16th International Input-Output Conference-Istanbul (Turkey)- July 2-7-2007

The Effect of R&D Subsidy Policy on Regional Growth and Unemployment[1]

{*Draft Paper; No to be quoted or cited.*}.

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Abstract

This paper analyse the effect of regional R&D subsidies on regional growth and unemployment taking also into account for external spillover effect. In so doing we use a dynamic computable general equilibrium model (CGE) calibrated using data from an Italian region, Sardinia.

JEL: R13, R58

Keywords: Regional CGE, Regional Economic and policy, R&D subsidy.

1. Introduction

Regional policy is a measure especially used to reduce and remove the unemployment disparities among different areas of a region or between different regions. At such purpose it is worth noting what Armstrong and Taylor (2000) say about the aim of regional policy: "..Regional policy exists primarily because of the persistence of regional unemployment

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disparities…"(p. 169). Essentially, we can see regional policy instruments as a mix or combination of different measures: subsidies, training scheme, infrastructure projects and general measure of policy effectiveness for job creation. Usually, regional assistance has been concentrated almost entirely on manufacturing sector through capital and labour subsidies. Such instruments have been widely used since 90th in Italy, Sweden, United Kingdom and Spanish to encourage employment and growth. Several authors have also attempt to analyse the impact in partial (Akerlof et. al 1991, Holden and Swales, 1997 and O'Donnel and Swales, 1977) and general equilibrium (Harrigan et. al. 1996, Gillespie et. al. 2001). However, in recent periods, besides the criticism of the traditional regional policy, a new route in regional policy has been taken especially in EU and US through a regional innovation system providing R&D subsidies to (high-tech) firms, funding of universities, support for research and technology organizations (Jung Duk Lim, 2006).

The main purpose of this paper is to analyse the impact of R&D subsidies on recipient region, and attempt to analyse the external spillover effect on growth and unemployment. R&D subsidies encourage domestic private R&D investment which in turn promote growth through knowledge spillover[2]. It is worth bearing in mind that regions do not have trade policy power, therefore they cannot affect directly cross-border spillover with e.g. trade liberalization policy or removing tariff protections on imports. They can indirectly affect trade policy creating favourable conditions for R&D generation. Regional government may stimulate cross-border spillover by making, for instance, multilateral agreements with the nearby regions or improving competitive environment within the region.

[2] It is our intention, for the future, to introduce internal spillover as well. Internal knowledge spillover (basically pure knowledge spillover) together with cross border spillover (national and foreign knowledge spillover) can be compared in order to see the main differences on employment, growth and competitiveness. Moreover, as the specification of labour market also matter in regional economics, alternative widely used labour market regimes will be taken into account.

This paper presents a regional computable general equilibrium (CGE) analysis for the Autonomous Region of Sardinia (SGEM). The Social Accounting Matrix (SAM) of Sardinia (Garau and Lecca, 2005) for the year 2001 has been used to parameterise the model. The *ad valorem* subsidy on R&D expenditure is considered externally-financed; that is to say, we are assuming that regional tax rates are not adjusted to finance the subsidy.

The paper proceeds with a brief outline of SGEM. The SAM of Sardinia with knowledge accounting is discussed in the third section. The fourth section is devoted to explaining the result of the simulation and the last section contains comments and a conclusion.

2. SGEM: an applied model of Sardinia.

2.1. General characteristics of the model. A brief description of the model[3] is outlined in this section. SGEM is a single-region dynamic CGE model calibrated on the SAM of Sardinia. It is a competitive model in which each good and service has a market price determined by the forces of supply and demand. All markets are in equilibrium at this set of prices. The model also assumes zero transaction costs and perfect information. SGEM considers three sectors (Agriculture, Manufacturing and Services[4]), two primary factors (Capital, K, and Labour, L) and four institutional sectors (Firms, Households, Government and External Sector). In our analysis, the Household sector is further split into six income groups and its demand system is represented by a linear expenditure system (LES). Government is a consolidated sector, merging central and local government levels and its real expenditure is held constant throughout. Moreover, government consumption is considered as adding to demand rather than as a public good. The external sector regards all exchanges

[3] A full model listing is provided in the appendix.
[4] It is easy to further disaggregate the economy.

between the region of Sardinia and the Rest of the World (ROW) including the Rest of Italy (ROI).

Intermediate inputs, K and L are the production inputs of the model. The model imposes non-substitutability between intermediate and primary inputs (L and K) but we allow for different treatments of primary and intermediate inputs making them price responsive. The value added is given by capital, K, and labour, L, combined in a CES production function. The intermediate goods produced locally or imported are considered as imperfect substitutes. Basically, we mix regional and import goods under the so called Armington's assumption by using a CES function. We also assume that exports are imperfectly transformable with regional goods. In so doing, we use the constant elasticity of transformation (CET) production technology.

In this paper we consider the interregional and the international trade as composing a unique external institution. The assumptions are those typically made for a small-open economy: the region is too small to affect prices in international markets and as it belongs to a common currency area the model does not consider the role played by the exchange rate[5]. We consider both import and export prices as exogenous and equal to the base year values.

As regions are more open than nations, SGEM does not require that saving be equal to investment. In this way through high migration of resources, flows of resources can move out (excess of saving) or in (excess of investment) of the region.

2.1.2 Features of the labour market. As we think that is usually good practice compare different market specifications SGEM incorporates two labour market regimes defining the form of wage setting according to the following labour market regimes:

- *Regional wage bargaining*.

[5] Given that Sardinia GDP amount to only around ?% of the Italy total (ISTAT, 2005), it is liable assumes that economic change in the region has insignificant effect on rest of Italy (ROI) and rest of the World (ROW). On the contrary if the target region was big enough to affect the economic system of ROI and ROW an interregional and more complex model would be required (Harrigan et al. 1996).

