The Impact of expenditure on R & D within the Brazilian economy: an approach to Computable General Equilibrium

Alexandre Gomes, Fernando Perobelli, João Pio

1. Introduction

The slowdown in Brazil's economic growth in the last decade gave rise to a debate about the mechanisms that generate sustainable growth of Brazilian products. One such mechanism is productivity because its influence increases the efficiency of the production system. Thus, productivity has become a major focus of discussion and analysis of its performance has become increasingly more present in economic studies.

In the period 2007-2012 the gross domestic product in Brazil grew at an average of 3.7% per year. One of the factors contributing to this scenario was the low level of observed productivity. On the other hand, emerging economies had an average annual GDP growth of 6.7% in the same period.

One of the key components to productivity growth is the product or process innovation, which enables the development of new technologies to improve production efficiency. Therefore, investment in research and development (R & D) is characterized as one of the main elements that provide innovation and has been recognized as an important factor in maintaining sustainable economic growth (FREEMAN, 2008).

Lane and Lubatkin (1998) argue that investments in R & D are the basis for the formation of capital knowledge. That being the element that incorporates the knowledge gained in the production process, generating competitive gains through increased productivity (STEWART, 2002). In addition, Dietzenbacher and Los (2002) point out that conducting R & D makes it able to generate positive externalities that benefit other agents (companies, sectors and economies) beyond the initial investor, because possesses characteristics of public goods, being unrivalled and partially exclusionary. This causes a process of knowledge diffusion, as the developed technology expands throughout society.

In this sense, incentives for innovation began to be implemented in Brazil from the time when the agenda of Science and Technology incorporated this issue as a priority of public policy (PACHECO, 2011). Thus, recognition of the association between innovation and economic development led to the adoption of a series of support mechanisms for innovation directed to the production sector of the country. The objective was to stimulate R & D investment to create an environment that would enable the development of new technologies that contribute to increased productivity and competitiveness of Brazilian industries.

In the period 2000-2013 the national expenditure on R & D increased from R $ 34.6 billion (1.04% of GDP) to R $ 63.7 billion (1.24% of GDP), which represented a variation of 83 92% in real terms. Additionally, since 2005 these expenditures have been intensified due to regulations of the laws on innovation in the country, including the Good Law and Innovation Act.

When analyzing the evolution of the national expenditure on R & D; there has been significant growth in the last decade, both in absolute terms and as a percentage of GDP. Public spending on R & D also increased during this period, although this was concentrated on higher education institutions and non-orientated research by area, indicating the government's concern in establishing a suitable framework for the development of new technologies.

Comparing the expenditure on R & D in Brazil with some developed member countries of the OECD, it is noted that these countries allocated a higher percentage of GDP to conduct R & D than Brazil in 2010. It is also worth mentioning that Japan has allocated 3.25% of its GDP investment in R & D, nearly 3 times the amount of resources used on R & D in Brazil in the same year. However, when compared with some emerging economies, Brazil was behind China, which spent 1.76% of GDP, but surpassed India and South Africa, which spent 0.8% and 0.76% of GDP respectively.

When comparing the amount of spending on R & D within Latin American countries, it can be noted that Brazil had a correlation that was higher than percentages observed in Argentina (0.62%), Chile (0.42%) and Mexico (0.46%). Therefore, public policies implemented in the last decade have contributed to Brazil at a higher level regarding expenditure on R & D, to other similar economies.

However, although the country has increased its level of spending on R & D in recent years, when comparing Brazil's productivity between 2008 and 2011 to other countries; a significant difference can be observed.

Considering the productivity of the United States as a reference and compared to some countries in Latin America (Argentina, Chile and Mexico), OECD (Italy, Japan and the United Kingdom) and other emerging countries (South Africa, China and India), it appears that the United States has shown significantly greater productivity levels to other countries.

Brazil has put itself in a much lower position in relation to the analysed countries, while Argentina, Chile and Mexico showed yield percentages of: 34.9%, 45.8% and 37.9% respectively. The average productivity of Brazil in the period from 2008 to 2011 was 25.3% in relation to US productivity.

When compared to OECD countries, productivity in Brazil becomes relatively less. Italy, Japan and the UK showed percentages of productivity with the US in the order of 80.4%; 63.2% and 73.4%.

The group of emerging countries showed the closest productivities to those observed in Brazil. South Africa (37.1%), China (14.3%) and India (9.7%) also presented values below those observed in the United States, however South Africa still surpasses Brazil in this indicator.

Therefore, it can be seen that although some measures have been taken to increase spending on R & D in recent years, Brazil is still far from obtaining productivity levels to those demonstrated by the developed countries and even by countries with economies that have similar levels of development. Consequently there is a loss of competitiveness in the Brazilian economy domestically and internationally.

Bonelli and Supplies (2013), argue that Brazil's economic growth in recent years was largely due to the intensification of the labour force, whereas in most developing countries the rise in GDP occurred through increased productivity. In fact, the data shows that the average employment growth between 2000 and 2011 was 2.47%, while the main emerging countries was at 1.92%.

The incorporation of R & D and capital knowledge in CGE models is relatively recent compared to other areas of the economy that have utilized this modelling. The first CGE models that incorporated R & D emerged in the 90s in order to analyse the effects of changing technology on productivity and to measure the capacity to absorb technology in these sectors.

Diao et al. (1996) proposed a CGE model which incorporates R & D based on the theory of endogenous economic growth. The author divided the capital into physical capital and capital knowledge, this being characterized as the factor of production carried out by the R & D sector. This work was the pioneer in this modelling strategy and served as the basis for the development of other models, in addition to introducing the R & D, other aspects were analysed: productivity [Diao et al. (1999); Ghosh (2007)], economic growth [Kristková (2012)], climate change [Wing (2001)] and energy issues [Zurn et al. (2007)].

As can be seen, the CGE modelling with the incorporation of R & D has been developed to analyze the effects of technological change on productivity and economic growth. However, many studies have extended their analysis to investigate other aspects such as: effects of the reduction of pollutants, subsidy policies and spillover of international technology. This highlights the growing concern of the studies to evaluate this type of phenomenon, because the investment in R & D is one of the most important elements in the innovation process, contributing to an increase in competitiveness, productivity and well-being.

Therefore, the purpose of this article is to analyse the impacts of capital knowledge formation, acquired through expenditure on R & D, production structure and long-term macroeconomic aggregates. Such analysis is performed by calibration of a general computable equilibrium model (CGE) for the year 2011 with detailed specification of investments in R & D and capital knowledge formation. Additionally, this article analyses the impact of the increase in capital stock knowledge in productivity and intersectoral spillovers.

Following this introduction, there are three sections to this paper: i) Methodology: showing the model structure, the procedures in the model database, and the strategies adopted for the investment specification in R & D and capital knowledge formation in the CGE model; ii) Results: describing the elaborative procedure of the shocks, the causal mechanisms and systemic effects, and the results at the macroeconomic and sectoral level; iii) Final considerations.

