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IMPACT ANALYSIS OF REGIONAL KNOWLEDGE SUBSIDY: A CGE APPROACH

Giorgio Garau

Patrizio Lecca

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CRENoS – Cagliari
Via San Giorgio 12, I-09100 Cagliari, Italia
tel. +39-070-6756406; fax +39-070- 6756402

CRENoS - Sassari
Via Torre Tonda 34, I-07100 Sassari, Italia
tel. +39-079-2017301; fax +39-079-2017312

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Impact Analysis of Regional Knowledge Subsidy: a CGE Approach

Giorgio Garau* and Patrizio Lecca**

* University of Sassari (Sardinia, Italy); [giorgio@uniss.it].

** University of Cagliari (Sardinia, Italy) and Strathclyde Business School (Scotland, UK); [Patrizio.lecca@strath.ac.uk].

Abstract

In this paper we present a computable general equilibrium model for the region of Sardinia for the purpose of evaluating the capacity of R&D policies to affect the long run rate of growth. The model incorporates induced technical change and allow for external knowledge spillovers. We find that the cost of R&D policies may change according to the wage setting prevailing into the region. Furthermore, the capacity of such a policy to generate knowledge spillovers from the international and interregional trade are quite modest. Indeed, the capacity of the regional system to internalize the technological level embody in the imported good is partially offset by an increase in internal efficiency lowering the share of import but increasing competitiveness.

Keywords: Regional modelling, Induced Technical Change and R&D policies

JEL: R13; R58.

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1. Introduction

Innovations in R&D, knowledge spillover and human capital accumulation have been identified in literature as the most important driving forces behind economic growth. Such forces are able to determine the growth that cannot be explained by the accumulation of traditional production factors such as physical capital and labour. Lucas (1988) emphasizes the role of human capital externalities while Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) focus on the capacity of industrial innovation in R&D to be a determining source of growth by means of the mechanism of knowledge accumulation. In all the above contributions, the capacity of public policy to impact the long-run rate of growth is put in evidence. Government policies can affect economic growth by encouraging firms to devote more resources to R&D activities with e.g. market incentives. Also, R&D subsidy may promote economic growth by stimulating domestic R&D and encouraging international knowledge spillover.

Normally, regional assistance in Sardinia has been devoted almost entirely on the manufacturing sector through physical capital and labour subsidies. The need to analyze the impact of regional R&D subsidy comes from the recent strategic policies undertaken by the Sardinia Executive. Most of the European Structural and Social funds are used by the Regional Government mainly to reach a significant target in terms of growth and competitiveness by increasing the domestic stock of R&D.

In this paper we present a regional computable general equilibrium (CGE) model for the autonomous Region of Sardinia used for the main purpose to evaluate the impact on a recipient region of R&D subsidy. The model also takes into account the important role played by the internationalization in promoting knowledge spillover. Indeed, more open economies lead to more competition that encourages the adoption of new technology, increasing the efficiency of the economic system which results in a greater productivity. In other words, internationalization may be the source able to stimulate the transmission of knowledge between countries (Parente and Prescott, 1994; Coe and Helpman, 1995; Holmes and Schmitz, 2001) and contribute to the creation of a better local innovation since as pointed out by Bazo et al. (2006), internationalization and local knowledge support each other, reinforcing their individual impact on productivity. Accordingly, the model allows for a potential knowledge spillover effect arising from interregional and international trade. We focus on the complementarities between, foreign trade and local and global stock of knowledge in a regional economy. As regions are more open than nations, we would expect stronger effect of foreign R&D capital stock on domestic productivity since, as suggested by the estimates of Coe and Helpman (1995), more open economies have larger productivity benefit from foreign R&D stock than less open economies. By importing more high quality and sophisticated inputs (either intermediate or capital goods), the local production may improve its efficiency and in turn the competition of the local system with respect to other regions. Therefore, the capacity to exploit the stock of global knowledge depends on the expansion of international trade. As a matter of fact, knowledge moves from one place to another according to the level of trade liberalization existing in the international market.

The model, that we call SGEM, incorporates induced technical change (ITC) by enlarging the envelope of all possible technologies; basically we are including an intangible factor in the production function. The intangible factors given by the regional level of knowledge endowment is divided into excludable and non-excludable knowledge. The first one is treated as a primary factor of production which accumulate according to the traditional perpetual inventory change. Instead, the second one, derives from the potential knowledge spillover effect arising from interregional and international trade.

We calculate the growth rate of R&D investment able to reach a pre-determined level of growth in GRP (Gross Regional Product) which is associated to the results we obtain by simulating an exogenous increase in competitiveness. After that the growth in R&D investment, is treated as a financial aid provided by the Regional Government to increase the level of domestic knowledge stock. Subsequently the analysis will be enriched allowing for external knowledge spillover.

We find that the cost of the R&D subsidy policy, as percentage increment of the base year R&D investment, may vary according to the regional labour market conditions. Its cost is quite high in Keynesian labour market closure and very small for flexible wages that respond to the regional excess demand for labour. This is quite an interesting result, since one of the region's interest is to use more efficiently the social and structural fund provided by the EU. So, labour market conditions can make more costly R&D policies. The interregional and international knowledge spillover improve growth even though their effect are quite modest. Indeed the capacity to exploit the stock of global knowledge depends on the expansion of international trade, which is an exogenous variable for regions. As a matter of fact, knowledge moves from one place to another according to the level of trade liberalization existing in the international market. The presence of rigidity might be mitigated by trade liberalization policies or removing tariff protections on imports. But as we know regions do not have trade policy power to encourage induced growth from technological spillovers.

The paper proceeds with the outline of the basic SGEM model. In section 3 we explain the endogenization of ITC in the model. The SAM of Sardinia with knowledge accounting is discussed in the fourth section. The fifth section is devoted to explain the simulation results. Finally, remarks and conclusions will be drawn.

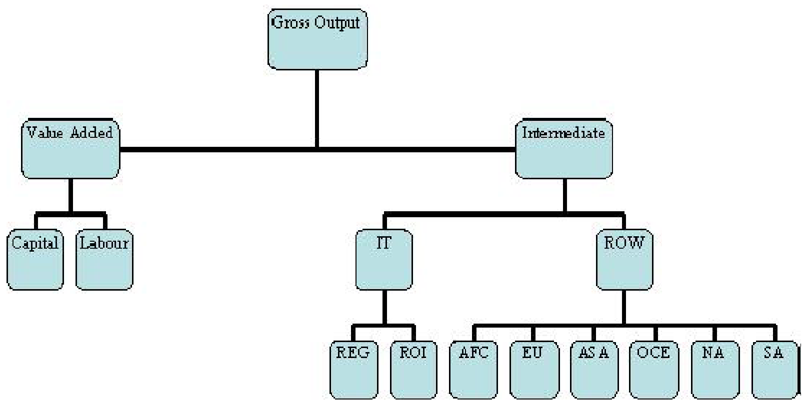
2. The model of Sardinia

A single-region dynamic CGE model built according to the Walrasian general equilibrium analysis formalized in the 1950s by Arrow and Debreu (1954) and Arrow and Hahn (1974), is presented in this section. The specification of the production and demand parameters that allow "the abstract general equilibrium model to be converted into a realistic model of an actual economy" (Shoven and Whalley, 1992) has been done through the well known calibration method using the Social Accounting Matrix (SAM) of Sardinia for the year 2001 (Ferrari, Garau and Lecca, 2007). The set of prices at which the excess demand is zero is the result of an optimization process, leading market clearing prices to equal marginal cost in each sector. Five economic activities or sectors are considered: Primary sector, Heavy Industry, Light Industry, Energy and Services. No distinction between traded and no traded sector is considered. Intermediate and primary inputs constitute the production inputs of the model. The model is also made up of three domestic institutional sectors: Firms, Households and Government. The external institutions are split into the Rest of the Italy (ROI) and Rest of the World (ROW). We adopt assumptions typically used for a small-open economy: the region is too small to affect prices in international and interregional markets. As a consequence, the ROI and ROW prices are taken to be exogenous. In addition, since Sardinia belongs to a common currency area the model takes the nominal exchange rate to be fixed. Households' and firms' behaviour are the result of an optimization process with myopic expectations while Government is a consolidated sector merging central and local government levels. Its expenditure can be either the result of an optimization process where Government is simply treated as a new consumer, maximizing utility subject to the budget constraints, or is held constant throughout. In the model's production structure illustrated in figure 1, the intermediate inputs (X), labour (L) and capital (K) constitute the production inputs of the model. L and K are combined in a CES production function in order to produce the value added, Y, allowing for substitution among primary factors of production. The demand for L and K is obtained from the first order condition of profit maximization. This means that the demand for both K and L is positively related to the volume of value added Y and is a decreasing function of their prices (rk and w, respectively):

$$\frac{\partial L}{\partial Y}, \frac{\partial K}{\partial Y} > 0; \frac{\partial L}{\partial w}, \frac{\partial K}{\partial rk} < 0$$

