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Regional Economies, Innovation and Competitiveness in a System Dynamics Representation

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Abstract

The System Dynamics methodology is used in this article as unifying approach in order to show how a number of theories about the performance of territories developed in the past 20 years can integrate the one with the other; to demonstrate this, a model of local economy coherent with these schools is constructed and simulated.
According to these theories, the ability to produce and use knowledge is at the centre of regional competitiveness in the advanced world; the model and the paper illustrate the elements of the local economic system and how they have to work coherently towards the continuous process of innovation, needed to be successful.
The model also shows in a new framework how, due to the cumulative nature of this innovation process, it is possible to obtain equilibria with regional income differentiation, even in the presence of identical territories. When this is the case, structural policies, aiming to allow lagging regions to better innovate and/or imitate external knowledge, are appropriate.

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1 Introduction

During the 80s and 90s there has been a resurgence (Storper, 1995) of interest for issues related to space, which gained new importance. This new attention can be re-conducted to four observations: first there is the evidence that the Fordist method of production has not eliminated the possibility for different types of production spaces to prosper. In particular there are aggregates of small and medium enterprises (SMEs) that draw from the features of their localities to be competitive in the global markets. A second observation concerns multinationals, which are often re-locating the production processes but at the same time usually keeping the highest-level phases of production and invention in specific areas of the most advanced countries. Then, there is the agglomeration of activities of many sectors in specific places. Finally, there is the convergence debate in its regional aspect: when regressions evidence a conditional convergence rate of around 2% a year (as in Barro and Sala-i-Martin, 1991 and a large number of followers) we still perceive the world as patchwork of richer and poorer places, between nations but also within, with no plausible conjecture for an extensive levelling in the next future.

In mainstream economics, the observation of uneven development levels and the re-discovery of the Marshallian external economies led to the birth of a now well established group of theories known with the name of New Economic Geography (Ottaviano and Puga, 1998, Fujita, Krugman and Venables, 1999, Fujita and Thisse, 2002, Baldwin et al. 2003); in the con-

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tributions belonging to N.E.G., various mechanisms, often but not always using the Dixit-Stiglitz (1977) monopolistic competition framework, drive to the possibility of multiple equilibria for the location of economic activities in space.

Besides the more orthodox economics, a number of theories, which we will jointly hereafter indicate, for the sake of simplicity, as 'heterodox', grew with the purpose of explaining why some local systems are more effective than others; the use of the term heterodox is here justified by the fact that these contributions are resting more on case studies and descriptive models than on analytical derivations and mathematical models, and are usually more interested in the dynamics of adjustment than on the eventual equilibrium outcomes. In this article, even if we use a number of concepts which are shared by orthodox economics and draw conclusions which are compatible with it, we rely on the developments of a number of 'heterodox' theories, which are briefly outlined in section 2.

This paper uses the System Dynamics as an unifying approach for all these heterodox schools of thought and in this way makes more evident their complementarity. The choice of this methodology is due to the possibility to represent loops and feedbacks, things which are hard to deal with traditional economic modelling tools; this feature, when dealing with heterodox theories, is so valuable that it more than compensates the disadvantage of the lack of maximization in a minor number of behaviors. With the System Dynamics a complex representation of a local economic system can be drawn as illustrated in section 3 and a simulation model consistent with the representation then built and simulated.

This effort is similar to the one of the French Regulation theorists when they tried to describe a "mode de régulation" (Boyer, 1986, 1998a); in this case the model aims at identifying and describing the mechanics the local economic system in a case in which technological spillovers are very high within a territory and the competition between regions is based on innovation.

The model built encompasses most of the features of the 'heterodox' theories without encountering any contradiction among them but, instead, being supported by issues of more than one theory in each block, therefore corroborating the argument of complementarity (Cooke et al., 1998).

In addition to this, this article shows how the outcome of different levels of development among similar territories, is also possible in an heterodox framework. In fact, when dynamic increasing returns (see section 5) are allowed, and in particular when competition is based on technology, the competitive advantage tend to reproduce itself and multiple equilibria exist so that the regions persist at different levels of competitiveness and welfare.