- *National Bargaining.*

In the regional wage bargaining regime[6] (McGregor, Swales and Yin, 1996), the labour market is defined by the wage curve (Blanchflower and Oswald, 1994) according to which, real wage and unemployment are negatively related. This means that in a low unemployment region workers earn more than workers in high unemployment regions. Thus the regional real wage is directly related to the worker's bargaining power and responds to the excess demand form labour. The regional wage can be expressed algebraically in this way:

$$ln\left[\frac{W_t}{\Pi_t}\right] = \beta_U - 0.1 \cdot lnU_t$$

where Π is the consumer price index, β_U is a parameter calibrated to the steady state and U is the regional unemployment rate. According to the estimate reported in Blanchflower and Oswald (1994) the elasticity of real wages related to the level of unemployment[7] is -0.1.

National Bargaining is a typical Keynesian way to specify the wage equation. It assumes that the nominal wage is exogenously determined at national 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 labour market regime may be called National Bargaining (Harrigan and al. 1991)

2.1.3 Incorporating dynamics into SGEM. In a static representation of the model, investment is a simple category of the final demand, which has no effect on production and capital stock (Robinson et. al. 1999). In a dynamic model, investment and its allocation across sectors play a relevant role in affecting gross product and capital accumulation. In the

[6] This wage setting regime is commonly selected for applications of the AMOS framework to the Scottish economy (Harrigan et. al. 1996 and McGregor et al., 1996).

[7] This elasticity tell us the curvature of the function, an index of wage flexibility, which is approximately the same in each of the fifteen countries in which the curve has been found, in Italy as well (Blanchflower and Oswald 1994). Basically, here we are assuming that the degree of wage flexibility present in Italy is the same as in Sardinia.

following part of the section we incorporate a recursive dynamic structure: the model is solved for a sequence of static periods by updating the capital stock and the labour supply.

2.1.4. Capital Stock Adjustment. The capital stock is updated via a simple capital adjustment rule, which represent the law of motion for sectoral capital stock (Gunning and Keyzer, 1995, McGregor et. al., 1996). The capital accumulation can be algebraically expressed in this way:

$$\overline{K}_{i,t+1} = (1-\delta)\cdot\overline{K}_{i,t} + Ind_{i,t}$$

where $\overline{K}_{t+1}$ is the capital stock for the next periods, Ind_t is the investment in the actual period, $\delta\cdot\overline{K}_t$ is the depreciation. The model assumes a fixed rate of depreciation δ equal to 0.1 and an interest rate r equal to 0.04. The investment function we use in this model is similar to those proposed by Jung and Thorbecke (2003) and Annabi et. al. (2005). Algebraically we can write:

$$\frac{Ind_{i,t}}{\overline{K}_{i,t}} = V_i \cdot \left[\frac{RK_{i,t}}{UCK_t}\right]^{\partial}$$

The capital accumulation rate $\frac{Ind_{i,t}}{\overline{K}_{i,t}}$ is the ratio of investment[8], Ind to the capital stock $\overline{K}$; it is positively related with respect to the ratio of $RK_{i,t}$, the rate of return to capital and UCK_t, the user cost of capital. The latter depends only from the variation of the price index of investment (*Pinv*) given that depreciation and the interest rate are considered exogenous. ∂ is the elasticity of the capital accumulation rate with respect to the ratio of return to capital and its user cost, it is assumed to be equal to 2 (see N. Annabi, 2003).

[8] In this way the investment is determined by the relation between capital rental rate and the user cost of capital. The former is the rental paid for a sector specific physical capital whilst the latter is the cost of a unit of capital. If the capital rental rate exceed the user cost, the capital stock increases.

2.1.5. Demographic development and labour supply. We assume the model starts with zero net migration flow and in any period is taken to be positively related to the gap between regional and national real wage and negatively related to the gap between national and regional unemployment rates (see Layard, Nickell and Jeckman, 1991). The parameter used in SGEM are those used in AMOS (McGregor, Swales and Yin, 1996) and are econometrically estimated by Layard, Nickell and Jeckman (1991).

$$nmig = B - 0.08 \cdot \left(\frac{ln(U_t)}{ln(U_N)} \right) + 0.06 \cdot \left(\frac{ln(W_t / \Pi_t)}{ln(W_N / \Pi_N)} \right)$$

The parameter B is calibrated in order to get zero net migration in the base period. U_N is the national unemployment rate fixed to the level of 8% according to the national account (ISTAT, 2005). W_N / Π_N is the national real wage that is exogenous and made equal to unity. According to the regional account system the regional unemployment rate at the base year is 20%.

2.2. SGEM+R&D

In order to incorporate technical change we introduce in SGEM substitution between tangible and knowledge (intangible) inputs in the value added production function. That is to say, we enlarge the envelope of all possible technologies[9]. In the model we developed, the substitution of knowledge for tangible inputs (Capital and Labour) determining the shift in the production function; basically the relative price change induce the creation of knowledge

[9] 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.

which in turn shift the envelope of substitution possibilities among tangible inputs[10]. The value added production function is:

$$Y_{i,t} = A_i \cdot K_{i,t}^{\alpha_k} \cdot L_{i,t}^{\alpha_L} \cdot H_{i,t}^{\alpha_H}$$

where $Y_{i,t}$ is the total value added, $H_{i,t}$ is the input of appropriable knowledge, $L_{i,t}$ represent the labour inputs and $K_{i,t}$ is the Capital. A_i is the fixed scaling factor while $\alpha_i^{K;L,H}$ are parameters.