2. Structure of the BIM-GERD Model

This section describes the model of the theoretical framework Intersectoral Brazilian Model with Gross Domestic Expenditure on R & D (BIM-GERD). This structure was developed from the Brazilian model 'Intersectoral Model with Dynamic Recursive' (BIM-RD). This served as the basis for specifying the behavioural equations and computational implementation. In the implementation phase, the computer code and BIM-RD database were adapted to the specifications of the BIM-GERD model.

Thus, it was possible to distinguish the investment in R & D and capital knowledge in detail in the model structure. The changes made to the model were aimed to enable it to make a more appropriate analysis of the effects of investment in R & D and capital knowledge formation in sectors of the Brazilian economy. The following describes the compatibilization process data, extraction of conducting R & D and capital knowledge of the data base and the theoretical structure of the BIM-GERD model[1].

2.1 Compatibilization of the BIM-GERD'S Database

[1] Although the BIM-RD model presents the recursive dynamic analysis, the development of BIM-GERD adopted only comparative static analysis.

The BIM-RD model is disaggregated into 68 industries and 128 products of the Brazilian economy and was developed by Betarelli Junior, Perobelli and Vale (2015). The database part of an input-output structure shows the relationship of Product x Sector in this case. This was constructed in the Laboratory of Territorial and Sectorial Analysis (LATES) of the Federal University of Juiz de Fora (UFJF) from the System of National Accounts (SNA) 2011 (BETARELLI JUNIOR; Perobelli, VALE, 2015)[2]. In the development of BIM-GERD model we used the same database matrix. However, it was necessary to carry out compatibilizations between this matrix and the data available to conduct R & D.

Data conducting of R & D was obtained from the Technological Innovation Research (PINTEC), that came with data according to the National Classification of Economic Activities - CNAE 2.0, having Extractive industries and transformation research sectors, as well as the Electricity and gas sectors and selected services (PINTEC, 2013). In addition, it recognized the importance of the agriculture sector for the country, using data from the Agricultural Science and Technology Indicators (ASTI) for the amount of R & D carried out by this sector in Brazil.

The compatibilization process data was done through the classification of the SNA and CNAE - 2.0. Furthermore, it was necessary to make aggregations in the products and sectors of the data base matrix so that producing sources of conducted R & D could be fully specified after the compatibilization. The aggregation method used followed the specifications proposed by Miller and Blair (2009)[3].

BIM-GERD model recognizes 62 sectors and 91 products. The system corresponds to a product Sector x relationship, and that there is the possibility of a sector producing more than one product. The definition of the number of sectors and products occurred through compatibilization and aggregation, which allowed specifying the production source that conducts R & D.

---

[2] Both the construction in the input-output matrix as the development of BIM-RD model are available in texts for discussion and can be found on the UFJF site: <http://www.ufjf.br/lates/publicacoes/textos-para- discussion>.

[3] According to the author, to conduct sectoral aggregations, it is necessary to define a matrix S consisting of zeros and with dimension (k x n), where k is the number of sectors you want to add and n is the number of sectors that are not aggregated. After this definition, multiply the matrix S with the original matrix to obtain the desired aggregation. For details see Miller and Blair (2009).

2.2 Extraction of investment in R & D and capital knowledge data base

The compliance process of investment in R & D data with the database is to specify the production sources that conduct R & D. However, there are some difficulties associated with this procedure. One of them is related to the fact that they directly enter this information into the database, which causes an imbalance and misalignment of the information, causing problems in the process of the simulation of BIM-GERD model. The other difficulty is that the main purpose of investment in R & D is the formation of capital knowledge, and this information is not available when entering the realization of R & D data directly.

Thus, so that it can carry out impact analysis of R & D and capital knowledge formation, it is necessary to carry out some procedures for extracting this information, so that the database remains balanced and suitable for use in the model. There are several ways of performing this procedure, for example, the method used by Bor et al. (2010) and the method used by Garau and Lecca (2008). In this article we used the Terleckyj approach to extract the investment in R & D and capital knowledge database. This method was also used by Sue Wing (2001) and Zurn et al. (2007)[4].

The *Terleckyj* approach assumes that investments in R & D and capital knowledge formation are implicitly expressed in economic transactions (inter-sectoral flows). Therefore, this information must be extracted from this matrix.

For the portion of capital knowledge it is necessary to divide each element of the intermediate transactions VLij by the sum of its respective line ΣjVLij. The result of the quotient is multiplied by investment in R & D INViP & D sector. By performing this procedure for each VLij element, one obtains the matrix Wij; this can be observed in equation (1).

$$W_{ij} = \frac{VL_{ij}}{\sum_j VL_{ij}} INV_i^{P\&D} \qquad (1)$$

The objective in doing this balancing is to allow investment in R & D, implicitly including the matrix Wij, encompass the technological spillover effect across sectors. Thus, the sum of lines Wij matrix is the vector investment column in R & D (RDVi), which must be identical to sector expenditure on R & D, and the sum of columns results in the vector knowi

[4] The approach was developed by *Terleckyj* (1974) in order to analyze the effects of R & D on increased productivity. The basic idea of this approach is that investments in R & D, performed by a sector, are transferred to other sectors through intermediate consumption. Thus, one can consider the intermediate transactions for conducting R & D to obtain capital knowledge.

line, which represents the portion of capital knowledge of each sector. Thus, the RDVi column vector becomes part of final demand and the vector knowi line becomes part of the added value.

In the last step of the extraction process, the matrix of VLij intermediate transactions must be corrected by Wij matrix. That is, one must subtract the VLij matrix from the Wij matrix, which results in the modified intermediate consumption matrix VLijmod. This new matrix is the economic transactions.

Thus, by using the *Terleckyj* approach, it is possible to obtain capital knowledge formation that can be used as a primary factor in conjunction with other factors. In addition, investment in R & D becomes part of the final demand. As the specification of physical capital formation, which occurs through investment, capital knowledge is formed and accumulated in accordance with the conducting of R & D. Figure 1 shows the database, in a more general way, with investment in R & D and capital knowledge.

It should be emphasized that although the System of National Accounts (SNA) of Brazil for 2011 contains the specification of the producer sector of R & D, the use of the Terleckyj approach is not unfeasible. According to Zurn et al. (2007), this method of extraction aims to capture the capital knowledge acquired through R & D investment itself and the effects obtained from the spillover. However, when applying this method, the database remains balanced, and maintains its core structure.

Figure 1 - Matrix database of investment in R & D and capital knowledge

	Sector(1)	Sector(2)	Sector(3)	...	Sector(j)	Invest.	Families	Gov.	**Invest. in R&D**	Export.	Stock	Total
C(1)												
C(2)												
C(3)	I Intermediary Consumption Quadrant					II Final Demand Quadrant						
...												
C(i)												
Trab.												
Cap.												
Terra	III Added Value Quadrant											
Knowledge												
Total												

Source: Adapted from Zürn et al. (2007, p13)

2.3 The theoretical structure of the BIM-GERD Model

The theoretical structure of the BIM-GERD model follows the standard framework assumptions of the Arrow-Debreu general equilibrium. Thus, the demand equations and supply for the sectors are derived from solutions to optimization problems (e.g. minimizing costs, maximizing utility, etc.) that specify the behaviour of agents based on neoclassical microeconomics theory.

