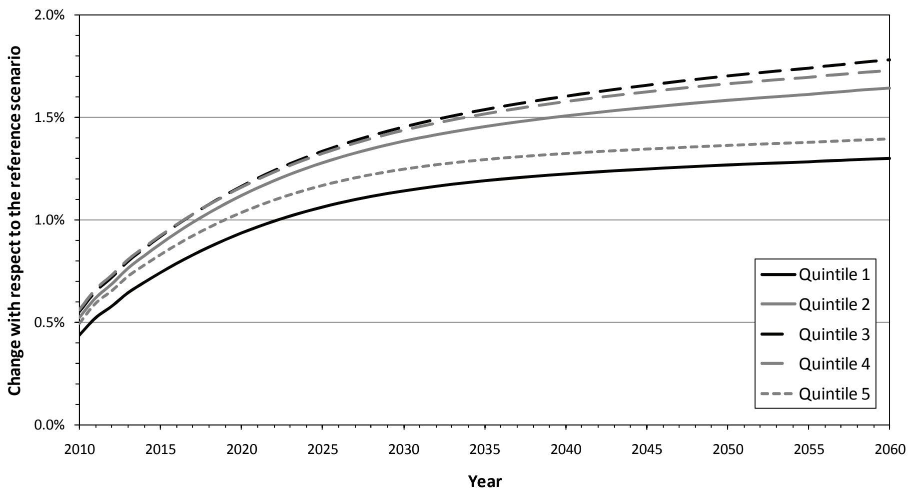
Source: Authors' simulations using SIDYN 2.0.

Figure 7 Real Gross Domestic Product in Slovenia, 2010-2060

One such measure is the household welfare, which comprises the consumption of material goods and services and consumption of leisure[8]. It turns out that the dynamic of aggregate welfare change (not shown) follows closely the dynamic of real GDP change. Namely, welfare increases noticeably with respect to the reference scenario in scenario SC4 (by 1.6% in the long run), while the increase is less profound in the remaining three scenarios (between 0.5% and 0.9%). Figure 8 illustrates the dynamic of welfare changes by household type in case of scenario SC4. One can observe that this dynamic is very similar irrespective of the income quintile, with some

[8] Household welfare in the model is defined in the form of its equivalent variation as a share of income. The equivalent variation represents the amount of income needed to achieve the same utility level as in the reference scenario at present prices.

divergence in levels in the course of time. Detailed analysis of other scenarios leads to the same conclusion; households that would gain more utility in case of implementing the analyzed policy scenarios are the ones from income quintiles 2-4, i.e. the households with more skilled and highly skilled labour, but neither the very top nor the bottom earners in the economy.



Source: Authors' simulations using SIDYN 2.0.

Figure 8 Welfare Change in Slovenia in Case of Increasing Government Spending on R&D by 20%, by Household Type, 2010-2060

5. Concluding Remarks

The debate whether long-run economic growth patterns can be best explained by traditional or endogenous growth is far from settled, but the notion that education and innovations can contribute to economic growth is nowadays widely accepted. This provided us with the motivation to develop a dynamic general equilibrium model with endogenous growth, driven by investment in education and R&D. In the present article, we demonstrate how R&D can be modelled as a major endogenous growth element in a small open economy general equilibrium framework, and consider several R&D policy scenarios for Slovenia, with primary focus on macroeconomic and welfare aspects.

Economic growth is endogenously determined by the development of human capital stock of households, sector-specific human capital and R&D stocks of firms, and the total factor productivity. R&D activity in the economy is thus modelled as a sector-specific R&D activity and represents the key driver of economic growth, which yields new product innovations and adds to the knowledge base of industry and the marketplace as a whole. The sector-specific R&D stock is accumulated over time through new investment made by firms, as well as by the government. The R&D investment of firms has country-level spillover effects via an increase of the total factor productivity. The country-level total factor productivity depends positively both upon the total output of the R&D sector and the openness of the economy, represented by the share of foreign trade in the GDP.

In the simulations, we analyzed several policy scenarios that directly or indirectly increase the R&D expenditure. Increase of the share of sectoral investment in R&D that is deductible from the CIT and a moderate increase of government spending on R&D turned out to be the most effective policy measures. By increasing the share of sectoral investment in R&D that is deductible from the CIT, it becomes rational for the firms to redistribute some profit from sharing to investing in order to increase future profits. However, this policy measure is still in part followed by a dividend increase, which is an undesired effect. On the other hand, increasing government spending on R&D boosts long-run productivity in the economy, thus increasing future profits and the future value of firms. This is reflected in the dividend increase, which is a side effect (a desired effect) of the policy measure. The households that would gain more utility in case of implementing the analyzed policy scenarios are the ones from middle-income quintiles, i.e. the households with more skilled and highly skilled labour, but neither the very top nor the bottom earners in the economy.