Leontief technology between X and Y is imposed, so the combination of the value added and intermediate inputs can be shown with an L-shaped isoquant. The intermediate goods produced locally or imported are considered as imperfect substitutes. Basically, we mix regional and imported goods under the so called Armington assumption through a CES function. The demand function for regionally produced and imported intermediate inputs (from ROI and ROW) derives from the solution of a cost minimization problem. Furthermore the imports from the ROW are split into Europe (EU), North America (NA), Middle and South America (SA), Africa (AFC), Oceania (OCE) and Asia (ASA).

Figure 1
Production Structure of the Basic Model



The regional commodities supply is bought by industries and by domestic and external institutions. That is to say, each industry in the region produces a composite commodity that can be exported or sold in the regional market. An export demand function closes the model where the foreign demand for Sardinian goods depends on the term of trade effect and on the export price elasticity.

The law of motion for sectoral capital stock (Gunning and Keyzer, 1995, McGregor et. al., 1996) can be algebraically expressed in this way: $\overline{K}_{i,t+1} = (1-\delta)\cdot\overline{K}_{i,t} + I_{i,t}$; where $\overline{K}_{t+1}$ is the capital stock for the next periods, I_t is the investment in the actual period and $\delta\cdot\overline{K}_t$ is the depreciation. The model incorporates a capital adjustment rule initially proposed[1] by Bourguignon et al. (1989) and compatible with Uzawa,s (1969) formulation, according to which the investment capital ratio φ is determined by the rate of return to capital (rk) and the user cost of capital (uck), allowing the capital stock to reach its desire level in a smooth fashion over time: $\varphi = \varphi(\mathrm{rk}, \mathrm{uck})$ where $\frac{\partial\varphi}{\partial \mathrm{rk}} > 0;\ \frac{\partial\varphi}{\partial \mathrm{uck}} < 0$. This formulation is also compatible with those used in AMOS (McGregor and Swales, 1994) where the optimal path of investment is derived trough the accelerator mechanism v: $\mathrm{I} = \mathrm{v}\,[\mathrm{K}^* - \mathrm{K}]$. Though, both formulations are incorporated in the model. The sectoral investment with the quadratic and homogeneous adjustment costs (see Hayashi, 1982 and Devarayan and Go, 1999) is:

$$\mathrm{J}_{i,t} = \mathrm{I}_{i,t}\left[1 + \frac{\beta_i}{2}\cdot\frac{\mathrm{I}_{i,t}^2}{\mathrm{K}_{i,t}}\right]$$

So, the total investment by destination $\mathrm{J}_{i,t}$, is given by the net investment demand by destination $\mathrm{I}_{i,t}$and adjustment cost $\left[1 + \frac{\beta_i}{2}\cdot\frac{\mathrm{I}_{i,t}^2}{\mathrm{K}_{i,t}}\right]$.

Regarding the demographic development and labour supply, we assume that there is no natural population change but labour forces adjust through a migration model commonly employed in AMOS (Harrigan et al.1991, McGregor at al. 1995). The model starts with zero net migration flow and in any period migration is taken to be positively related to the gap between regional, (w/cpi) and national, (w^N/cpi^N)

[1] See also Jung and Thorbecke (2003).

real wage and negatively related to the gap between national, (u^N) and regional unemployment rates (u):

$$\mathrm{nim}_t = \varsigma - \nu^u[\ln(u_t) - \ln(\bar{u}^N)] + \nu^w \left[\ln\left(\frac{w_t}{\mathrm{cpi}_t}\right) - \ln\left(\frac{w^N}{\mathrm{cpi}^N}\right)\right]$$

where nim is the rate of net migration and ς is a parameter calibrated in order to get zero net migration. ν^u and ν^w are elasticities that measure respectively the impact of the gap between regional and national unemployment rate and real wage rate.

The model also incorporates two labour market closures defining the form of wage setting according to the following labour market regimes: regional wage bargaining (RB), and national bargaining (NB). In the regional wage bargaining regime[2] the labour market is defined by the wage curve (Blanchflower and Oswald, 1994) according to which, wage and unemployment are negatively related. The wage-setting function is defined as follow:

$$\ln\left[\frac{w_t}{\mathrm{cpi}_t}\right] = \beta - \mu \ln(u_t)$$

where cpi is the consumer price index, β is a parameter calibrated to the steady state and u is the regional unemployment rate. μ is the elasticity of wages related to the level of unemployment rate and it can also be interpreted as an index of wage flexibility. This means that in a low unemployment region workers earn more than workers in high unemployment regions. Thus the regional wage is directly related to the worker's bargaining power and it responds to the excess demand for labour.

NB is a typical Keynesian closure rule. It assumes that the nominal wage is fixed at the base year level. We can imagine that the regional nominal wage is fixed at the value of the national wage due to a national bargaining regime. For that reason this closure rule could be called National Bargaining (Harrigan and al. 1991).

[2] This wage setting regime is commonly selected for applications in AMOS framework of the Scottish economy (McGregor, Swales and Yin, 1996).

With regards to the transfers of incomes among institutions, the receipts and payments among institutions (Household, Firm, Government, ROI and ROW) are an increasing function of the consumer price index (CPI).

The equations of the model are solved simultaneously for a given finite time horizon. Since the model does not incorporate jumping variables the results are clearly those of the recursive one. The model can also be run for two static specific time closure: Short Run (SR) and Long Run (LR). In the SR the supply side is maintained fixed, so capital and labour supplies are fixed to their base year value. In the LR, instead, we run SGEM by relaxing all supply side constraints allowing for capital and labour adjustment. The capital stock is at its optimal level, then the rental rate and the user cost of capital are equal. With regard to the labour supply, the population is fully adjusted so that the system exhibits zero net migration. For each time closure, SGEM is run in order to find a set of prices that clears all markets: the supply of each produced good equals its demand. The vector of equilibrium prices we find is the result of myopic expectations since agents are not forward-looking.

3. Incorporating Knowledge in SGEM.

The creation of knowledge is the source of ITC in the model. The approach we follow is to enlarge the set of substitution possibilities into the value added production function by allowing substitution between tangible (K and L) and intangible (H, knowledge) inputs. The magnitude of shifting between these alternative technologies is related to their relative prices and the elasticity of substitution ρ_i, that define the shape of Y :

$$Y_{i,t} = A(\xi_{i,t})\left[\delta_i^k K_{i,t}^{-\rho_i} + \delta_i^h H_{i,t}^{-\rho_i} + \delta_i^l L_{i,t}^{-\rho_i}\right]$$

In other words, we are considering knowledge services as a primary factor of production. Price changes encourage substitution of knowledge for tangible input, so technical change arise as a consequent increase in the quantity of knowledge which in turn through the accumulation process creates the condition for an output effect by increasing also the quantity of tangible inputs. This is an alternative approach, with respect to the traditional one according to which the induced technical change is determined by augmented inputs technological coefficients. To some extent our approach is quite similar to the one used by Bovenberger and Smulders (1995), Goulder and Shneider (1999) and Sue Wing (2003) to model ITC for climate policy analysis. However, in our case we consider the knowledge as part of the value added allowing substitution only between primary factors of production.