The system of equations can be specified into sets of blocks that compose the core of the model. These blocks specify the behaviour of six groups of agents: Producers; Investors who determine the creation of capital; Investors in R & D, who drive the creation of knowledge capital; families; governments; and external consumers (exports). In addition, the model also recognizes four factors of production: labour, capital, land and Capital Knowledge.

It is assumed that the agents are price makers and producers that operate in a competitive market; thus, for each productive activity, economic profit is equal to zero (Horridge, 2000). The government acts on the economy by implementing tax and / or subsidies on the price of goods. In addition, they identified four types of banks: trade and vehicle repair; Wholesale trade and retail; land transport cargo; and Water Transport (BETARELLI JUNIOR, Perobelli AND VALE, 2015).

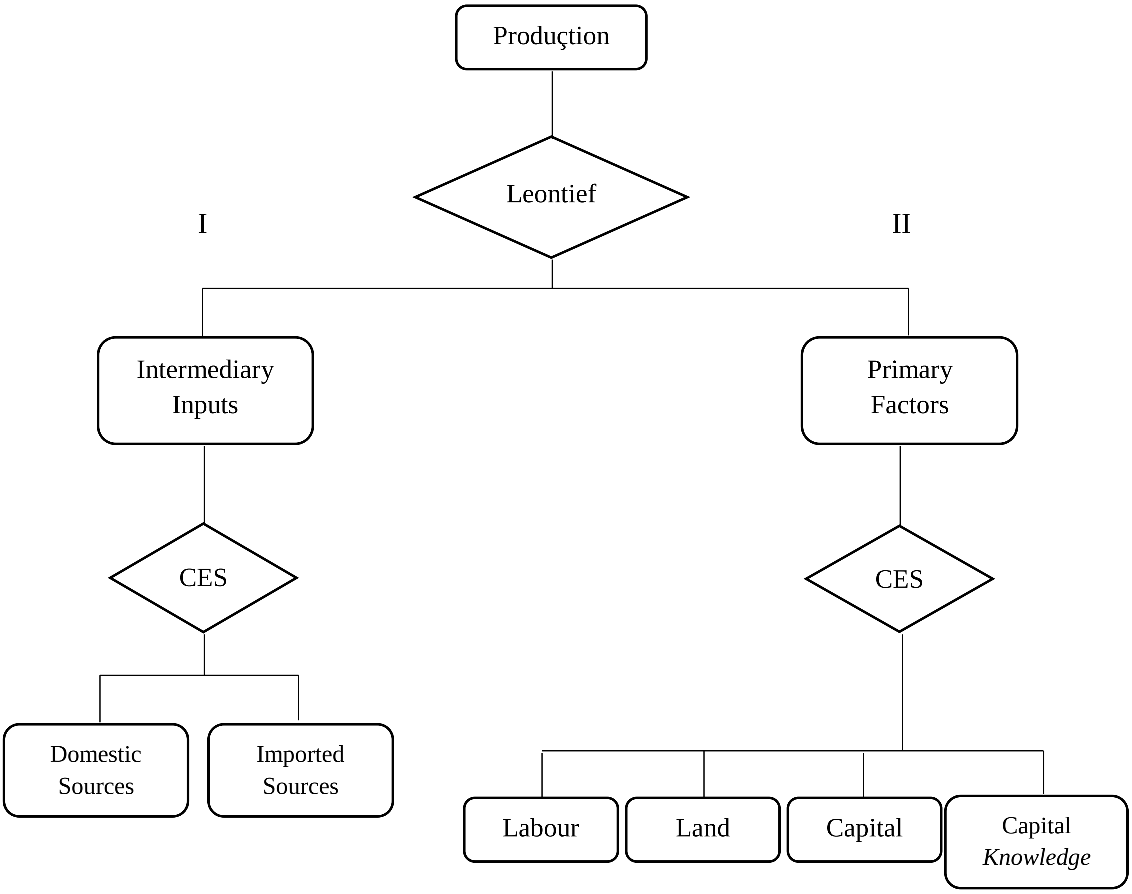
The main contribution from the BIM-GERD model is the detailed specification of investment in R & D as a generating element of capital knowledge. This, in turn, affects the composition of the primary factors used in the production process, which makes them more productive.

Figure 2 shows the nested structure of the production technology of BIM-GERD model. This figure is divided into two parts: Part I refers to the replacement structure between domestic and imported goods; Part II corresponds to the replacement structure of primary inputs, in which capital knowledge is inserted as a new factor. On the first level of the nested structure, a hypothesis of a fixed combination between the inputs used in the production process has been adopted. On the second level of the nested structure, there is the possibility of substitution between intermediary inputs that are domestically produced and imported. Furthermore, there is the possibility of substitution among the primary factors.

In Part I a constant elasticity of substitution function (CES)[5] is defined, which determines the amount of domestic and imported inputs used in the production process. In Part II the process of replacing primary factors by specification of a CES function is established. Unlike standard CGE models, the BIM-GERD model assumes capital knowledge to be one of the primary factors. This identification is based on Griliches' model (1979), in which this new element eventually replaces other factors (labour, capital and land). This makes it possible to model the increasing process of production efficiency, acquired from R & D investment.

[5] Constant Elasticity of Substitution (CES) is a function that if the elasticity of substitution is 1, the demands behave as a Cobb-Douglas function. If the parameter is zero, the demand follows the Leontief shape. For details see Dixon et al (1982). The employment of the CES function type is based on Armington's hypothesis (1969), which simulates an imperfect replacement process between the inputs of these two sources.

Figure 2 – Nested structure of production technology



Source: Adapted from Horridge (2000).

Equations (2), (3) and (4) summarize the characteristics of the model shown above.

$$Z_i = g(VA_i, X_i) = min(VA_i, X_i) \quad (2)$$

$$VA_i = f(T_i, K_i, L_i, H_i) = CES(T_i, K_i, L_i, H_i) \quad (3)$$

$$X_i = f(Dom_i, Imp_i) = CES(Dom_i, Imp_i) \quad (4)$$

The final goods Z are produced from the use of value added (VA) and intermediary goods (X) by means of a cost minimization decision (Leontief). The value added is composed of the primary inputs Land (T), Capital (K), labour (L) and Capital Knowledge (H), described by a function of production technology (CES). The intermediary inputs are specified by a CES function, which defines the process of substitution between domestic and imported goods. The subscript i represents the productive sectors of the economy.

Modifications to the pattern presented CGE model structure refer to the introduction of investment in R & D as part of final demand and the incorporation of capital knowledge as a primary factor used in the production process. Therefore, as the capital knowledge increases, the necessary amount of primary inputs to produce the same volume of goods decreases. Or, you can increase production with the use of lower proportions of labour, capital and land. This phenomenon is called increased productivity.