References

Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica*, 60(2): 323-351.

Alvarez-Pelaez, Maria J., and Christian Groth. 2005. "Too Little or Too Much R&D?" *European Economic Review*, 49(2): 437-456.

Arrow, Kenneth J., and Gerard Debreu. 1954. "Existence of an Equilibrium for a Competitive Economy." *Econometrica*, 22(3): 265-290.

Arrow, Kenneth J. 1962. "The Economic Implications of Learning by Doing." *Review of Economic Studies*, 29(6): 155-173.

Barro, Robert J., and Xavier Sala-i-Martin. 2003. *Economic Growth: Second Edition*. Cambridge, MA: The MIT Press.

Becker, Gary S., and Robert J. Barro. 1988. "A Reformulation of Economic Theory of Fertility." *Quarterly Journal of Economics*, 103(1): 1-25.

Bernstein, Jeffrey I. 1998. "Inter-Industry and U.S. R&D Spillovers, Canadian Industrial Production and Productivity Growth." Micro-Economic Policy Analysis Branch, Strategic Policy Sector, Industry Canada, Ottawa, Working Paper 19.

Boserup, Ester. 1981. *Population and Technological Change: A Study of Long-term Trends*. Chicago: University of Chicago Press.

Bye, Brita, Taran Fæhn, and Tom-Reiel Heggedal. 2007. "Welfare and Growth Impacts of Innovation Policies in a Small, Open Economy: An Applied General Equilibrium Analysis." Research Department, Statistics Norway, Kongsvinger, Discussion Paper 510.

Canton, Erik, Bert Minne, Ate Nieuwenhuis, Bert Smid, and Marc van der Steeg. 2005. "Human Capital, R&D, and Competition in Macroeconomic Analysis." Central Planbureau, Den Haag CPB Document 91.

Cassou, Stephen P., and Kevin J. Lansing. 2004. "Growth Effects of Shifting from a Graduated-rate Tax System to a Flat Tax." *Economic Inquiry*, 42(2): 194-213.

Coe, David T., and Elhanan Helpman. 1995. "International R&D Spillovers." *European Economic Review*, 39(5): 859-887.

Čok, Mitja, Polona Domadenik, Tjaša Redek, and Miroslav Verbič. 2009. "Labour Market Reforms in the Context of Political Power Theory: The Case of Slovenia." *Zbornik radova Ekonomskog fakulteta u Rijeci – Proceedings of Rijeka Faculty of Economics*, 27(1): 57-82.

Diao, Xinshen, Terry Roe, and Erinc Yeldan. 1999. "Strategic Policies and Growth: An Applied Model of R&D-driven Endogenous Growth." *Journal of Development Economics*, 60(2): 343-380.

Ferris, Michael C., and Todd S. Munson. 2000. *GAMS/PATH User Guide: Version 4.3*. Washington, DC: GAMS Development Corporation.

Freire-Serén, Maria J. 2001. "R&D-Expenditure in an Endogenous Growth Model." *Journal of Economics*, 74(1): 39-62.

Ghiglino, Christian. 2002. "Introduction to a General Equilibrium Approach to Economic Growth." *Journal of Economic Theory*, 105(1): 1-17.

Ghosh, Madanmohan. 2007. "R&D Policies and Endogenous Growth: A Dynamic General Equilibrium Analysis of the Case for Canada." *Review of Development Economics*, 11(1): 187-203.

Globerman, Steven. 2000. "Linkages Between Technological Changes and Productivity Growth." Micro-Economic Policy Analysis Branch, Strategic Policy Sector, Industry Canada, Ottawa, Occasional Paper 23.

Glomm, Gerhard, and B. Ravikumar. 1994. "Growth-Inequality Trade-Offs in a Model with Public Sector R&D." *Canadian Journal of Economics*, 27(2): 484-493.

Griliches, Zvi. 1988. "Productivity Puzzles and R&D: Another Non-explanation." *Journal of Economic Perspectives*, 2(4): 9-21.

Griliches, Zvi. 1992. "The Search for R&D Spillovers." *Scandinavian Journal of Economics*, 94(0): S29-S47.

Grossman, Gene M., and Elhanan Helpman. 1991. *Innovation and Growth in the Global Economy*. Cambridge, MA: The MIT Press.

Howitt, Peter. 1999. "Steady Endogenous Growth with Population and R&D Inputs Growing." *Journal of Political Economy*, 107(4): 715-730.

Ikazaki, Daisuke. 2006. "R&D, Human Capital and Environmental Externality in an Endogenous Growth Model." *International Journal of Global Environmental Issues*, 6(1): 29-46.