As we have announced in the introduction, we extend SGEM in order to account for external knowledge spillover enjoyable by all industry. The spillover effect[11] act as technical change by augmenting input technical coefficients:

$$CY_{i,t\_R\&D} = \overline{CY_{i\_R\&D}} \cdot \left[1+\zeta_t\right]$$

ζ depends on the spillover elasticity ξ and on $\kappa_{r,t}$ that is, the share of investment good imports from country *r:*

$$\zeta_t = \xi \cdot \sum_r \kappa_{r,t} \; ; \; \kappa_{r,t} = \frac{\sum_i PWM_i \cdot MInv_{i,t}}{\sum_i PQ_{i,t} \cdot Qinv_{i,t}}$$

In each industry, stocks of excludable knowledge capital accumulate according to the standard perpetual inventory formulation:

$$H_{i,t+1} = (1-\delta_H) \cdot H_t + R_{i,t}$$

[10] To some extent our approach is similar to that used by Goulder and Shneider (1999) and Sue Wing (2003) to model induced technical change for climate policy analysis. However in our case we consider the knowledge inputs as part of the value added.
[11] The way in which we are calculating external spillover is similar to those proposed by Diao et al (1999) and Coe and Helpman (1995).

where H_{t+1} is the capital stock for the next periods, $R_{i,t}$ is the investment in the actual period, $\delta_H \cdot H_{i,t}$ is the depreciation. The capital accumulation ratio given by the ratio between R and H is positively related with the rental rate of knowledge RH and negatively related with its user cost:

$$\frac{R_{i,t}}{\overline{\overline{H}}_{i,t}} = \beta_i^H \cdot \left[\frac{RH_{i,t}}{UCK_t}\right]^2;$$

The user cost of knowledge is the same as that of physical capital because both are related to the investment price index. The capital accumulation elasticity as in the case of physical capital is equal to two.

3. The SAM dataset

The accounting framework used in this work is the Social Accounting Matrix (SAM) for Sardinia, RSAM, related to the year 2001 (Garau and Lecca, 2005). The RSAM includes thirty sectors, the value added is shared between capital and labour. The institutional sectors are separated into Household, Enterprise and Government, which consume commodities and save, except for the Enterprise[12] which plays a role only in the distributional part of the SAM. Households are disaggregated into six groups by income and government is a consolidated sector, merging central and local government levels. The external institution is represented by “Rest of Italy” and “Rest of the World”. Also the SAM shows the depreciation and the government net debt. Depreciation are given by the intersection between the row of capital formation and the columns of productions sectors while the government debt is showed by the intersection between the row of Government and the column of Capital formation. To

[12] The enterprises do not consume. They earn factor incomes (their ownership of capital) and receive transfers from other institutions. The income is used for savings, pay tax and transfers to other institutions.

simplify the analysis the production sectors have been aggregated in thirteen sectors. The results of the aggregation have led to the SAM in table ?.

The SAM in Table 2 is represented in monetary values but the general equilibrium requires an analysis in relative price. Thus all the price and rents must be normalized to unity in the initial equilibrium. With prices normalized to one, the values in the SAM may be interpreted as a physical quantity in the industry and factor markets.

Once prices are normalized, the model can be calibrated specifying all the parameters of the model. Subsequently, we have to check if the model, that identifies the agents and their optimizing behaviour by algebraic equations, is able to reproduce the base values of the SAM in Table 2.

3.1. Knowledge in a SAM dataset

The lack of additional data on intangible components embodied in the SAM does not allow us to obtain a precise scheme which includes R&D services. The intangible components are conceptually embodied in the intermediate transaction matrix (**X**), in figure 1. Therefore, our main concern is to extract from **X** a matrix of knowledge flows **V,** whose sum of row are the value of industries intangible investments and whose sum of column are the value of inputs of intangible knowledge services used by industries for producing final goods and services. To estimate the element of **V** we use an aggregate version of the Yale Technology Matrix, YTM (Evenson et. al., 1989) and a vector *R* of regional R&D spending in each sector. The YTM, $\varpi_{i,j}$ has been set up by Evenson et al. (1989) during 1972-89 based on patent granted in Canada, therefore we are using the same industrial knowledge linkages[13] where the row represent the industries that produce knowledge while in the columns the industries

[13] The use of YTM has been widely used to account for knowledge linkage for different country, although some country specific elements can affect the knowledge flow. For Example Evenson and Putman (1993) have used the YTM for Italy, Basant (1993) for India and H. van Meijl has used it for France. Therefore, it is an usual assumption, albeit debatable.

receive technology. From table 3 taking, for example, inventions originating in the *Coke, Petroleum and Chemical* industry, the concordance indicates that these are used primarily in the same industry (39.5%) and in the *Rubber and Plastic* industry (4.9%).

The single elements, $v_{i,j}$ of the matrix **V** is equal to the R&D spending time knowledge flows $\varpi_{i,j}$, $v_{i,j} = \varpi_{i,j} \cdot R_i$. The column and the row sums lead to the value of knowledge services *H* and the value of knowledge investment *HR* respectively:

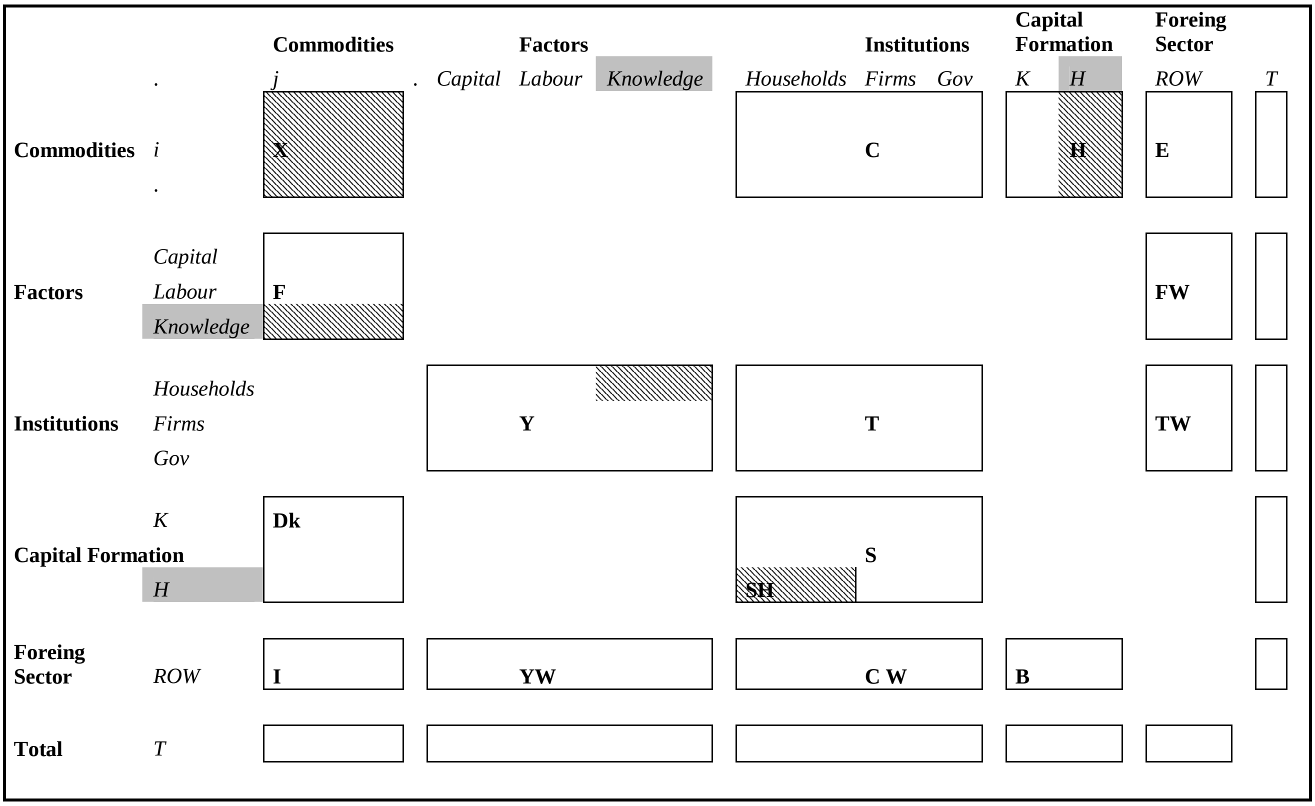
$$H_j = \sum_i \varpi_{i,j} \cdot R_j \; ; \qquad HR_i = \sum_j \varpi_{i,j} \cdot R_j$$

H_j and HR_i are allocated respectively in the shaded parts of the sub matrix **F** and in the capital formation vector. This way to proceed has generated an intermediate transaction matrix $\hat{X}$ that contains only physical commodity flow, $\hat{x}_{i,j} = x_{i,j} - v_{i,j}$ and a vector of intangible capital H_j and intangible investment HR_i. As intangible capital increase the household financial wealth (shaded part of the sub-matrix Y), the total household income does not equal its expenditure, for each income group. In order to rebalance the SAM we ascribe the resulting differences as saving (the Sh vector in figure 1)[14].

[14] We follow, to some extent, the Goulder and Shneider's procedure (also used by Ian Se Wing, 2003) for generating the necessary estimates. These authors unlike us estimate the elements of **V** assuming that the intermediate knowledge flows are completely concentrated in knowledge intensive industries.

Figure 1

Knowledge within the SAM



4. Policy analysis

In this section, with the help of tables and charts we explain the proportionate change in key economic variables resulting from SGEM+R&D simulation of 5% subsidies on rental rate of knowledge in all sectors. We compare the result obtained with and without external spillover effect (KPS and KWS, respectively; see table 1). We also consider a 5% subsidies on capital rental rate in all sectors (CAP, see table 1) in order to analyse the differences among traditional and the innovative regional policy. All simulations have been performed under regional bargaining labour market specification[15].

SGEM+R&D is run for 50 periods and for three specific static models: short, medium and long run (SR, MR and LR). The SR specification is characterized by supply side

[15] This labour market specification is widely used in regional CGE analysis. See for example, Harrigan et al. (1995).

constraints; basically labour, capital and knowledge are fixed. In the medium run, physical and intangible capital are fixed but we allow for migration adjustment. In the LR all supply side constraint are relaxed.

In table 1 we report the summary results for SR, MR and LR simulations, the chart 1, 2 and 3 refer to the knowledge accumulation, dynamic adjustment of labour market and unemployment respectively.

Starting with the analysis of KWS, we see that the effect of such policy on GRP and unemployment is very small, respectively -0.017 and 0.02 percentage change in respect to the base year values. This is actually due to the small initial endowment of knowledge capital which account only for 0.09% of the total value added. In the long run we achieve about 0.7% of GRP, improving competitiveness by an increase in export in all sector. These are not hopeful results if the aim of regional policy is to increase growth and employment. We can obtain better and encouraging results with capital instead of R&D subsidies. As we show in table 1, capital subsidy determines an unemployment reduction of 1.1% in respect to the benchmark equilibrium value, while the GRP increase of 2.55%. Under regional bargaining labour market regime the unemployment rate goes back to its initial long run equilibrium, consequently the real wage after tax adjust as well. This happens in all simulations that we have run.

We have seen, then, that the effect of capital subsidy are quite different from a simple subsidy on R&D. We have also understood how much the initial endowment matter for regional policy. However, what would be happen if R&D subsidy policy is accompanied by spillover effect? Are we able to achieve the growth rate obtained in the case of capital subsidies and to cover up the gap in the initial endowment?

The outcome shown in table 1 suggest that by taking into account for external spillover we improve quantitatively the results. We need to bearing in mind as well that the quantitative nature of these results depends crucially on the size of the spillover effect which in turn depend on the spillover elasticity .

In chart 1 we present the dynamic effect of R&D subsidy on the R&D accumulation adjustment. As the investment in R&D is determined by the relation between knowledge rental rate and the user cost of capital we see that when the knowledge rental rate exceed the user cost, the knowledge stock increases. This increase up to knowledge rental rate and user cost adjust to their long run equilibrium. As we show in chart 3 unemployment rate, CPI and real wage adjust going back to their benchmark equilibrium values.

By analysing the differences between capital subsidy and R&D subsidy with spillover effect we see that in SR, MR and LR the GRP increase in both simulations but under KPS is still below the change we have seen under CAP: it means that the spillover effect is not able to reach the same level of growth. In the SR under KPS the change in unemployment rate is bigger than the change in CAP; consequently the real wage increase more under KPS than under CAP. The higher level of wages determines a bigger negative effect on prices leading to a loss of competitiveness more marked in KPS in respect to CAP. Such a difference still remain in the MR but in the LR as the price adjust to their base values the export increase. At this time, in KPS export increase less than in CAP.