The model distinguishes between the appropriable (H) and non-excludable knowledge ($\xi_{i,t}$). H, accumulates following the perpetual inventory formulation. Given R, the investment in R&D, we have:

$$\dot{H}_{i,t} = \psi(R_{i,t}, H_{i,t})$$

where,

$$\frac{\partial \psi}{\partial R} > 0; \frac{\partial \psi}{\partial H} < 0$$

The adjustment accumulation mechanism is similar to the physical capital one:

$$\chi_{i,t} = \varphi(rh_{i,t}, uch_{i,t})$$

where $\chi_{i,t}$ is the knowledge capital accumulation rate; it is related to the rental price of capital $rh_{i,t}$ and to the user cost of knowledge $uch_{i,t}$. Essentially, we are introducing a specific knowledge stock adjustment according to which accumulation is driven by the gap between $rh_{i,t}$ and $uch_{i,t}$.

The scale factor A in the production function is related to the non-excludable knowledge which is the result of external spillover enjoyed by all firms in sector j. The external spillover represents the non-excludable knowledge that originate from the foreign R&D stock. Based on some econometric finding (i.e. Coe and Helpman, 1995) and recent applied economic models (i.e. Diao et al., 1999) the external spillovers are assumed to be generated through the import of intermediates goods.

$$A_{i,t} = \left(1 + \xi_{i,t}\right)\bar{A}$$

where $\bar{A}$ is the initial level of the scale factor in the production function; $\xi_{i,t}$ is the external spillover coefficient which in turn by following Coe and Helpman (1995) and Diao et al. (1999), is related to the import-weighted foreign R&D stock:

$$\xi_{i,t} = \vartheta \sum_r \omega_r \ln(\overline{FSK}_r)$$

This equation allows us to link the knowledge spillover with the foreign R&D capital stock FSK_r and the international trade trough ω_r, which is the fraction of import from r regions on total import (where r = EU, NA, SA, ASA, AFC, OCE, ROI). ϑ is the spillover elasticity of the regional productivity with respect to foreign R&D stock. Whilst ϑ is a proxy of the capacity to exploit the level of technology existing in foreign country, ω_r is a measure of the intensity of spillover or a metric to appraise the technological closeness of the region.

4. Data and Calibration

The accounting framework used in this work is the Social Accounting Matrix (SAM) for Sardinia, RSAM, related to the year 2001 (Ferrari, Garau and Lecca, 2007). The lack of information at regional level on intangible components, obstruct a straightforward determination of a precise scheme which includes R&D services in a SAM framework. We have proceeded in the following way. From the National Account System, a vector of Sardinia R&D investment expenditure by sectors, R_i^d has been found (ISTAT, 2005). In order to determine a vector of investment by sector of origin R_i^o, an aggregated version of the Yale Technology Matrix, YTM (Evenson et. al., 1989) has been used. The YTM is based on patent granted in Canada, where the row represent the industries that produce knowledge and the columns the industries that is receiving technology. The YTM has been widely used in order to account for knowledge linkage for different countries. For instance, Evenson and Putman (1993) have used the YTM for Italy, Basant (1993) for India and H. van Meijl (1997) has used it for France. By multiplying the YTM, $\psi_{i,j}$ for the diagonal vector of investment in R&D by sector of destination j, $\widehat{R}_j^d$, we obtain the investment by sector of origin i, R_j^o.

$$R_i^o = \sum_j \psi_{i,j} \widehat{R}_j^o$$

The intangible capital H_j has been determine by using the perpetual inventory change equation that in a steady state condition with zero growth leads to the following formulation:

$$H_j = \frac{R_j^d}{\delta^H}$$

where δ^H is the depreciation rate of knowledge capital. A corresponding amount of saving S^H, generated from knowledge income must be determined. Since in equilibrium saving equal investment we have:

$$S^H = \sum_i R_i^0 = \sum_j R_j^d$$

Both $H_j$and R_i^0 are allocated respectively in the shaded parts of the sub matrix F and in the knowledge capital formation vector HF in table 2. The resulting knowledge income and saving is allocated exclusively to the Household, respectively the shaded part of the sub-matrix YF and SH in table 2. We make the assumption that the intangible components are already embodied in the RSAM. In particular H_j is conceptually embodied in the value added and R_i^0 is already included in the investment vector of the RSAM. Furthermore Household income and saving derived from the intangible component, are already incorporated in the Household wealth. So the new components previously determined have to be subtracted for the corresponding values of the RSAM. Unfortunately this simple operation lead to some negative figures. Hence we have decide to use a Cross Entropy (CE) model in order to maintain the total values of the RSAM and, by imposing some macro variable control as constraints, we allocate the new component to the corresponding sub-matrices. Essentially, we base our estimations on the well known works of Golan, Judge and Robinson (1994) and Robinson, Cattaneo and El-Said (2001). The application of the CE approach on the RSAM is used as a simple balancing method as well as an adjusting procedure to incorporate new information in order to produce a well defined scheme of data. The CE model and the set of additional restrictions that constraint some sub-matrices of the RSAM are reported in appendix.

The data on import concerning EU, NA, SA, AFC, OCE and ASA are supplied by ISTAT (2005) whilst the level of R&D capital stock by regions is derived from the data provided by OECD (2004).

The model calibration process takes the economy to be initially in long-run equilibrium. The parameters are generally given by the RSAM.

As in a deterministic approach some parameters remains unspecified, we need to find them outside of the model. For this reason the elasticity of substitutions σ (in trade and production) as well as others behavioural parameters are based on econometric estimation or best guess. The unemployment elasticity, μ is equal to 0.03. This is the value econometrically estimated for the South of Italy in Devicenti et al. (2007). $\nu^u$and ν^w are the coefficients in the migration function, econometrically estimated by Leyard et al. (1991) for the UK economy. Someone can raise objection concerning these parameters which are estimated using UK data. Unfortunately, the lack of data at regional level (especially in Sardinia) precludes a more suitable approach. The elasticity of substitution is set at 0.3 in production and equal to 2 for trade.

5. Simulation strategy and policy analysis

We attempt to identify the rate of R&D investment required to achieve a pre-determined level of growth associated to a given increase in competitiveness. The simulations are performed for both labour market regimes: National Bargaining (NB) and Regional Bargaining (RB). It should be stressed from the beginning that the figures we obtain are not forecasts for the Sardinia economy rather the results of an exogenous stimulus which should help us to track the impact analysis, in a general equilibrium framework, using a numerical support represented by the RSAM that allows to deal with a specific regional production structure.

Firstly, we simulate a permanent 5% increase in interregional export. The long run level of growth in GRP we obtained will constitute our target growth. Secondly we determine the growth rate of R&D investment associated to that level of growth for all labour market closures incorporated in the model. After that, cross-border spillovers are integrated in the model. The exogenous increase in export also gives us the opportunity to present the mains features of the model. Indeed, as we have said above our model is quite similar to the behavioural adjustment present in AMOS (McGregor and Swales, 1994). So, the increase in competitiveness lead to Leontief results in the long run where the new steady state equilibrium is equal for all labour market closures. This should happen because all factors of production adjust overtime endogenously.

Table 1 SAM structure -Knowledge within the SAM-

		Commodities	**Factors**	**Institutions**	**Capital Formation**		**Foreing Sector**	
	.	*j* .	*Capital* *Labour* *Knowledge*	*Households* *Firms* *Gov*	*K*	*H*	*ROW*	*T*
Commodities	*i* .	**X**		**C**	**I**	**HF**	**E**	
Factors	*Capital* *Labour* *Knowledge*	**F**					**FW**	
Institutions	*Households* *Firms* *Gov*		**YF**	**T**			**TW**	
Capital Formation	*K* *H*	**Dk**		**S** **SH**				
Foreing Sector	*ROW*	**M**	**YW**	**C W**	**B**			
Total	*T*							

Capital stock (tangible and intangible), increase with investment which in turn is affected by the real shadow price given by the ratio between the capital rental rate and the user cost of capital. As aggregate demand raises, we would expect an increase in prices and so in firm's profit expectation: the capital rental rate increases more than the user cost of capital. This would lead to an increase in investment that will be moderated by the replacement cost of capital. Labour supply should increase over time in response to a raise in real wages and falling in the unemployment rate, until the labour market in the long run clears, where all the increase in employment is covered by the increase in working population. Furthermore, the increase in labour demand reduces unemployment rate, albeit such reduction became less significant over time through in-migration. The growth in labour supply should put downward pressure on wages until the labour market is in long run equilibrium where the real wage is restored to its original level and goods price adjust totally.