In equation (5), the parameter α_{Va_i} represents the required fraction of the added value to produce the final product of a sector. As this parameter decreases, the added value needed to produce the same amount is smaller. Therefore, this parameter describes the productive efficiency of an industry or productive activity, and can be characterized as productivity.

$$VA_i = \alpha_{VA_i} Z_i \qquad (5)$$

This modelling strategy was based on the theories developed by Scherer (1982) and Griliches (1979), who reported that the main capital knowledge formation mechanism is the internal processing of R & D. However, part of the learning about the sectors takes place in the process of buying and selling intermediary inputs, which allows the sectors to have access to the technology developed by others. That is, to the extent that companies spill over knowledge, part of the capital knowledge developed is transferred to other sectors in the inter-sector transactions. With the aim to capture this effect, equation (6) was defined:

$$spl(i) = [H_{others}(i)] \qquad (6)$$

$$H_{others}(i) = \sum_{j \neq i} intindwt(j,i) H(j)$$

The *spl* coefficient corresponds to the portion of capital knowledge of other sectors (H_{others}), which is incorporated into the intermediary inputs used in sector production. The spillover is weighted by the parameter$intindwt(j,i)$, which is defined as the ratio between the amount of intermediary inputs purchased from a sector by total inputs used in production. This makes it possible to measure the amount of capital *knowledge* absorbed in intersectoral relationships of each sector.

Therefore, after an exogenous shock, both equations show the new equilibrium relationships, and it is possible to observe increases in production efficiency and the percentage of capital knowledge transferred via the spillover effect.

3. Results

The BIM-GERD model in its condensed version; contains 9066 variables and 7014 equations. Therefore, it was necessary to exogeneizar 2052 variables. Two standard types of closure can be adopted for the simulation in comparative statistics: the short and the long term. The main distinction of both is the treatment employed in microeconomics in addressing adjustment of capital stock. In the short term closure of the capital stock is held constant. However, the capital stock may be affected by changes in policy in the long term.

The long term closure, the adopted hypotheses made, enable the steady state of equilibrium to be reached. Thus, the capital may vary depending on the investment. The aggregate level of employment is determined by population growth, participation rates in the labour force and natural rates of unemployment. The actual salary is variable, which allows the workforce to allocate itself among sectors of the economy. Investments in R & D and capital knowledge follow a similar specification to physical investments and capital. Thus, both the investment in R & D and capital knowledge moves to establish a new point of equilibrium after an exogenous shock.

The results of the simulation exercises are analysed: i) the economic effects of the change of capital knowledge stock in sectors of the Brazilian economy; ii) the effects of variation on the productivity of sectors; and iii) intersectoral technology spillovers of the economy.

The closure used in this case is similar to the long-term closure structure shown above, ie, the capital stock and actual earnings are endogenous to respond to the propagation mechanisms of the systemic effects defined in the model. The difference lies in determining the capital knowledge variable. Since the purpose of this paper is to analyse the effects of the capital knowledge stock change in the economy, it has become this exogenous variable in order to allow exogenous shocks to be made from this variable.

The use of long-term closure is justified by the fact that R & D does not have an effect on the short term as relevant changes require a certain period of time. Therefore, the implemented simulation exercise consists of increasing the capital stock of the knowledge sectors of the Brazilian economy, which may occur due to increased investments in R & D or through the expansion of the technological absorption capacity. It is worth mentioning that the exogenous shock was not performed initially in R & D, as this creates the possibility of broadening knowledge capable of increasing productivity. However, the formation of capital knowledge depends on other factors, in addition to conducting R & D, as pointed out by Griliches (1979): are the level of economic transactions, and the informational and absorptive capacity of the technology developed.

Therefore, the model simulation assumes that the sectors have reached the necessary level of technological absorption capacity, due to investments in R & D, capable of generating increases in capital knowledge stock. This simulation strategy was also used by Bor et al (2009) and Hong et al (2014).

In this study we performed simulations in order to assess the impact of capital knowledge on the productive structure and the macroeconomic aggregates of the country considering a shock of 1% in the stock of capital knowledge only in sectors that performed R & D at a proportion above 1% of their gross value of production (GVP). The strategy adopted was based on the national expenditure on R & D in proportion to GVP, which for 2011 was 1.14%. Therefore, it is expected that only the sectors that performed R & D close to this proportion are able to increase their stock of capital knowledge.

For a better analysis of the selected sectors, Table 1 presents conducting R & D in proportion to the GVP of the most intensive sectors for the year 2011, which were selected for the application of shock.

Table 1 - The most intensive sectors in R & D in proportion to GVP in 2011.

Sectors	R&D/GVP (%)
Oil refining and coking plants	1,38
Manufacturing of cleaning products, cosmetics, perfumes and personal hygiene	3,75
Manufacturing of pharmachemical and pharmaceutical products	2,72
Manufacuring of IT equipment, optical and electronic products	1,91
Manufacturing of machinery and electrical equipment	1,38
Manufacturing of automobiles, trucks and buses (except spare parts)	1,51
Manufacturing of parts and accessories for vehicles	1,21
Manufacturing of other transport equipment, except automobiles	2,03
Development of systems and other information services	1,72
Architectural services, engineering, technical analysis and R & D	2,05

Source: Extracted from the data by PINTEC (2011)

3.1 Systemic effects in the causal relationships

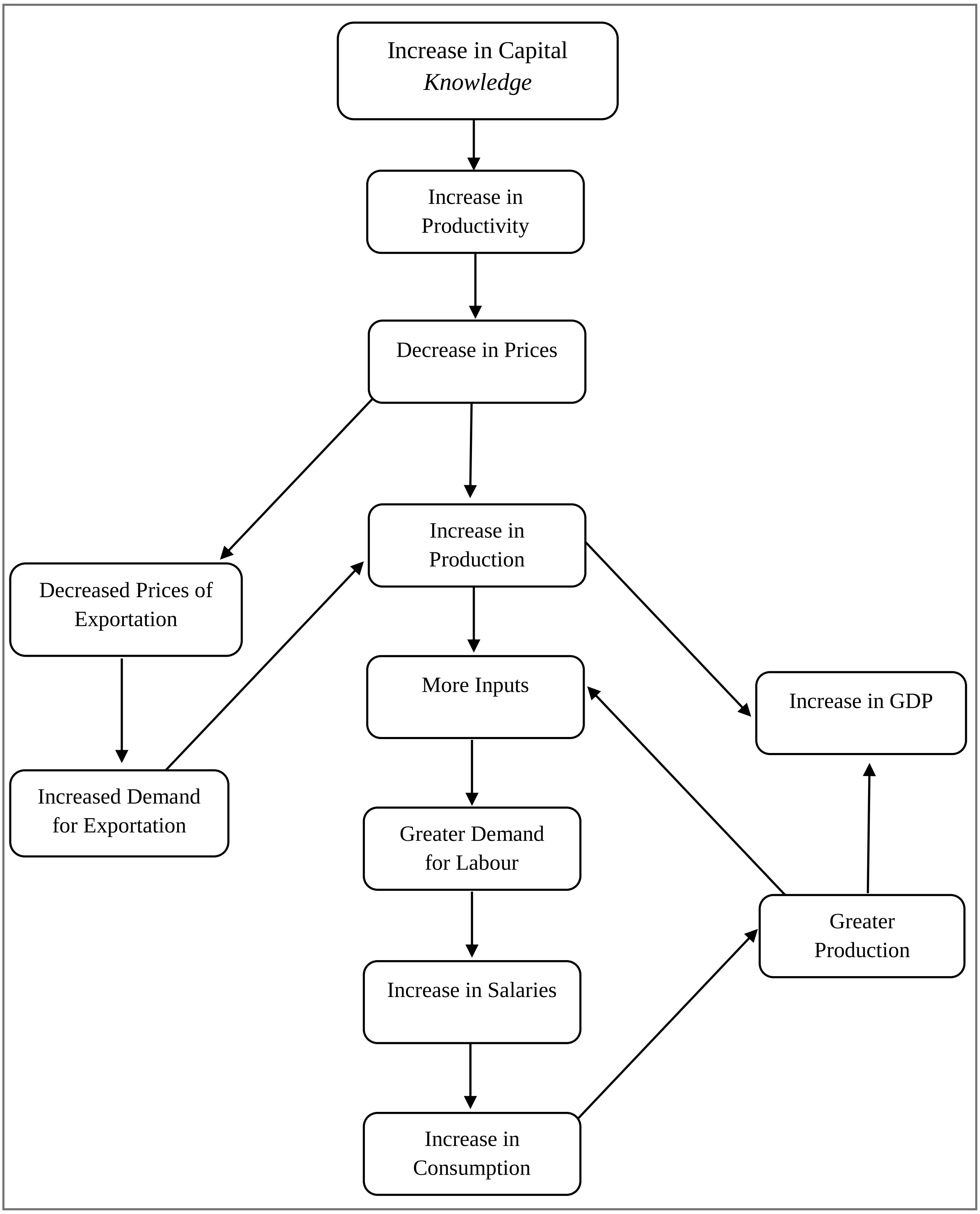
The fact that the model incorporates a detailed specification of the investment in R & D and capital knowledge formation; it allows the portrayal of systemic effects of input substitution due to changes in productivity. Thus, it is expected that the sectors showing increase (decline) of capital stock knowledge, get an elevated (reduction) level of economic activity, generating linkages throughout the economic system. Accordingly, Figure 3 shows the main causal relationships of the effect of an increase (decrease) in the stock of capital knowledge in sectors of the economy.