5. Conclusion

In this paper we have attempted to evaluate R&D subsidy and to compare the results with a simple subsidy on capital. The main results we have found can be summarize as follow. First of all, the small size of the initial knowledge endowment are an important obstacle for regional economic development. We have seen in fact, that by using the same accumulation property as physical capital the level of knowledge stock still remain weak to generate high level of growth.

Second, the capacity to generate a satisfactory level of growth in the long run depends crucially on the ability to attract knowledge spillover in the region (the share of investment imported good) and on the talent to exploit such spillover effect (spillover elasticity). In this paper we did not compare the result arising from different spillover elasticity. It is evident however that if the spillover elasticity increase the non-excludable knowledge enjoyable by all firm amplify the technical change making more attractive the region and the ability to take advantage of the external spillover.

Table 1

5% R&D and Capital subsidy (percentage change from base year value)

	CAP			KWS			KPS		
	SR	**MR**	**LR**	**SR**	**MR**	**LR**	**SR**	**MR**	**LR**
UNEMPLOYMNET RATE	-1.097	0.000	0.000	-0.017	0.000	0.000	-1.244	0.000	0.000
CONSUMER PRICE INDEX	0.665	0.110	-0.002	0.011	0.010	0.000	0.943	0.903	0.000
NOMINAL GROSS WAGE	0.776	0.110	-0.002	0.013	0.010	0.000	1.069	0.903	0.000
WAGE AFTER TAX	0.776	2.549	-0.002	0.013	0.010	0.000	1.069	0.903	0.000
REAL GROSS WAGE	0.110	0.000	0.000	0.002	0.000	0.000	0.125	0.000	0.000
REAL WAGE AFTER TAX	0.110	0.000	0.000	0.002	0.000	0.000	0.125	0.000	0.000
GROSS REGIONAL PRODUCT	2.549	2.710	4.138	0.020	0.023	0.069	1.208	1.392	2.686
OUTPUT PRICE									
AGR	0.323	0.270	0.000	0.009	0.008	0.000	1.117	1.060	0.000
ADV	-0.001	-0.010	0.000	0.005	0.005	0.000	0.301	0.294	0.000
OTH	-0.097	-0.144	0.000	0.011	0.010	0.000	0.603	0.558	0.000
ENE	0.205	0.200	0.000	-0.003	-0.003	0.000	1.704	1.700	0.000
SER	1.130	1.087	0.000	0.012	0.012	0.000	1.076	1.034	0.000
IMPORT									
AGR	-1.900	-1.706	1.055	0.014	0.017	0.044	0.153	0.391	1.439
ADV	-2.267	-1.966	1.299	0.007	0.012	0.094	-1.348	-0.997	1.704
OTH	-3.457	-3.246	1.027	0.025	0.029	0.031	-0.465	-0.195	1.341
ENE	-1.417	-1.158	1.392	-0.004	0.001	0.104	0.619	0.922	1.578
SER	0.372	0.562	1.688	0.020	0.023	0.082	0.250	0.471	1.579
EXPORT									
AGR	-2.267	-1.830	1.664	-0.033	-0.026	0.178	-5.874	-5.413	1.451
ADV	-1.755	-1.448	1.374	-0.014	-0.009	0.236	-2.763	-2.419	1.778
OTH	-2.276	-1.954	0.828	-0.016	-0.011	0.117	-2.511	-2.148	1.125
ENE	-0.829	-0.689	1.258	0.011	0.013	0.138	-5.929	-5.779	1.080
SER	-1.488	-1.228	2.996	-0.024	-0.020	0.120	-2.782	-2.495	2.030
COMMODITY OUTPUT									
AGR	-1.637	-1.300	1.659	-0.016	-0.010	0.133	-3.836	-3.472	1.406
ADV	-1.757	-1.467	1.372	-0.003	0.002	0.173	-2.079	-1.749	1.714
OTH	-2.465	-2.237	0.825	0.007	0.011	0.062	-1.246	-0.973	1.070
ENE	-0.423	-0.291	1.225	0.004	0.006	0.078	-1.677	-1.529	1.020
SER	0.749	0.930	2.992	0.003	0.006	0.083	-0.477	-0.275	1.992