In the transitional pathway all closures behave differently. In the short run, factor of production are fixed putting upward pressure on prices. Indeed prices of goods adjust according to the wages dynamic so the capacity to reach the new steady state faster will depend on the speed of price adjustment. In NB, prices adjust faster because wages are fixed. This should imply less resistance to reach their long run equilibrium because workers do not have the power to re-establish their purchasing power since wage bargaining is centralized, leading to a less upward pressure on prices of consumption goods. So in the NB case we would expect a faster adjustment toward the new steady state than the RB. This can also be seen in the figure 1 above.

In table 1 the percentage variations on the key macroeconomic variables are shown. As we have said above, in the long run we obtain Leontief outcome for all closures. Instead, in the short run the main differences can be seen in the behavior of the real wage. For the NB case the real wage is below its initial equilibrium. As workers cannot bargain their wage in the region, the increase of the aggregated demand raise prices lowering the purchasing power of workers. Over time, with capital and labour adjustment, the real wage moves to approach its initial level. In RB the demand stimulus increases the labour demand which in turn reduces the unemployment rate increasing as a consequence the bargaining power of workers and so the real wage.

With regard to the capacity of such a demand shock to reduce the trade deficit, we see that, in both labour market closures, in short run the trade deficit gets worse, however year by year there are some improvements of the current account reducing the trade deficit in the long run about 2.17%. Indeed, the exogenous increase in export raises competitiveness but the augmented aggregate demand generates an increase in production that needs to be satisfied by increasing the demand of import goods driven also by the increase in regional prices. Essentially the term of trade effect produce a substitution effect which lowers foreign export and raises imports in the initial periods whilst in the medium and long run, exports begin to increase more than import because of price adjustments. Prices are going to approach a new steady state in which they return back to their initial position. Such a behavior can also be seen in table 3 where the value added price show zero change in the long run. However the percentage change in the quantity of value added are positive, and are increasing over time.

5.1 Knowledge subsidy.

The key focus of this section is identify the rate of growth in R&D investment required to achieve a pre-determined target growth in GRP, which has been obtained in the previous simulation and reported in table 1. To this end we run the model for both labour markets specifications using long term closures and fixing the level of GRP growth at 1.4407%. This sustainable target can be reached by means of the accumulation of the three components of growth: labour, tangible capital and intangible capital. In this framework the introduction of imperfect labour market may improve our understanding of the determination process of sustainable growth. Indeed, given that knowledge stock is endogenously determined, and for all closures we have the same behavior of tangible capital, what is going to make the difference is the behavior of wages and unemployment and so the labour accumulation through migration. The level of R&D investment will change according to the level of knowledge stock required to obtain that level of GRP growth. The results we obtain are the following: 2.57% for RB and 5,95% for NB.

So, the wage setting really matters in this context. When wages are fixed, R&D investment needs to increase to about 5.95% to reach the sustainable target growth. Instead, we can reach the same level of growth with a small increase in R&D investment when the wages is bargained locally. This is happening because firms's labour demand is lower in NB than the RB closure, since wages cannot be re-bargained. Now we can

Figure 2

Impact on GRP of 5% increase in export

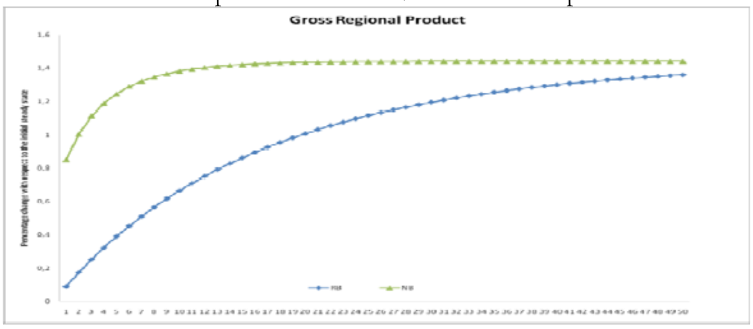


Table 2

Permanent 5% increase in total export, key macroeconomic results.
Percentage change with respect to the initial steady state

	1	10	20	30	40	50	LR
GRP at factor cost							
RB	0,0896	0,6637	1,0072	1,1950	1,3002	1,3600	1,4407
NB	0,8513	1,3812	1,4342	1,4400	1,4406	1,4407	1,4407
Trade deficit							
RB	1,6211	-0,0743	-1,0242	-1,5300	-1,8093	-1,9667	-2,1777
NB	4,9822	-1,7781	-2,1366	-2,1731	-2,1772	-2,1776	-2,1777
Nominal wage							
RB	1,1446	0,6304	0,3460	0,1945	0,1107	0,0634	0,0000
NB	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Real wage							
RB	0,0332	0,0174	0,0093	0,0051	0,0029	0,0017	0,0000
NB	-1,0533	-0,0505	-0,0052	-0,0006	-0,0001	0,0000	0,0000
Unemployment rate							
RB	-1,1009	-0,5773	-0,3083	-0,1709	-0,0965	-0,0550	0,0000
NB	-10,5157	-0,1589	-0,0187	-0,0021	-0,0002	0,0000	0,0000

Table 3

Impact on the quantity and price of value added.

	Value added								*Value added Price*						
	1	10	20	30	40	50	LR		1	10	20	30	40	50	LR
RB								**RB**							
Primary sector	0,2825	1,4913	2,1868	2,5653	2,7770	2,8970	3,0590	Primary sector	1,3990	0,7453	0,4065	0,2278	0,1294	0,0741	0,0000
Heavy Industry	0,1217	1,1770	1,8886	2,2860	2,5107	2,6390	2,8129	Heavy Industry	1,3723	0,8076	0,4448	0,2499	0,1421	0,0814	0,0000
Light Industry	0,1822	0,9919	1,4290	1,6671	1,8007	1,8767	1,9794	Light Industry	1,3667	0,7166	0,3911	0,2195	0,1248	0,0715	0,0000
Energy	0,1022	0,7868	1,1629	1,3692	1,4850	1,5509	1,6398	Energy	1,4221	0,7318	0,4003	0,2246	0,1277	0,0731	0,0000
Services	0,0640	0,5256	0,8029	0,9539	1,0383	1,0862	1,1507	Services	1,2307	0,6796	0,3720	0,2088	0,1187	0,0680	0,0000
NB								**NB**							
Primary sector	1,2136	2,8394	3,0362	3,0565	3,0587	3,0590	3,0590	Primary sector	1,0869	0,1054	0,0101	0,0011	0,0001	0,0000	0,0000
Heavy Industry	0,9083	2,5421	2,7823	2,8094	2,8125	2,8128	2,8129	Heavy Industry	1,6986	0,1664	0,0182	0,0021	0,0002	0,0000	0,0000
Light Industry	1,3043	1,9513	1,9763	1,9790	1,9793	1,9794	1,9794	Light Industry	1,5885	0,0451	0,0044	0,0005	0,0001	0,0000	0,0000
Energy	0,6057	1,5243	1,6270	1,6383	1,6396	1,6398	1,6398	Energy	1,6428	0,1007	0,0106	0,0012	0,0001	0,0000	0,0000
Services	0,7746	1,1170	1,1470	1,1503	1,1507	1,1507	1,1507	Services	1,0384	0,0422	0,0042	0,0005	0,0001	0,0000	0,0000

treat these percentage change in R&D investment as subsidy to firms provided by the regional Government.

The subsidy is clearly financed outside of the region, namely we consider Sardinia as the recipient region of the financial aid.

So, we apply for every specific labour market the rate of subsidy we have obtained. These simulations are performed by increasing the R&D investment by destination which are transformed into investment by origin through the YTM. As in the short run we impose capacity constraint the effect we obtain is a clear demand side shock. Indeed, the exogenous increase in investment by destination when knowledge stock is fixed, leads only to raise the investment by origin which is a component of the aggregate demand. So, supply side effect begins in the second periods when capacity constraints are relaxed.