The main effect of the chain reaction on the economic system occurs by reducing the need to use primary factors (capital + labour) to produce the same quantity of goods, that is, there is an increase in productivity sectors. In this case, some effects can be highlighted:

i) The relative prices of primary factors and the economy are altered;
ii) The structure of the cost of sectors alters, shifting the demand for input;
iii) The demand for factors of production (capital, labour and intermediary inputs) increases, since the increase in productivity frees up resources that can be used to buy more inputs, which results in an increase in economic activity;
iv) Increased demand for labour due to a greater level of economic activity, raises the salary level of the economy;
v) The earnings in household income due to the increase in salary causes an expansion of consumption;
vi) The reduction of the price level of goods in the economy, reduces the price of exported goods;
vii) Domestic goods become more competitive, with a positive effect on the demand for exports.

As can be seen in Figure 3, after an increase in the stock of capital knowledge, systemic effects tend to reduce the price level of the economy, due to both the production factors and final goods, causing a rise in export demand and consequently, increased productivity in the economy. Furthermore, the increase of the sectors on the output level tends to shift labour demand, which in turn provides a higher level of income for families, resulting in increased consumption. This stimulus in the economy will lead to an increased demand for factors, which results in further expansion of income. All effects described contribute to GDP growth of the economy.

Figure 3–Causal Relationship of Operation Mechanisms of the model after a Variation in Capital *Knowledge* Stock



Source: Adapted from King (2012)

3.2 Macroeconomic Results

Table 2 presents the macroeconomic impacts of the simulations and shows the shock of impact on capital knowledge stock in sectors that have invested the most in R & D. The first finding is that, with the exception of government pricing index, all price indices were negatively impacted, especially the rate of export prices, which decreased by 0.007%.

In regards to the primary sectors, the return on capital and capital knowledge had negative effects, and real estate factors, labour and land, had positive effects due to the increased demand for them. The highest level of pay and the reduction in the price level caused increases in all components of aggregate demand, and again, especially the volume of exports, which showed increases of 0,008%.

Table 2 - Long-term aggregate results of the change in stock of capital knowledge (% change)

Variables	(1%) Selected Sectors
Prices	
Investment price index	-0,0065
Investment price index in R&D	-0,0154
Consumer price index	-0,0057
Government demand price index	0,0013
Export price index	-0,0077
GDP price index	-0,0056
Primary Factors	
Aggregate capital remuneration	-0,0017
Aggregate capital *knowledge* remuneration	-0,3046
Aggregate labour remuneration	0,0042
Aggregate land remuneration	0,0128
Aggregate capital stock	0,0049
Aggregate Demand	
Actual consumption aggregate of families	0,0033
Actual aggregate investment	0,0049
Actual aggregate investiment in R&D	0,0000
Actual aggregate government demand	0,0033
Export volume	0,0087
Other Aggregate Indicators	
Actual GDP	0,0044
Actual salary	0,0098
Equivalent variance (R$ millions)	86,9260

Source: Gathered from the results of the simulations with the BIM-GERD model

The end result is an increase of 0,004% in GDP and a change in well-being (equivalent variance) positive of R $ 86.92 million. This strong result is linked to exports, both the price index and in the volume of export which occurred at greater magnitudes. This indicates that the main effect of increasing the capital knowledge is to increase the level of competitiveness of the economy, which produces positive effects of GDP on economic well-being.

3.3 Results on productivity and intersectoral spillovers

Figure 4 shows the simulation results on productivity and intersectoral spillovers[6]. The sectors were aggregated into 5 groups (Agriculture, Extractive Industries, Manufacturing Industries and SIUP + Construction and Services), as highlighted.

The effect of increasing the stock of capital knowledge on productivity is associated with reduced use of the primary factors to produce the same production volume. As expected, the sectors with above average productivity were those who received the exogenous shock. Also, bear in mind that sectors with strong backward linkages show an above average dispersion of power[7]. This indicates that in the event of increased productivity, the greater the number of productive activities affected by an exogenous variation in these sectors will be, and there will also be greater intersectoral spillovers.