Chart 1

Knowledge Accumulation

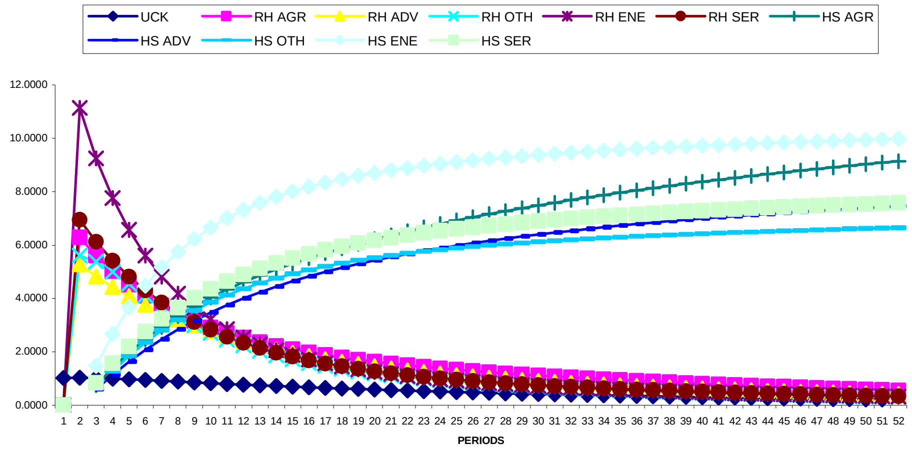


Chart 2

Labour Market adjustment

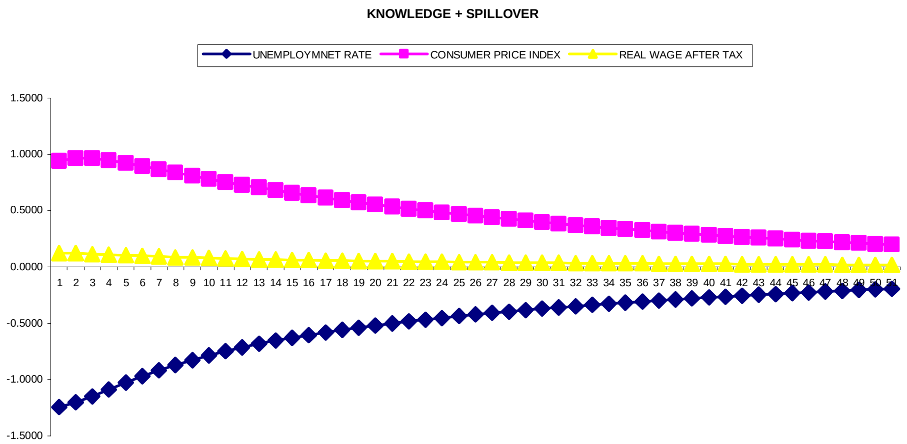
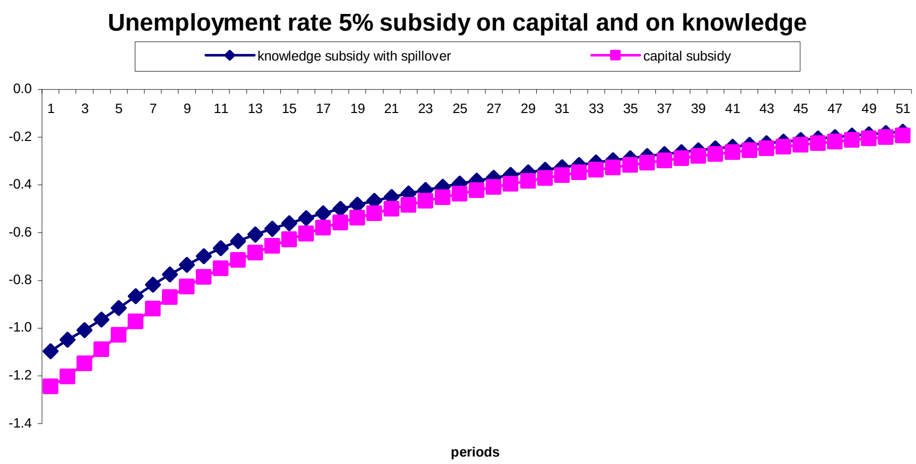


Chart 3

Unemployment rate



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Variables

X_i	Total output	RK_i	Rental rate of Capital
Y_i	Value added	RH_i	Rental rate of Knowledge
$V_{i,j}$	Intermediate input	UCK	User cost of Capital
LD_i	Labour demand	Piv	Investment Price index
KD_i	Capital demand	CPI	Consumer Price index
HD_i	Knowledge demand	W	Unified wage rate
LY	Labour Income	PQ_i	Commodity Price
KY	Capital Income	PR_i	Regional Price
HY	Knowledge Income	PY_i	Value added price
HY_h	Household income	$nmig$	net in migration
$HC_{i,h}$	Household Consumption	un	Unemployment rate
$HSAV_h$	Household Saving	GRP	Gross Regional Product
$ESAV$	Enterprise saving	PM_i	Import Price
$GSAV$	Government Saving	PE_i	Export Price
YNG_{dngi}	Domestic non Gov. income	HS_i	Knowledge Stock
$TRSNG_{dngi,dngip}$	Transfer between reg. non Gov. Inst.	KS_i	Physical Capital Stock
GY	Government Income	LS	Labour Supply
GC_i	Government Consumption	$Qinv_i$	Investment (origine)
IND_i	Capital Investment (Destination)	IDH_i	Knowledge Investment
CY_i	Value added Technical coefficient	IMT_i	Tax on import
IBT_i	Indirect Business Tax	M_i	Import
ζ	Spillover effect	E_i	Export

Parameters

$cv_{i,j}$	Input output coefficient	δ	Depreciation rate
α_i	Share Parameter in all functions	ir	Interest rate
A_i	Scale factor in all functions	DSHR	Income share between inst.
ρ_i	Elasticity Parameter in CES/CET	MTRF	Share transfer between inst
σ_i	Elasticity of substitution	Frish	Frisch parameter for LES
ε_i	Exchange rate (numéraire)	Un(N)	National unemployment rate
$btax_i$	business tax rate	ξ	Spillover elasticity
$mtax_i$	Import tax rate	$KP_{i,j}$	Invest. matrix origin-destination

Production

1. $$X_{i,t} = \min\left(\frac{Y_{i,t}}{a_i^{Zy}};\frac{V_{ij,t}}{a^{Zv}{}_{i,j}}\right)$$

2. $$V_{ij,t} = cv_{i,j} \cdot X_{j,t}$$

3. $$Y_{i,t} = CY_{i,t} \cdot X_{j,t}$$

4. $$Y_{i,t} = A_i \cdot K_{i,t}^{\alpha_k} \cdot L_{i,t}^{\alpha_L} \cdot H_{i,t}^{\alpha_H}$$

5. $$CY_{i,t\_R\&D} = \overline{CY_{i\_R\&D}} \cdot \left[1+\zeta_t\right]$$

6. $$\frac{L_{i,t}}{K_{i,t}} = \left[\left(\frac{(1-\alpha_i^y)}{\alpha_i^y}\right)\cdot\left(\frac{RK_{i,t}}{w_t}\right)\right]^{\frac{1}{1-\rho_i^y}}$$

7. $$RH_{i,t} = \frac{PY_{i,t}\cdot Y_{i,t} - (w_t \cdot L_{i,t} + RK_{i,t}\cdot KD_{i,t})}{K_{i,t}}$$

Household

8. $$HEXP_{h,t} = YNG_{h,t} - HSAV_{h,t} - HTAX_{h,t} - \sum_{DNGINS} TRSNG_{DNGINS,h,t}$$