For both labour market closures we achieve the same level of growth in GRP even though the transitional pathway towards the new steady state is different (see figure 3). The short and long run results of these simulations are illustrated in table 4. In the national bargaining case we see that the capital goods price for tangible and intangible input is above its benchmark equilibrium in the short run because of capacity constraints. Labour supply is fixed, though labour demand raises as a consequence of the expansion in the aggregated demand reducing as a result the unemployment rate. Note that the increase in employment is greater than the proportionate change in GRP because of fixed capacity. This is happening for both closures.

The increase in commodity price reduce competitiveness and increase import. In the long run the supply side effects are put in evidence. Indeed, with respect to the previous simulation (increase in export) we do not get Leontief results. These are no longer consistent with supply side shock where the price adjustment is the result of an increase in investment which in turn generates direct change in the aggregate demand and in production. Such a shock yields to an increase in the system-wide efficiency by reducing prices and encouraging export. So, in the long run we have improvements of the current account and furthermore, the labour supply increases more than labour demand generating an increase in the unemployment rate. Typically these are Keynesian results of unemployment equilibrium.

Even when wages are bargained regionally, supply side effect is neglected in the short run. So induced technical change begin from the second period when the increase in R&D investment yields an expansion of knowledge stock which in turn leads to an increase in other production factors. Such an output effect has determined an increase in employment equal to 1.36% in the long run, which is substantially greater than the one we have obtained in National Bargaining (0.92%). As the level of growth is the same this means that in a Keynesian framework, tangible capital stock has increased more than the regional bargaining case and that the output effect that arise from ITC encourage employment more when wages are flexible and respond to the regional bargaining power of workers in the region. Real wage in the long run returns back to its initial position because the unemployment rate return to its initial level too. In the RB case the purchasing power of workers move to zero change through an endogenous process according to which in-migration reduces the fall in the unemployment rate thereby limiting the rise in the real wage as regional employment expands.

In order to evaluate whether the policy implemented has produced some sectoral structural change, the percentage change with respect to the initial steady state of the share of sectoral output on total output are reported in figure 4. An increase in output share for an economic activity implies that this sector will grow faster than the rest of the economy as a result of the subsidy. We see that for the NB scenario, the sectoral share of Heavy industry has the biggest change in the long run. Although substantially less than Heavy industry, the other sectors benefiting are Primary, Light industry and Energy. On the other hand, Service sector experience a significant drop in its share of total output.

The positive structural change for the Primary sector is due to the positive impact of the subsidy on the regional demand which is though partially offset by a decrease in the share of export on total output (see figure 4: respectively the share of sectoral domestic demand on total output and the share on sectoral export on total output). For Services, the negative regional demand effect is exacerbated by a negative change in export demand. The main differences with respect to the RB case is the behavior of Primary sector and Services. Indeed in the RB case the Primary sectors and Services has also positive change in the share of export from the medium to the long run.

Figure 3
The impact of R&D subsidy on GRP
for different labour market closures

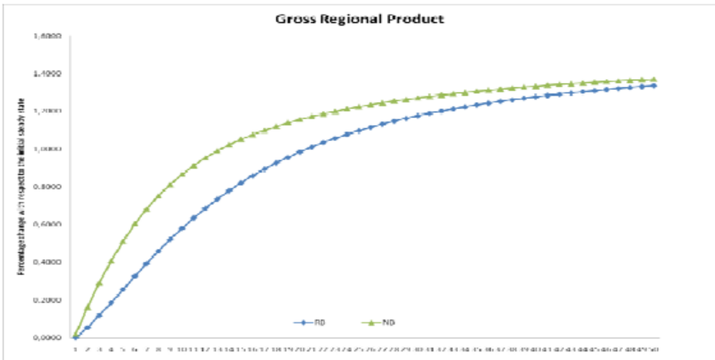


Table 4
The impact of R&D subsidy on key macroeconomic variable -percentage change with respect to the initial steady state

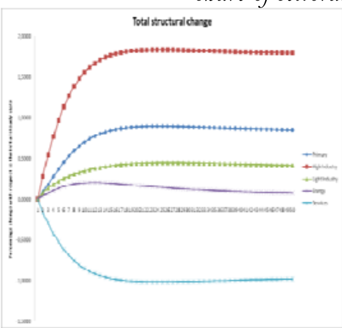
% Rate of Subsidy	5,95		2,57	
Labour market	National Bargaining		Regional Bargaining	
	SR	LR	SR	LR
Grp at Factors Cost	0,0194	1,4407	0,0005	1,4407
Consumer price index	0,0260	-0,9613	0,0120	-1,0742
Unemployment rate	-0,1303	0,7271	-0,0036	0,0000
Total employment	0,0326	0,9205	0,0009	1,3635
Nominal gross wage	0,0000	0,0000	0,0121	-1,0742
Real gross wage	-0,0260	0,9706	0,0001	0,0000
Inv. price index TANG	0,0220	-0,8423	0,0109	-1,0545
Inv. price index INTANG	0,0340	-1,1977	0,0139	-1,0138
Current account deficit	0,3581	-2,4916	0,1225	-2,6492
Labour supply	0,0000	1,1042	0,0000	1,3635
Households Cons	0,0166	1,1269	0,0013	1,0490
Investment TANG	0,1234	1,4384	0,0130	1,3988
Investment INTANG	5,9502	5,9502	2,5661	2,5661
Structural change				
PrimarySector	0,0079	0,8207	0,0021	0,7218
Heavy Industry	0,0023	1,7712	0,0014	0,8271
Light Industry	0,0114	0,3812	0,0017	0,2825
Energy	0,0152	0,0437	0,0098	-0,1412
Services	-0,0067	-0,9515	-0,0020	-0,5075
Commodity Price				
PrimarySector	0,0115	-0,3990	0,0064	-0,4667
Heavy Industry	0,0411	-1,5485	0,0155	-1,0016
Light Industry	0,0399	-1,4239	0,0155	-1,2562
Energy	0,0536	-0,7617	0,0223	-0,7022
Services	0,0184	-0,7642	0,0099	-1,0712

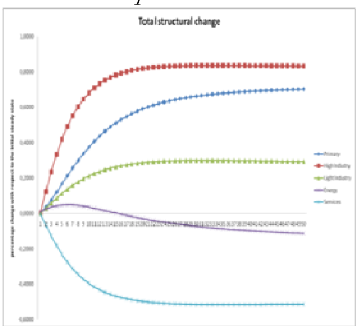
Figure 4

Sectoral structural change - percentage change with respect to the initial steady state-

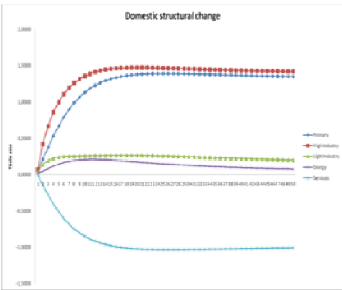
National Bargaining	Regional Bargaining

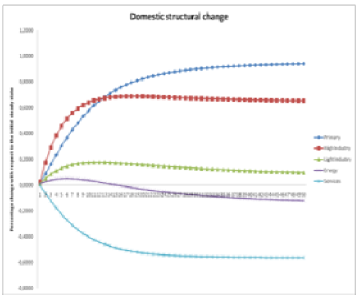
share of sectoral output on total output



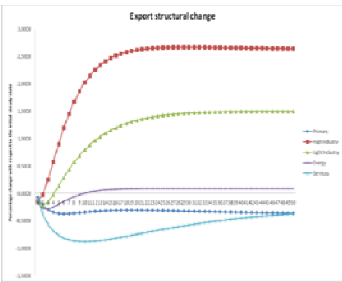


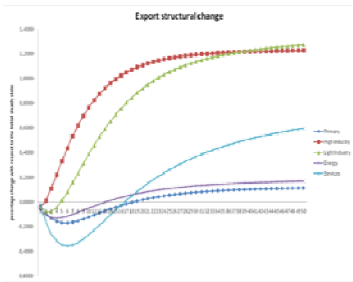
share of sectoral domestic output on total output





share of sectoral export output on total output





5.2 Knowledge spillover effect.

In this section we analyze the capacity of interregional and international trade to improve growth. The kind of simulations we run are the same as seen above. The only difference is that now we allow for change in the total factor productivity through interregional and international knowledge spillover. So, positive changes may increase growth and increase the system-wide efficiency. As the spillover elasticity and the foreign stock of knowledge are fixed, the only change is related to the change in the share of import.