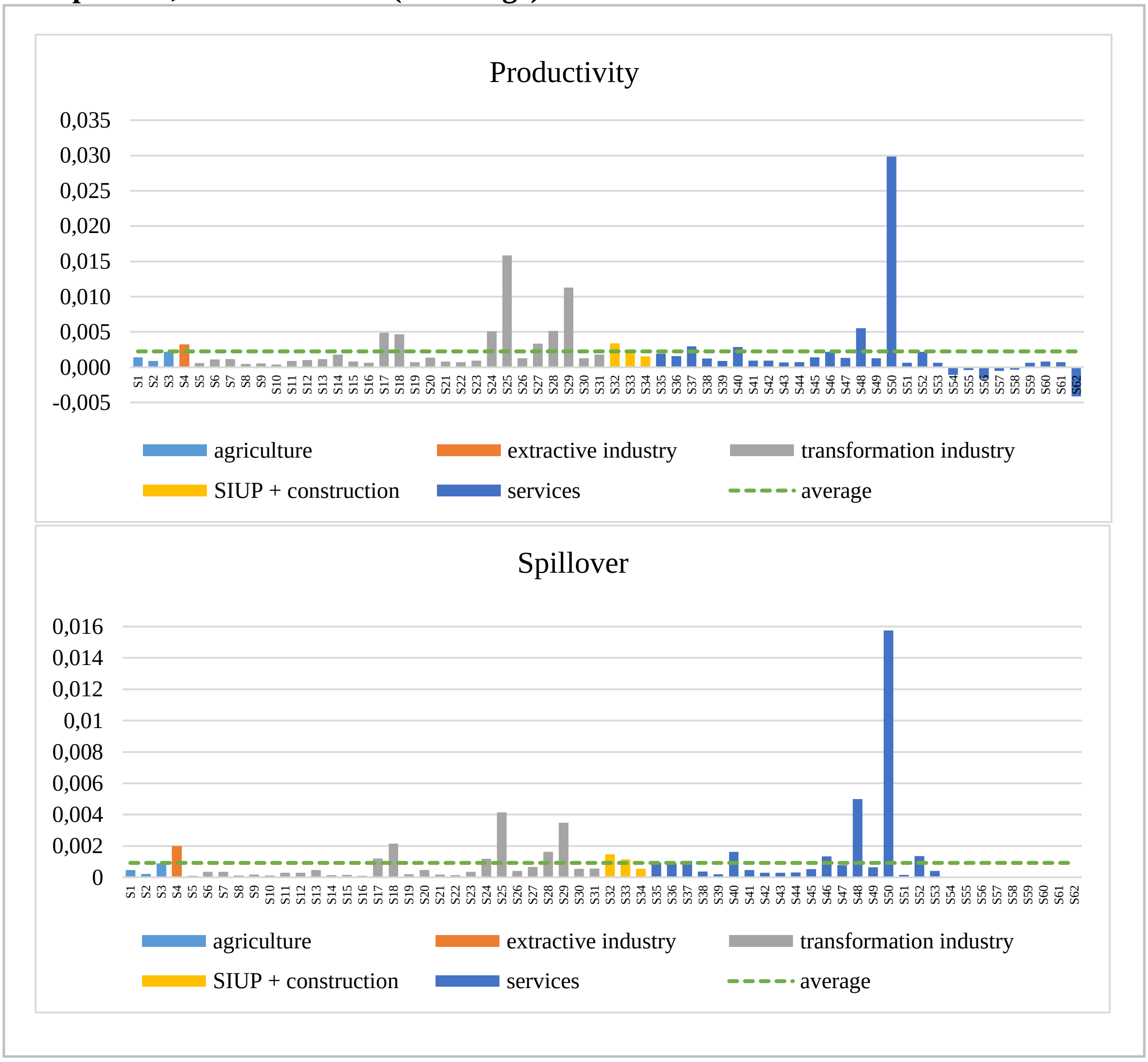
From a theoretical point of view, this phenomenon can be explained by the assumptions of Cohen and Levinthal (1989), who reported that the most intensive sectors in technology are able to incorporate developed technology more efficiently, as they "take on" greater ability of technology absorption by conducting R & D. Mostly these are the ones that incorporate technology through economic transactions.

---

[6] Productivity increase refers to the decrease in the use of factors to produce the same amount, so the table is presented with a negative sign, and in the Figure with the inverted sign for it to be clearer. Opposite results occur in the case of a decrease in productivity.

[7] The Rasmussen-Hirschman connection indexes were initially devised by Rasmussen (1956) and later developed by Hirschman (1958) to determine the key sectors of the economy. Through these indexes, it is possible to check the sectors that have the greatest power of linkage within the economy, it is possible to determine the backward connecting indexes to indicate how much a sector demands of the others, and the forward connecting indexes, show how much this sector is demanded by the others (Guilhoto AND SON, 2005). The work developed by Betarelli Junior, Perobelli and Vale (2015) detail, more precisely, the aspects related to connection indexes and variability statistics for this database.

Figure 4 - Long-term results of inventory variation of capital knowledge on productivity and spillover, selected sectors (% change)



Source: Gathered from the results of the simulations with the BIM model-GERD.

In this simulation exercise some sectors showed reduced productivity: surveillance activities, Security and investigation (S54), public administration, defence and social security (S55), public education (S56), Private Education (S57), Public Health (S58) and domestic services (S62). Because these are labour intensive sectors, as there was an increase in labour remuneration, the costs of the labour factor rose, since initially these sectors did not obtain increases in capital knowledge stock.

The sectors showed similar results in the spillover effect, so that the same sectors with low technological intensity obtained above average effects on productivity and intersectoral spillovers, as shown in Figure 4.

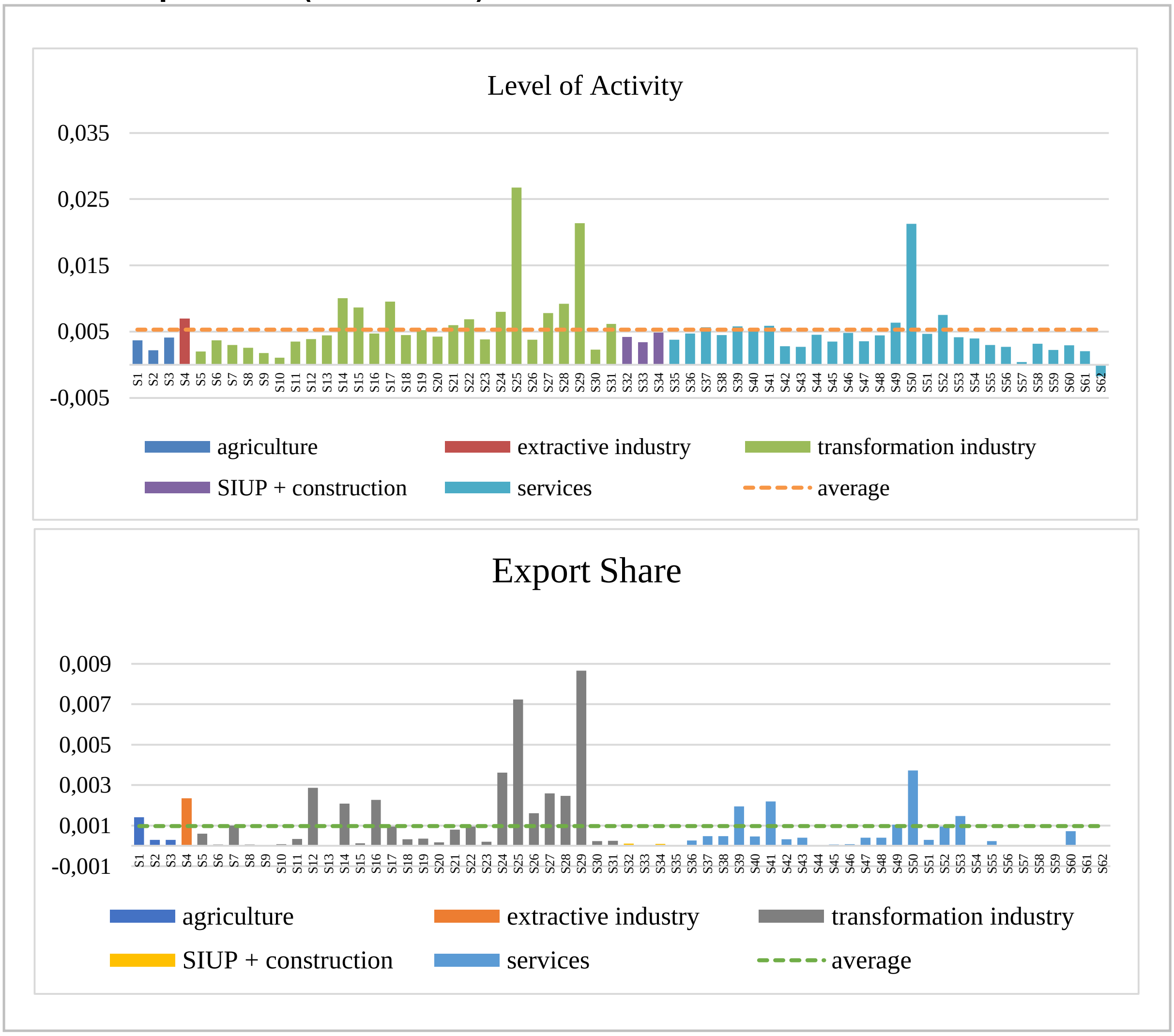
It is worth highlighting some characteristics of these sectors: a) are sectors with low technology; b) are the ones who get the above average effects on intersectoral overflow; c) Storage sectors, auxiliary activities of transport and mail (S40), Food (S42) and non-real estate