9. $$HSAV_{h,t} = MPS_h \cdot YNG_{h,t}$$

10. $$HTAX_{h,t} = DTR_h \cdot [(IRPEF_t + SSCEE_t)\cdot LY_t]$$

11. $$HC_{i,h,t}\cdot PQ_{i,t} = CMIN_{i,h}\cdot PQ_{i,t} + \varphi_{i,h}\cdot(HEXP_{h,t} - \sum_j PQ_{j,t}\cdot CMIN_{j,h})$$

12. $$HC_{i,h,t} = A_H \cdot \left[\alpha_{i,h}^H \cdot HCR_{i,h,t}^{\rho_i^H} + (1-\alpha_{i,h}^H)\cdot HCM_{i,h,t}^{\rho_i^H}\right]^{\frac{1}{\rho_i^H}}$$

13. $$\frac{HCM_{i,h,t}}{HCR_{i,h,t}} = \left[\left(\frac{(1-\alpha_{i,h}^H)}{\alpha_{i,h}^H}\right)\cdot\left(\frac{PR_{i,t}}{PM_t}\right)\right]^{\frac{1}{1-\rho_i^H}}$$

Factor income and transfer

14. $$LY_t = \sum_i L_{i,t}\cdot W_t$$

15. $$KY_t = \sum_i K_{i,t}\cdot RK_{i,t}$$

16. $$GRP_t = LY_t + KY_t + \sum_i IBT_{i,t}$$

17. $$TRSNG_{DNGINS,DNGINSP,t} = MTRF_{DNGINS,DNGINSP}\cdot YNG_{DNGINSP,t}$$

18. $$YNG_{DNGINSP,t} = DSHR^{L}{}_{DNGINS} \cdot LY_t + DSHR^{K}{}_{DNGINS} \cdot KY_t + \sum_{DNGINSP} TRSNG_{DNGINS,DNGINSP,t} + TGOV_{DNGINS} + TROW_{DNGINSP} \cdot \varepsilon$$

19. $$ESAV_t = MPSE \cdot YNG_t^E$$

20. $$ETAX_t = DTREE \cdot YNG_t^E$$

Government

21. $$KY_t^G + \sum_i IBT_{i,t} + \sum_i IBM_{i,t} + \sum_h HTAX_{h,t} + ETAX_t + \overline{TGW} \cdot \varepsilon = \\ = \sum_i GC_{i,t} \cdot PQ_{i,t} + CPI_t \cdot \overline{TGOV} + \sum_i SUBSY_{i,t}$$

22. $$GC_{i,t} = \left(\frac{\mu_i}{PQ_{i,t}} \right) \cdot \left(GYN_t \right)$$

23. $$GC_{i,t} = A_G \cdot \left[\alpha_i^G \cdot GCR_{i,t}^{\rho_i^G} + (1-\alpha_i^G) \cdot GCM_{i,t}^{\rho_i^G} \right]^{\frac{1}{\rho_i^G}}$$

24. $$\frac{GCM_{i,t}}{GCR_{i,t}} = \left[\left(\frac{(1-\alpha_i^G)}{\alpha_i^G} \right) \cdot \left(\frac{PR_{i,t}}{PM_t} \right) \right]^{\frac{1}{1-\rho_i^G}}$$

Investment and physical and knowledge stock

25. $$\frac{Iv_{i,t}}{K_{i,t}} = \beta_i^I \cdot \left[\frac{RK_{i,t}}{UCK_t} \right]^2;$$

26. $$\frac{R_{i,t}}{\overline{H}_{i,t}} = \beta_i^H \cdot \left[\frac{RH_{i,t}}{UCK_t} \right]^2;$$

27. $$UCK_t = Piv_t \cdot (ir + \delta)$$

28. $$Piv_t = \frac{\sum_j PQ_{i,t} \cdot (Iv_{i,0} + R_{i,0})}{\sum_j PQ_{i,0} \cdot (Iv_{i,0} + R_{i,0})}$$

29. $$Qinv_{i,t} = \sum_j Iv_{j,t} \cdot KP_{i,j} + R_{i,t}$$

30. $$\overline{K}_{i,t+1} = (1-\delta_K) \cdot K_t + Iv_{i,t}$$

31. $$\overline{H}_{i,t+1} = (1-\delta_H) \cdot H_t + R_{i,t}$$

Population update

32. $$nmig_t = B - 0.08 \cdot \left(\frac{\ln(un_t)}{\ln(un_N)} \right) + 0.06 \cdot \left(\frac{\ln(rw_t)}{\ln(rw_N)} \right)$$

33. $$LS_t = LS_{t-1} \cdot (1 + nmig_{t-1})$$

Factor market equilibrium

34. $K_{i,t} = KS_{i,t}$

35. $LS_t = \sum_i L_{i,t}$

Foreign trade

36. $X_{i,t} = A_{X_{i,j}} \cdot \left[\alpha_i^X \cdot E_{i,t}^{\rho_i^X} + (1-\alpha_i^X) \cdot N_{i,t}^{\rho_i^X}\right]^{\frac{1}{\rho_i^X}}$

37. $\dfrac{R_{i,t}}{E_{i,t}} = \left[\left(\dfrac{(1-\alpha_i^X)}{\alpha_i^X}\right) \cdot \left(\dfrac{PE_{i,t}}{PR_t}\right)\right]^{\frac{1}{1-\rho_i^X}}$

38. $V_{ij,t} = A_{V_{i,j}} \cdot \left[\alpha_{i,j}^V \cdot VW_{ij,t}^{\rho_i^V} + (1-\alpha_{i,j}^V) \cdot VN_{ij,t}^{\rho_i^V}\right]^{\frac{1}{\rho_i^V}}$

39. $\dfrac{VR_{ji,t}}{VW_{ji,t}} = \left[\left(\dfrac{(1-\alpha_{i,j}^V)}{\alpha_{i,j}^V}\right) \cdot \left(\dfrac{PM_{i,t}}{PR_t}\right)\right]^{\frac{1}{1-\rho_i^V}}$

Prices

40. $PX_{i,t} = \left(\dfrac{PE_i \cdot E_{i,t} + PR_{i,t} \cdot R_{i,t}}{E_{i,t} + R_{i,t}}\right)$