In figure 5 the behavior of the knowledge spillover is reported for the two closures, whilst the long run change in the key macroeconomic variables can be seen in table 5 where the long run change for the no-spillover case seen above, is also reported.

When nominal wage is fixed we would expect an increase in import greater than the RB scenario. Indeed, the increase in R&D investment produces a decrease in prices that will be greater if wages do not have downward rigidities. The greatest change is in fact in NB where the difference in GRP growth between the spillover and no-spillover case is about 0.1%; substantially less is for the case of RB which is about 0.03%.

These results suggest that policies that are trying to enhance the long-run rate of regional economic growth increasing the regional stock of knowledge are not able to generate large cross-border technological spillovers. The magnitude of the shift in production is not so large since the increase in efficiency produce positive term of trade effect encouraging export. From the change in the current account we see that export increase more in NB than RB, paradoxically the former is also able to generate a bigger import share and then more knowledge spillover.

Figure 5

External knowledge spillover for NB and RB

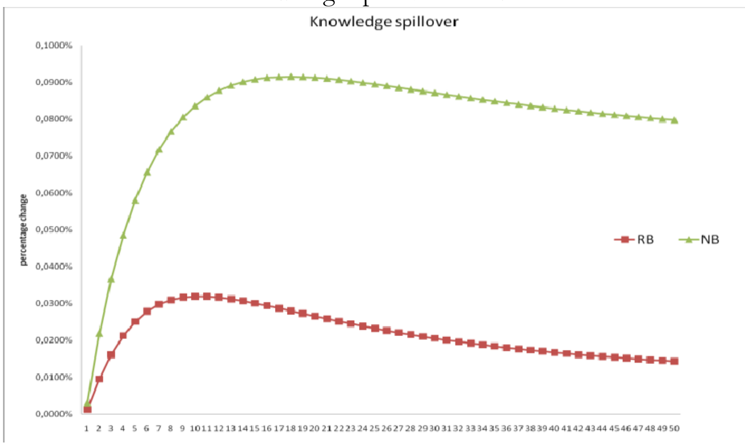


Table 5

Impact of R&D subsidy for different labour market closures

- spillover and no spillover case-

	National Bargaining		Regional Bargaining	
	No spillover	Spillover	No spillover	Spillover
Grp Factor Cost	1,4407	1,5405	1,4407	1,4756
Consumer price index	-0,9613	-1,0436	-1,0742	-1,1021
Unemployment rate	0,7271	0,7899	0,0000	0,0000
Total employment	0,9205	0,9336	1,3635	1,3909
Nominal gross wage	0,0000	0,0000	-1,0742	-1,1021
Real gross wage	0,9706	1,0546	0,0000	0,0000
Inv. price index TANG	-0,8423	-0,9266	-1,0545	-1,0836
Inv. price index INTANG	-1,1977	-1,2662	-1,0138	-1,0357
Current account deficit	-2,4916	-2,7327	-2,6492	-2,7219

6. Conclusion

In this work our intention was to understand the important role played by the knowledge as a factor of regional development. A better utilization of foreign R&D capital stock would require a regional production structure with a strong manufacturing sector which is the one with high intensity of intangible capital. However, in the past ten years, Sardinia has experienced an intensive deindustrialization process especially in the Heavy industry sector. Therefore, it may need to change its production structure making manufacturing the leading sectors in order to accommodate R&D policies.

We have also seen that the region may take advantage from its openness (in the interregional and international trade market) if it is able to exploit the knowledge embodied in the imported goods which actually depends on the capacity of the regional system to internalize the technological level embodied in the imported good. We shown that endogenous productivity effect that occurs in response to external spillovers are quite modest. Yet, regions cannot improve their capacity of gaining from knowledge spillover by mitigating the rigidity eventually existing in the international market because they do not have trade policy power.

Furthermore, the kind of wage setting really matters in this model according to the behavioral parameters we have used and to some extent to the Sardinia production structure. The output effect among primary factors of production due to the induced technical change incorporated in the model benefits of flexible wage. Indeed, the cost of R&D policies might be quite high if in the region the prevailing wage setting is bargained nationally.

Appendix A

The mathematical presentation of the model

Prices

$$PM_{i,t} = \varepsilon_t \cdot PWM_i \cdot (1 + MTAX_i) \quad (A1)$$

$$PE_{i,t} = \varepsilon_t \cdot PWE_i \cdot (1 - TE_i) \quad (A2)$$

$$PX_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PE_{i,t} \cdot E_{i,t}}{R_{i,t} + E_{i,t}} \quad (A3)$$

$$PQ_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PM_{i,t} \cdot M_{i,t}}{R_{i,t} + M_{i,t}} \quad (A4)$$

$$PIR_{j,t} = \frac{\sum_i VR_{i,j,t} \cdot PR_{j,t} + \sum_i VI_{i,j,t} \cdot \overline{PI}_j}{\sum_i VIR_{i,j,t}} \quad (A5)$$

$$PY_{j,t} \cdot a_j^Y = \left(PX_{j,t} \cdot \left(1 - btax_j - sub_j - dep_j\right) - \sum_i a_{i,j}^V PQ_{j,t} \right) \quad (A6)$$

$$UCK_t = PINV \cdot (ir + \delta) \quad (A7)$$

$$PC_t^{1-\sigma^c} = \sum_j \sum_h \delta_{j,h}^f \cdot PQ_{j,t}^{1-\sigma^c} \quad (A8)$$

$$w_t^b = \frac{w_t}{(1 + sscee + sscer) \cdot (1 + ire)} \quad (A9)$$

$$\ln\left[\frac{w_t^b}{PC_t}\right] = \beta - \mu \cdot \ln(u_t) \quad (A10)$$

$$rk_{j,t} = PY_{j,t} \cdot \delta_j^k \cdot A\left(\xi_{j,t}\right)^{\varrho_j} \cdot \left(\frac{Y_{j,t}}{K_{j,t}}\right)^{1-\varrho_j} \quad (A11)$$

$$rh_{j,t} = PY_{j,t} \cdot \delta_j^h \cdot A\left(\xi_{j,t}\right)^{\varrho_j} \cdot \left(\frac{Y_{j,t}}{H_{j,t}}\right)^{1-\varrho_j} \quad (A12)$$

$$PINV_t = \frac{\sum_j PQ_{j,t} \cdot \sum_i KM_{i,j}}{\sum_i \sum_j KM_{i,j}} \quad (A13)$$

$$PINVH_t = \frac{\sum_j PQ_{j,t} \cdot \sum_i YTM_{i,j}}{\sum_i \sum_j YTM_{i,j}} \quad (A14)$$

Production technology

$$X_{i,t} = \min\left(\frac{Y_{i,t}}{a_i^Y}; \frac{V_{i,j,t}}{a_{i,j}^V}\right) \tag{A15}$$

$$Y_{i,t} = a_i^Y \cdot X_{i,t} \tag{A16}$$

$$V_{i,t} = a_{i,j}^V \cdot X_{i,t} \tag{A17}$$

$$Y_{i,t} = A(\xi_{i,t}) \cdot \left[\delta_i^k K_{i,t}^{\varrho_i} + \delta_i^h H_{i,t}^{\varrho_i} + \delta_i^l L_{i,t}^{\varrho_i}\right]^{\frac{1}{\varrho_i}} \tag{A18}$$

$$A_{i,t} = (1 + \xi_{i,t}) \cdot \overline{A} \tag{A19}$$

$$\xi_t = \sum_r \vartheta_r \cdot \omega_r \cdot \ln(\overline{FSK}_r) \tag{A20}$$

$$\omega_{r,t} = \frac{\sum_j \sum_r TVMREG_{j,r,t}}{\sum_j TVMREG_{j,r,t}} \tag{A21}$$

$$L_{j,t} = \left(A\left(\xi_{j,t}\right)^{\varrho_i} \cdot \delta_j^l \cdot \frac{PY_{j,t}}{w_t}\right)^{\frac{1}{1-\varrho_j}} \cdot Y_{j,t} \tag{A22}$$