Rental and management of intellectual property assets (S52) belong to the group services sectors and electric power, natural gas and other utilities (S32) refer to the group of SIUP + Building, that is, these groups of sectors are the ones that absorb technology in economic transactions; and d) have strong forward linkages. Therefore, the sectoral interdependence of the Brazilian economy allows the effects of the increase in capital knowledge to be diffused into the economy as a whole.

3.4 Results on the level of economic activity

The results presented in Figure 5 show that the sectors with above average results in economic activity are mostly those that obtained a greater effect on productivity. In this simulation the same sectors mentioned previously received exogenous shock in the stock of capital knowledge and some sectors received negative effects on productivity, although all have increased their level of activity, with the exception of domestic services (S62).

Figure 5 - Long-term results of the variation in the stock of capital knowledge, activity level and export share (% variation)



Source: Gathered from the results of the simulations with the BIM model-GERD.

It has been found that the most intensive sectors in technology were those that obtained above average results in productivity and level of activity, such as the sectors manufacturing of machinery and electrical equipment (S25), architectural services, engineering, testing / technical analysis and R & D (S50) and petroleum refining and coking plants (S14). However, when analyzing the characteristics of these sectors, it is observed that they possess strong backward linkages and great power of dispersion and, furthermore, are the main exporters of the economy. Thus, a possible explanation for all sectors that have increased their economic activity is that the sectors affected by the rise in the capital knowledge stock have above average power dispersion, which produces positive effects throughout the economic system in the long term.

One of the effects of increased productivity was the increase observed in the level of economic activity, since sectors become more efficient. However, the main effect resides in the increase of competitiveness, allowing sectors to conquer new markets, which increases the impact on the income and well-being of the economy (MARQUES, 2002). Therefore, Figure 7 shows the portion of increased economic activity that is destined for exports for both established scenarios.

The results show that most sectors increased their share of production destined for export, mainly to: Manufacturing of other transport equipment, except motor vehicles (S29); Manufacturing of machinery and electrical equipment (S25); architectural services, engineering, testing / technical analysis and R & D (S50); and computer equipment manufacturing, electronic and optical products (S24).

The sectors that achieved above average results for exports were the most intensive in technology. Therefore, an exogenous shock in selected sectors, through the criteria of conducting R & D, could cause an increase in exports of products with higher levels of technology. It is an important result, since these sectors have strong backward linkages and high dispersion power, which increases the effects on the economy, raising the level of income and well-being.

4. Final considerations

The main objective was to analyse the impact of capital formation knowledge acquired by conducting R & D in the productive structure and the macroeconomic aggregates in the long term. This analysis was performed using the calibration of a CGE model, with detailed specification of investments in R & D and capital knowledge formation in its structure. This methodology proved to be applicable, since it provided a more in-depth view of technological characteristics of sectors in Brazil.

Analysis of innovation and investment in industry R & D incentive policies has shown that incentives to conduct R & D in Brazil have been intensified since the 2000s, which boosted the demand in companies and sectors for new technologies and improvement techniques in the productive process. Because of the support for innovation, the expenditure on R & D in the country rose from 2000 to 2013, with the largest proportion being held by the public sector, mainly directed at higher education and non-oriented research.

By analysing the sector expenditure on R & D, it was found that there were significant increases, surpassing even those of other emerging economies, but Brazilian productivity has fallen within these economies in relative terms. This "paradox" led to the investigation and search for new methods of application which culminated in the development of this paper.

The starting point was to use the theoretical structure of the BIM-DR model, in which the computer code and data base are adapted to the specifications of the BIM-GERD model. The first step in the development work was to incorporate the capital knowledge decision in the production process. For this, the demand function by factors at the bottom of the nested structure of production technology set up a compound of primary inputs with the possibility of substitution between labour, capital, land and capital knowledge. Thus, changes in the capital knowledge stock generate alterations in the use of primary factors, which it involves in the change in productivity. With ‘final demand’, we defined a nested structure for the decision to invest in R & D, which enables the formation of capital knowledge.

The second model development step was to adapt the database to contain information related to conducting R & D and capital knowledge formation. We used the Terleckyj approach strategy to incorporate these new elements into the database structure, in which the conducting of R & D is weighted by economic transactions to set the initial level of capital knowledge stock.

Simulations with the BIM-GERD model had to evaluate the impacts of capital knowledge on the productive structure and on the macroeconomic aggregates of the country.

The simulation results showed that increases in stock capital knowledge produce positive effects on economic activity, competitiveness, income and welfare. However, the results on productivity and spillovers showed aspects relevant to the understanding of the interdependence of the sectoral and technological flows of the country.

The first finding shows that the most intensive sectors in technology are responsible for most of the technological spillovers, since they have strong backward linkages, in the sense that the effects on their productivity reverberate throughout the Brazilian production system through technology diffusion.

The second shows that the effects of the exogenous shock changed the export agenda of the country, so that the main export sectors became technology-intensive. This effect broadens the impact on income and well-being of the economy. On the other hand, this result can provide data in evaluating Brazilian participation in external markets policies. In other words, the study sheds light on policies that take a systematic character into account, that is, rather than have policies that focus on certain sectors with an already established competitive advantage; it is possible to have positive results with improved productivity in sectors that have no established participation on the international market.

In general, the main contributions of this article refer to a detailed analysis of the country's productive structure with a focus on issues related to technology flows and technology change. Moreover, the model applications reinforce the need for continuous policy incentives for innovation, since the long-term effects are positive and allow productivity increases, competitiveness, income and welfare.

When specifying, conducting R & D and capital formation knowledge in the structure of a CGE model, this paper contributes to the advancement of the methodology since, as far as has been researched, using this method involving issues related to conducting R & D were not found . Moreover, the development of the BIM-GERD model leaves room for new applications and extensions to be made.