Jones, Charles I. 1995. "R&D Based Models of Economic Growth." *Journal of Political Economy*, 103(4): 759-784.

Jones, Charles I., and John C. Williams. 2000. "Too Much of a Good Thing? Economics of Investment in R&D." *Journal of Economic Growth*, 5(1): 65-85.

Klun, Maja, and Renata Slabe-Erker. 2009. "Business Views of the Quality of Tax, Environment and Employment Regulation and Institutions: The Slovenian Case." *International Review of Administrative Sciences*, 75(3): 529-548.

Kong, Tao. 2007. "A Selective Review of Recent Developments in the Economic Growth Literature." *Asian-Pacific Economic Literature*, 21(1): 1-33.

Lipsey, Richard G., and Kenneth I. Carlaw. 2004. "Total Factor Productivity and the Measurement of Technological Change." *Canadian Journal of Economics*, 37(4): 1118-1150.

Mahadevan, Renuka. 2003. "To Measure or not to Measure Total Factor Productivity Growth?" *Oxford Development Studies*, 31(3): 365-378.

Majcen, Boris, Miroslav Verbič, and Saša Knežević. 2005. "The Effects of Foreign Trade Liberalisation and Financial Flows between Slovenia and the EU after Accession." *Post-Communist Economies*, 17(2): 251-267.

Majcen, Boris, Miroslav Verbič, Ali Bayar, and Mitja Čok. 2009. "The Income Tax Reform in Slovenia: Should the Flat Tax Have Prevailed?" *Eastern European Economics*, 47(5): 5-24.

Majcen, Boris, Miroslav Verbič, Olga Ivanova, and Sonja Uršič. 2011. *Research and Development, Education and Economic Growth: A Dynamic General Equilibrium Approach with Endogenous Growth*. Ljubljana: Institute for Economic Research.

Mathiesen, Lars. 1985. "Computation of Economic Equilibria by a Sequence of Linear Complementarity Problems." In *Economic Equilibrium: Model Formulation and Solution*, ed. A. S. Manne, 144-162. Amsterdam: North-Holland.

Nadiri, Ishaq M. 1970. "Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey." *Journal of Economic Literature*, 8(4): 1137-1177.

Peretto, Pietro F. 1998. “Technological Change and Population Growth.” *Journal of Economic Growth*, 3(4): 283-311.

Raut, Lakshmi K., and Thirukodikaval N. Srinivasan. 1994. “Dynamics of Endogenous Growth.” *Economic Theory*, 4(5): 777-790.

Romer, Paul M. 1987. “Growth Based on Increasing Returns due to Specialization.” *American Economic Review*, 77(2): 56-62.

Romer, Paul M. 1990. “Endogenous Technological Change.” *Journal of Political Economy*, 98(5): S71-S102.

Rymes, T. K. 1983. “More on the Measurement of Total Factor Productivity.” *Review of Income and Wealth*, 29(3): 297-316.

Simon, Julian L. 1981. *The Ultimate Resource*. Princeton, NJ: Princeton University Press.

Simon, Julian L. 1996. *The Ultimate Resource 2*. Princeton, NJ: Princeton University Press.

Solow, Robert M. 1956. “A Contribution to the Theory of Economic Growth.” *Quarterly Journal of Economics*, 70(1): 65-94.

Steger, Thomas M. 2005. “Welfare Implications of Non-scale R&D-based Growth Models.” *Scandinavian Journal of Economics*, 107(4): 737-757.

Stokey, Nancy L. 1991. “Human Capital, Product Quality and Growth.” *Quarterly Journal of Economics*, 106(2): 587-616.

Verbič, Miroslav, Boris Majcen, and Renger van Nieuwkoop. 2006. “Sustainability of the Slovenian Pension System: An Analysis with an Overlapping-generations General Equilibrium Model.” *Eastern European Economics*, 44(4): 60-81.

Verbič, Miroslav. 2007. “Varying the Parameters of the Slovenian Pension System: An Analysis with an Overlapping-Generations General Equilibrium Model.” *Post-Communist Economies*, 19(4): 449-470.

Verbič, Miroslav. 2009. “A Note on Varying the Parameters of the Slovenian Pension System: An Analysis of Supplementary Pension Insurance.” *Post-Communist Economies*, 21(3): 373-382.

Verbič, Miroslav, Boris Majcen, and Olga Ivanova. 2009. *SIDYN, Version 2.0: Technical Description of an Intertemporal Dynamic Computable General Equilibrium Model for Slovenia*. Ljubljana: Institute for Economic Research.

Young, Alwyn. 1998. “Growth Without Scale Effects.” *Journal of Political Economy*, 106(1): 41-63.