Trade

$$VV_{i,j,t} = \gamma_{i,j}^{vv} \cdot \left[\delta_{i,j}^{vm} VM_{i,t}^{\rho_i^A} + \delta_{i,j}^{vir} VIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A23}$$

$$\frac{VM_{i,j,t}}{VIR_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vm}}{\delta_{i,j}^{vir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A24}$$

$$VIR_{i,j,t} = \gamma_{i,j}^{vir} \cdot \left[\delta_{i,j}^{vi} VI_{i,t}^{\rho_i^A} + \delta_{i,j}^{vr} VR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A25}$$

$$\frac{VR_{i,j,t}}{VI_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vr}}{\delta_{i,j}^{vi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A26}$$

$$TV_{j,t} = \sum_i VV_{i,j,t} \tag{A27}$$

$$TVR_{j,t} = \sum_i VR_{i,j,t} \tag{A28}$$

$$TVI_{j,t} = \sum_i VI_{i,j,t} \tag{A29}$$

$$TVM_{j,t} = \sum_i VM_{i,j,t} \tag{A30}$$

$$TVMREG_{j,r,t} = \begin{cases} \delta_{j,r}^{reg\,\sigma_r^{reg}} \cdot TVM_{j,t} & r \in \langle AFC, EU, ASA, OCE, NA, SA \rangle \\ TVI_{j,t} & r \in ROI \end{cases} \tag{A31}$$

$$E_{i,t} = \overline{E}_i \cdot \left(\frac{PE_{i,t}}{PR_{i,t}}\right)^{\sigma_i^x} \tag{A32}$$

$$R_{i,t} = \sum_j VR_{i,j,t} + \sum_h QHR_{i,h,t} + QVR_{i,t} + QGR_{i,t} + QHK_{i,t} \tag{A33}$$

$$X_{i,t} = R_{i,t} + E_{i,t} \tag{A34}$$

Domestic Institutions

$$YNG_{dngins,t} = d_{dngins}^{L} \cdot w_t \cdot \textstyle\sum_i L_i + d_{dngins}^{K} \cdot rk_{i,t} \cdot \sum_i K_i + d_{dngins}^{h} \cdot rh_{i,t} \cdot \sum_i H_i + \sum_{dnginsp} TRSF_{dngins,dnginsp,t} + PC_t \cdot TRG_{dngins} + \varepsilon_t \cdot REM_{dngins} \tag{A35}$$

$$TRSF_{dngins,dnginsp,t} = PC_t \cdot \overline{TRSF}_{dngins,dnginsp} \tag{A36}$$

$$SAV_{dngins,t} = mps_{dngins} \cdot YNG_{dngins,t} \tag{A37}$$

$$HC_t = \sum_{dngins \in \langle HH \rangle} YNG_{dngins,t} - \sum_{dngins \in \langle HH \rangle} SAV_{dngins,t} - HTAX_t - \sum_{dngins} \sum_h TRSF_{dngins,h,t} \tag{A38}$$

$$QH_{i,h,t} = \delta_{i,h}^{f\;\rho_i^c} \cdot \left(\frac{PC_{i,t}}{PQ_{i,t}}\right)^{\rho_i^c} \cdot HC_t \tag{A39}$$

$$QH_{i,h,t} = \gamma_{i,h}^{f} \cdot \left[\delta_{i,h}^{hr} \cdot QHR_{i,h,t}^{\rho_i^A} + \delta_{i,h}^{hm} \cdot QHM_{i,h,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A40}$$

$$\frac{QHR_{i,h,t}}{QHM_{i,h,t}} = \left[\left(\frac{\delta_{i,h}^{hr}}{\delta_{i,h}^{hm}}\right) \cdot \left(\frac{PM_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A41}$$

$$\begin{aligned} GOVBAL_t = \sum_i QG_{i,t} \cdot PQ_{i,t} + \overline{GSAV} + PC_t \\ \cdot \sum_{dngins} TRG_{dngins,t} - (d_g^k \cdot \sum_i rk_{i,t} \cdot K_{i,t} + d_g^h \\ \cdot \sum_i rh_{i,t} \cdot H_{i,t} + \sum_i IMT_{i,t} + HTAX_t + \overline{FE} \\ \cdot \varepsilon_t \end{aligned} \tag{A42}$$

$$QG_{i,t} = \overline{QG}_i \tag{A43}$$

$$QG_{i,t} = \gamma_i^g \cdot \left[\delta_i^{gr} \cdot QGR_{i,t}^{\rho_i^A} + \delta_i^{gm} \cdot QGM_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A44}$$

$$\frac{QGR_{i,t}}{QGM_{i,t}} = \left[\left(\frac{\delta_i^{gr}}{\delta_i^{gm}}\right) \cdot \left(\frac{PM_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A45}$$

$$QV_{i,t} = \sum_j KM_{i,j} \cdot J_{j,t} \tag{A46}$$

$$QV_{i,t} = \gamma_i^v \cdot \left[\delta_i^{qvm} \cdot QVM_{i,t}^{\rho_i^A} + \delta_i^{qvir} \cdot QVIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A47}$$

$$\frac{QVM_{i,t}}{QVIR_{i,t}} = \left[\left(\frac{\delta_i^{qvm}}{\delta_i^{qvir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A48}$$

$$QVIR_{i,t} = \gamma_i^{vir} \cdot \left[\delta_i^{qvi} \cdot QVI_{i,t}^{\rho_i^A} + \delta_i^{qvr} \cdot QVR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A47}$$

$$\frac{QVR_{i,t}}{QVI_{i,t}} = \left[\left(\frac{\delta_i^{qvr}}{\delta_i^{qvi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A48}$$

$$QHK_{i,t} = \sum_j YTM_{i,j} \cdot IH_{j,t} \tag{A49}$$

Investment

$$\frac{I_{i,t}}{KS_{i,t}} = \delta^K \cdot \left(\frac{rk_{i,t}}{uck_{i,t}}\right)^{\alpha_i} \tag{A50}$$

$$J_{i,t} = I_{i,t}\left[1 + \frac{\beta_i}{2} \cdot \frac{I_{i,t}^2}{K_{i,t}}\right] \tag{A51}$$

$$R\&D_{i,t} = \lambda \cdot \left[HS_{i,t}^* - HS_{i,t}\right] + \delta^H \cdot KS_{i,t} \tag{A52}$$

Factors accumulation

$$KS_{i,t} = \left(1 - \delta^K\right) \cdot KS_{t-1} + I_{i,t-1} \tag{A53}$$

$$HS_{i,t} = \left(1 - \delta^H\right) \cdot HS_{t-1} + R\&D_{i,t-1} \tag{A54}$$

$$LS_{i,t} = (1 + nim_t) \cdot LS_{i,t-1} \tag{A55}$$

$$nim_t = \varsigma - \nu^u[\ln(u_t) - \ln(\bar{u}^N)] + \nu^w\left[\ln\left(\frac{w_t}{cpi_t}\right) - \ln\left(\frac{w^N}{cpi^N}\right)\right] \tag{A56}$$

$$K_{i,t} = KS_{i,t} \tag{A57}$$

$$H_{i,t} = HS_{i,t} \tag{A58}$$

$$LS_t \cdot (1 - u_t) = \sum_j L_{j,t} \tag{A59}$$

$$M_{i,t} = \sum_j VI_{i,j,t} + \sum_j VM_{i,j,t} + \sum_h QHM_{i,h,t} + QGM_{i,t} + QVI_{i,t} + QVM_{i,t} \tag{A60}$$