41. $PQ_{i,t} = \left(\dfrac{PR_{i,t} \cdot R_{i,t} + PM_{i,t} \cdot M_{i,t}}{M_{i,t} + R_{i,t}}\right)$

42. $PM_{i,t} = \bar{\varepsilon} \cdot PWM_i \cdot (1 + mtax_i)$

43. $PE_{i,t} = \bar{\varepsilon} \cdot PWE_i \cdot (1 - TE_i)$

44. $PY_{i,t} = \dfrac{PX_{i,t} \cdot (1 - btax_i - sub_i - dep_i) - \sum_j PQ_{i,t} \cdot a_{i,j} - PM_i \cdot cmt_i}{a_{y,i}}$

45. $X_{i,t} + M_{i,t} = \sum_j V_{i,j} + HC_{i,t} + GC_{i,t} + Qinv_{i,t} + E_{i,t} + EXR_{i,t}$

Other equations

46. $M_{i,t} = \sum_j VM_{ij,t} + HCM_i + GCM_i$

47. $IBT_{i,t} = btax_i \cdot X_{i,t} \cdot PX_{i,t}$

48. $IMT_{i,t} = M_{i,t} \cdot mtax_i \cdot PM_i$

49. $SUBSY_{i,t} = sub_i \cdot X_{i,t} \cdot PX_{i,t}$

Table 2

The SAM for Sardinia extended to knowledge (2001; millions of Euro)

	AGR	ADV	OTH	ENE	SER	LAB	CAP	KWL	IBT	SOP	HG1	HG2	HG3	HG4	HG5	HG6	FIRMS	GOV	KFOR	HFOR	IIP	ROI	ROW	Total
AGR	175	8	480	1	69	-	-	-	-	-	54	67	56	97	27	43	0	0	1	0	0	797	6	1880
ADV	80	3023	1295	357	1446	-	-	-	-	-	119	221	196	332	142	170	0	2	1568	7	0	2393	1864	13215
OTH	129	193	1409	124	1362	-	-	-	-	-	471	677	630	1163	375	588	0	6	3585	7	0	1726	214	12657
ENE	33	287	121	266	453	-	-	-	-	-	105	122	118	178	59	83	0	5	0	0	0	40	0	1870
SER	167	1174	1216	128	8248	-	-	-	-	-	1216	1654	2036	3506	1347	1627	0	7380	953	4	0	751	672	32079
LAB	581	980	1520	217	10920	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14219
CAP	166	416	542	230	6204	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7558
KWL	0	12	7	0	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19
IBT	22	864	831	193	1313	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3223
SOP	-103	-327	-61	-21	-2113	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-2626
HG1	0	0	0	0	0	1143	866	2	0	0	14	0	0	0	0	0	116	756	0	-	0	0	10	2908
HG2	0	0	0	0	0	1633	1121	2	0	0	0	33	0	0	0	0	267	1737	0	-	0	0	24	4818
HG3	0	0	0	0	0	1816	897	2	0	0	0	0	14	0	0	0	117	759	0	-	0	0	11	3616
HG4	0	0	0	0	0	4974	1837	7	0	0	0	0	0	23	0	0	189	1232	0	-	0	0	17	8280
HG5	0	0	0	0	0	1750	547	2	0	0	0	0	0	0	7	0	58	379	0	-	0	0	5	2749
HG6	0	0	0	0	0	2902	721	4	0	0	0	0	0	0	0	6	52	336	0	-	0	0	5	4025
FIRMS	0	0	0	0	0	0	897	0	0	0	82	90	42	315	108	158	179	44	0	-	0	0	64	1979
GOV	0	0	0	0	0	0	672	0	3223	-2626	339	330	35	1232	414	571	885	2721	0	-	124	0	21	7942
KFOR	257	488	337	324	2677	0	0	0	0	0	499	1615	484	1401	259	762	54	-7554	0	-	0	3219	3184	8007
HFOR	0	0	0	0	0	0	0	0	0	0	2	2	2	7	2	4	0	0	0	0	0	0	0	19
IIP	4	49	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	124
ROI	204	2950	3235	33	1004	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	-	0	0	0	8926
ROW	166	3097	1655	18	495	0	0	0	0	0	7	7	3	26	9	13	62	139	400	-	0	0	0	6097
Total	1880	13215	12657	1870	32079	14219	7558	19	3223	-2626	2908	4818	3616	8280	2749	4025	1979	7942	8007	19	124	8926	6097	

Table 3

Aggregate version of the Yale Technology Matrix

	AGR	MIN	CPH	RAP	MET	MEE	ELE	OTH	TRA	ENE	CON	SER	OCS
AGR	0	0	0	0	0	0	0	0	0	0	0	0	0
MIN	0.005	0.375	0.016	0.003	0.087	0.057	0.088	0.024	0.038	0.018	0.216	0.055	0.021
CPH	0.036	0.006	0.395	0.042	0.016	0.006	0.017	0.045	0.004	0.010	0.004	0.014	0.407
RAP	0.020	0.008	0.049	0.324	0.020	0.039	0.046	0.104	0.107	0.003	0.137	0.078	0.064
MET	0.013	0.025	0.008	0.014	0.222	0.152	0.019	0.051	0.034	0.022	0.274	0.116	0.049
MEE	0.031	0.039	0.024	0.023	0.025	0.478	0.030	0.090	0.019	0.036	0.028	0.075	0.100
ELE	0.003	0.007	0.007	0.001	0.013	0.084	0.537	0.018	0.032	0.016	0.035	0.070	0.177
OTH	0.074	0.004	0.009	0.006	0.005	0.028	0.046	0.526	0.013	0.003	0.063	0.090	0.133
TRA	0.001	0.000	0.000	0.000	0.001	0.005	0.000	0.000	0.922	0.001	0.002	0.046	0.022
ENE	0.026	0.092	0.039	0.000	0.000	0.026	0.000	0.000	0.000	0.474	0.053	0.289	0.000
CON	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
OCS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: Evenson et al. 1989.