It is recommended that advances be made in the enhancement of the model database and econometric estimation of behavioural parameters. In the database enhancement, it is possible to use econometric methods to capture the capital knowledge embedded in the production process more accurately. In regards to the estimation of behavioural parameters, it is necessary to assess the substitution elasticity, mainly of production factors. These advances will help to provide greater power of analysis and reliability of the model applications.

Regarding the methodological extensions from the BIM-GERD model, it will be possible build a multi-regional CGE model, which will consider the inter-regional technology flows and regional and international technological spillovers more explicitly. This extension will allow further insight into the competitive advantages of the regions and the distribution of production factors, especially capital knowledge. In addition, other applications may be performed, according to the specification of conducting R & D, with for example, issues related to the use of energy inputs and subsidy policies.

5. References

ARMINGTON, Paul S. A Theory of Demand for Products Distinguished by Place of Production. **Staff Papers-International Monetary Fund**, p. 159-178, 1969.

BETARELLI JUNIOR, Admir Antônio.; PEROBELLI, Fernando Salgueiro; VALE, Vinicius de Almeida. Estimação da matriz de Insumo-Produto de 2011 e análise do sistema produtivo brasileiro. Texto para Discussão n. 001/2015. Juiz de Fora: Programa de Pós Graduação em Economia, Universidade Federal de Juiz de Fora, 2015. Available on: <http://www.ufjf.br/poseconomia/files/2015/06/001-15.pdf>. Acesso em: 10 may. 2015.

BETARELLI JUNIOR, Admir Antonio; PEROBELLI, Fernando Salgueiro; VALE, Vinicius de Almeida. Um Modelo Nacional de Equilíbrio Geral Computável Dinâmico Recursivo (EGC-RD) para o Brasil no Ano de 2011 (BIM-RD). Texto para discussão nº 01-2015. Laboratório de Análises Territoriais e Setoriais (LATES), Programa de Pós-Graduação em Economia, Universidade Federal de Juiz de Fora, Juiz de Fora, 2015. Available on: <http://www.ufjf.br/lates/files/2015/11/TD-LATES_01-2015.pdf>. Accessed on: 12 apr. 2015.

BONELLI, R.; FONTES, Júlia. O desafio brasileiro no longo prazo. Ensaios IBRE de Economia Brasileira, n. 1, Rio de Janeiro, 2013.

BOR, Yungchang Jeffery *et al*. A dynamic general equilibrium model for public R&D investment in Taiwan. **Economic Modelling**, v. 27, n. 1, p. 171-183, 2010.

COHEN, W. M.; LEVINTHAL, D. A. Innovation and Learning: The Two Faces of R&D Source. **The Economic Journal**, v. 99, n. 397, p. 569-596, 1989.

DIAO, Xinshen. *et al*. **A dynamic CGE model: an application of R&D-based endogenous growth model theory**. University of Minnesota, Economic Development Center, 1996.

DIAO, Xinshen; ROE, Terry.; YELDAN, Erinc. Strategic policies and growth: an applied model of R&D-driven endogenous growth. **Journal of Development Economics**, v. 60, n. 2, p. 343-380, 1999.

DIETZENBACHER, Erik; LOS, Bart. Externalities of R&D expenditures. **Economic Systems Research**, v. 14, n. 4, p. 407-425, 2002.

DIXON, Peter B. *et al.* **ORANI: a multisectorial model of the Australian economy**. Amsterdam: North-Holland, 1982.

FREEMAN, C. **A Economia da Inovação Industrial.** São Paulo: Unicamp, 2008. 816 p.

GARAU, G., LECCA, P. Impact Analysis of Regional Knowledge Subsidy: A CGE Approach. **Working Papers CRENoS**, v. 11. p. 36, 2008.

GHOSH, Madanmohan. R&D Policies and Endogenous Growth: A Dynamic General Equilibrium Analysis of the Case for Canada*. **Review of development economics**, v. 11, n. 1, p. 187-203, 2007.

GRILICHES, Z. Issues in assessing the contribution of research and development to productivity growth. **The Bell Journal of Economics**, v. 10, n. 1, p. 92–116, 1979.

GRILICHES, Z. Returns to research and development expenditures in the private sector. In: **New developments in productivity measurement**. University of Chicago Press, p. 419-462, 1980.

HONG, Chanyoung. *et al*. Validation of an R&D-based computable general equilibrium model. **Economic Modelling**, v. 42, p. 454-463, 2014.

HORRIDGE, J. M. **ORANI-G: A General Equilibrium Model of the Australian Economy, CoPS**. IMPACT Working Paper Number OP-93, Centre of Policy Studies, Victoria University. Disponível em: <http://www. monash. edu. au/policy/elecpapr/op-93. htm, 2000>. Acesso em: 26 set. 2015.

IBGE. **Pesquisa de Inovação Tecnológica (PINTEC 2011)**. Rio de Janeiro. 2013. Available on: < http://www.pintec.ibge.gov.br >. Accessed on: 12 may. 2015.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Sistema de Contas Nacionais: Brasil referência 2010-2011. Rio de Janeiro: **IBGE**, 2015. (Contas Nacionais, n.44).

KŘÍSTKOVÁ, Zuzana. Impact of R&D Investment on Economic Growth of the Czech Republic-A Recursively Dynamic CGE Approach. **Prague Economic Papers**, v. 2012, n. 4, p. 412-433, 2012.

LANE, P. J.; LUBATKIN, M. Relative absorptive capacity and interorganizational learning. **Strat. Mgmt. J**., v.19, p. 461–477, 1998.

LOS, Bart; VERSPAGEN, Bart. R&D spillovers and productivity: evidence from US manufacturing microdata. **Empirical economics**, v. 25, n. 1, p. 127-148, 2000.

MARQUES, Alfredo. Crescimento, Produtividade e Competitividade. Problemas de desempenho da economia Portuguesa. **Centro de Estudos da União Europeia, FEUC**, 2002. Disponível em: < http://www4.fe.uc.pt/ceue/working_papers/alfredomarquesi.pdf>. Accessed on: 09 sept. 2015.

MILLER, Ronald E.; BLAIR, Peter D. **Input-output analysis: foundations and extensions**. Cambridge University Press, 2009.

PACHECO, Carlos Américo. O financiamento do gasto em P&D do setor privado no Brasil e o perfil dos incentivos governamentais para P&D. **Revista USP**, n. 89, p. 256-276, 2011.

SCHERER, Frederic M. Inter-industry technology flows and productivity growth. **The review of economics and statistics**, p. 627-634, 1982.

STEWART, Thomas T. **Capital intelectual; a nova vantagem competitiva das empresas**. 14.ed.. Rio de Janeiro: Campus, 1998. 237p. ISBN: 85-352-0247-1.

SUE WING, Ian. **Induced technical change in computable general equilibrium models for climate-change policy analysis**. 2001. Tese de Doutorado. Massachusetts Institute of Technology.

ZÜRN, Marcel *et al*. R&D investment and knowledge input in a technology oriented CGE model. In: **EcoMod Conference on Energy and Environmental Modelling, Moscow**. 2007. Disponível em: <http://econpapers.repec.org/paper/ekd000240/24000067.htm>. Acesso em: 10 abr. 2015.