Other Equations

$$IBT_{i,t} = btax_i \cdot X_{i,t} \cdot PX_{i,t} \tag{A61}$$

$$IMT_{j,t} = \sum_i MTAX_j \cdot VM_{i,j,t} \cdot PM_{i,t} \tag{A62}$$

$$SUBSY_{i,t} = SUB_i \cdot X_{i,t} \cdot PX_{i,t} \tag{A61}$$

$$HTAX_t = \sum_h dtr_h \cdot (ssce + sscer) \cdot \sum_j L_{j,t} \cdot w_t \tag{A62}$$

$$CA_t = \sum_i M_{i,t} \cdot PM_{i,t} - \sum_i E_{i,t} \cdot PE_{i,t} + \varepsilon_t \cdot \left(\sum_{dngins} \overline{REM}_{dngins} + \overline{FE} \right) \qquad (A63)$$

Glossary

i,j	the set of goods or industries
ins	the set of institutions
dins ($\subset$ ins)	the set of domestic institutions
dngins ($\subset$ dins)	the set of non government institutions
h ($\subset$ dngins)	the set of households
r	the set of regions

Prices

$PX_{i,t}$	output price
$PY_{i,t}$	value added price
$PR_{i,t}$	regional price
$PQ_{i,t}$	commodity price
$PIR_{i,t}$	national commodity price (regional + ROI)
$PI_{i,t}$	ROI price
$rk_{i,t}$	rate of return to tangible capital
$rh_{i,t}$	rate of return to intangible capital (knowledge)
w_t	unified nominal wage
w_t^b	after tax wage
$pinv_t$	capital good price
uck_t	user cost of physical capital
PC_t	aggregate consumption price
ε_t	exchange rate [numeraire]

Endogenous Variables

$X_{i,t}$	total output
$R_{i,t}$	Regional supply
$M_{i,t}$	total import
$E_{i,t}$	total export (interregional + international)

$Y_{i,t}$	value added
$A_{i,t}$	TFP
$L_{i,t}$	labour demand
$K_{i,t}$	physical capital demand
$H_{i,t}$	knowledge demand
$KS_{i,t}$	physical capital stock
$HS_{i,t}$	knowledge stock
$LS_{i,t}$	labour supply
$VV_{i,jt}$	intermediate inputs
$VR_{i,jt}$	regional intermediate inputs
$VM_{i,jt}$	ROW intermediate inputs
$VIR_{i,jt}$	national intermediate inputs
$VI_{i,jt}$	ROI intermediate inputs
$TVMREG_{j,rt}$	intermediate import from region r
$QGR_{i,t}$	regional government expenditure
$QGM_{i,t}$	government expenditure from ROI+ROW
HC_t	aggregated household consumption
$QH_{i,h,t}$	total households consumption in sector i for h
$QHR_{i,h,t}$	regional consumption in sector i for group h
$QHM_{i,h,t}$	import consumption in sector i for group h
$QV_{i,t}$	total investment by sector of origin i
$QVR_{i,t}$	regional investment by sector of origin i
$QVM_{i,t}$	ROW investment
$QVIR_{i,t}$	national investment (REG+ROI)
$QVI_{i,t}$	ROI investment
$QHK_{i,t}$	R&D investment by sector of origin i
$I_{j,t}$	investment by sector of destination j
$J_{j,t}$	investment by destination j with adjustment cost
$R\&D_{j,t}$	R&D investment by sector of destination j
$HS^*_{j,t}$	optimal level of knowledge stock
u_t	regional unemployment rate
nim_t	net in migration
ξ_t	external knowledge spillover
ω_t	import share in the knowledge spillover function
$SAV_{dngins,t}$	domestic non government saving
$YNG_{dngins,t}$	domestic non government income
$TRSF_{dngins,dnginsp,t}$	transfer among dngins

$HTAX_t$	total household tax
CA_t	current account balance
$SUBSY_t$	production subsidies
$GOVBAL_t$	government balance

Exogenous variable

$\overline{FSK}_{r,t}$	R&D stock of region r
$\overline{REM}_t$	remittance for dngins
$\overline{FE}_t$	remittance for the Government
$QG_{i,t}$	government expenditure
$GSAV_t$	government saving

Elasticities:

ϱ_j	between knowledge and physical inputs in sector j
ρ_i^A	in armington function
σ_i^x	of export with respect to term of trade
μ	of real wage with respect to unemployment rate
α_j	of acc. rate with respect to the real shadow price
ϑ	of non-excludable H with respect to foreign R&D
σ_r^{reg}	elasticity of substitutions of imported import from country r

Parameters

$a_{i,j}^V$	input output coefficients for i used in j
a_j^Y	share of value added on production
$\delta_j^{k.h,l}$	shares in value added function in sector j
$\delta_{i,j}^{vir,vm,vr,vi}$	shares parameters in Armington function for intermediate goods
$\delta_{i,j}^{qvir,qvm,qvr,qvi}$	shares parameters in Armington function for investment goods
$\delta_{i,h}^{hr,hm}$	shares parameters in Armington function for households consumption goods
$\delta_i^{gr,gm}$	shares parameters in Armington function for government consumption goods

$\gamma_{i,j}^{vv,vir}$	shift parameter in Armington functions for intermediate goods
γ_i^f	shift parameter in Armington function for households consumption goods
γ_i^g	shift parameter in Armington function for government consumption goods
$\delta^{K,H}$	rate of depreciation for K and H
λ	accelerator in R&D investment function
β_i	adjustment cost in tangible investment function
$btax_i$	business tax
sub_i	rate of production subsidy
$MTAX_i$	rate of import tax
$YTM_{i,j}$	Yale Technology Matrix
$KM_{i,j}$	physical capital matrix
mps_{dngins}	rate of saving in institutions dngins
ssce	rate of social security paid by emploees
sscer	rate of social security paid by emploer
ire	rate of income tax

Appendix B

CE model. The ill-specified RSAM+R&D provide the prior distribution coefficient $\bar{c}_{i,j}$ and data on column sum x_j .We minimize the entropy distance H between the prior $\bar{c}_{i,j}$ and the new estimated coefficient matrix $c_{i,j}$:

$$\text{Min } H = \left[\sum_i \sum_j c_{i,j} \ln \frac{c_{i,j}}{\bar{c}_{i,j}} \right] \qquad (B1)$$

subject to: $\sum_j c_{i,j} x_j = y_i$ (B2)

and

$$\sum_i c_{i,j} = 1 \text{ and } 0 < c_{i,j} \leq 1 \qquad (B3)$$

Where y_i are the resulting sum in row. Considering k aggregates constraints and an n-by-n aggregator matrix G, we can write:

$$\sum_i \sum_j g_{i,j}^k t_{i,j} = \gamma^k \qquad (B4)$$

where $t_{i,j}$ is the SAM transaction matrix and γ^k is the value of the aggregate constraints. With equation B4 we introduce in the set of constraints, some aggregated macro-control variables to treat with intangible components in the corresponding sub-matrices of the RSAM seen in table 1. The macro variables control, regard the following sub-matrices: F, YF, S and I. The macro-control variables allow us to maintain the original aggregated figures and so considering intangible component already incorporated into the RSAM.

Appendix C
The method to obtain the physical capital matrix $KM_{i,j}$

The physical capital matrix $KM_{i,j}$ has been derived by means of a doubly constraint minimum information (MI) model (Schneider and Zenios, 1990). Let *T* denote the total amount of investment and for each j, let I_j be the investment by sectors of destination and QV_i the investment by sectors of origin i. Considering $t_{i,j}$ the model estimated probabilities and some prior probabilities $\bar{t}_{i,j}$, the model can be formalized as follow:

$$\text{Min} \sum_i \sum_j t_{i,j} \left[\ln \left(\frac{t_{i,j}}{\bar{t}_{i,j}} \right) - 1 \right]$$

subject to

$$\sum_i t_{i,j} = \frac{I_j}{T}; \quad \sum_J t_{i,j} = \frac{QV_i}{T};$$

where

$$\sum_i \sum_j t_{i,j} = \sum_i QV_i = \sum_j I_j = T$$

In this problem as we do not have previous capital matrix concerning Sardinia the prior probabilities $\bar{t}_{i,j}$ are derived from the Italian matrix estimated by Costa and Marangoni (1995) for the year 1985. The investment by destination are supplied by the regional account system (ISTAT, 2004) whilst the investment by origin are provided by the RSAM.

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