Finally, with the introduction of stochastic behaviors, this approach is able to represent the stickiness of the development rankings without assuming any deterministic outcome.

Summary

A simulation model of a local production system, compatible with all the theories of section 2, is built with the System Dynamics approach (section 3) as extensively explained in section 4. The focus is on the capability (or non capability) of the system to engender the right virtuous circles, which allow it to continuously innovate and, in this way, to be competitive.

Examples of simulations are in section 5; these show, on the one side, the ample possibility of the model to implement and simulate the effects of a large number of regional policies and, on the other side, they reveal the advantage of structural policies on transfers of resources when the purpose is to generate long lasting development.

Section 6 demonstrates that, also with a model based on a heterodox framework, it is possible to get different levels of development in identical production spaces, something which is usual, but in the more orthodox new economic geography approach: a number of models identical to the one of section 4 may be appended the one besides the other and linked through technology. It is in this way illustrated that different but structurally equal regional systems may persist at different relative technological levels; consequently they are differently competitive and, therefore, at different welfare levels. All this is due to the cumulative nature of knowledge (Fratesi, 2003). This outcome is more similar to what we observe in the advanced world than agglomeration through the movement of people or firms.

Sections 7 and 8 concludes with the achievements and the limits of the model and the policy recommendation that can be drawn from this exercise.

2 The heterodox schools

Among the first to re-discover the study of the localized processes of production, the industrial districts school, which completely revisited the Marshallian contribution and applied it to the Italian case, where, beyond the duality between the richer and based on the large firm North West and the lagging South, the regions of North East and Centre (NEC) had developed a dynamic economic model made of specialized districts of SMEs able to compete worldwide. These districts were characterized by (Becattini, 1990) the presence in the same area of a community of people and a community of firms, the one and the other strictly linked because of the share of common values and a number of informal economic links.

Since the ability to compete of many districts, is not only based on this flexible system of production, but also on the capability to innovate and to share knowledge in the area, the research project on Innovative Milieux was born in the 80's with Philippe Aydalot. In the definition of Camagni (1991, p.3) the Innovative Milieu is "the set, or the complex network of mainly social relationship on a limited geographical area, often determining a specific external 'image' and a specific internal 'representation' and a sense of belonging, which enhance the local innovative capability through synergetic and collective learning processes". The concept has evident similarities with the industrial district one, but there is a different focus of innovation: in fact the milieu is able to guarantee a continuous process of innovation diffused among the firms of the milieu itself, so that it is dynamically efficient and not only statically.

The space, in the milieu, is active and the learning process is outside the single firm but inside the milieu, this owing to a spontaneous collective learning process due to the mobility of the workforce inside the milieu, to the cooperation of firms that allows them the transfer of tacit knowledge, to the fact that risks are taken collectively, reducing the dynamic risk for the individual and therefore allowing more propensity to innovate.

Without any connection with the above theories but with a focus on the economics of innovation, the book of Nelson and Winter "An Evolutionary Theory of Economic Change" (1982) gave birth to the theories called 'evolutionary'. In the words of Dosi and Nelson (1993, p.3) "The term 'Evolutionary' ought to be reserved for theories about dynamic time paths, that is ones which aim to explain how things change over time, or to explain why things are what they are in a manner that places weight on 'how they got there'". The concepts of technological paradigm, technological trajectory and technological regimes are helpful in explaining the processes and some "unexpected" outcomes as the lock-in. In the '90s a number of publications (Lundvall, 1992, Nelson, 1993, Edquist, 1997), not always explicitly evolutionary, extended the analysis to the "Systems of Innovations" that is to "all parts and aspects of the economic structure and institutional set up affecting learning as well as searching and exploring" (Lundvall, 1992, p.12, 'broad definition'). These investigations rapidly extended from the national to subnational contexts and are generally considered fully compatible with the new regional science (Cooke, Uranga and Extebarria, 1998) when intending to explain why different levels of regional development co-exist.

The 80's witnesses a renewed attention to the regional economies also outside Europe. In particular, from the observation of the Silicon Valley, a theory was born in California, thanks to the works of a number of authors;

among these Storper (1995) extended the analysis from the traded to the untraded interdependencies, that is from the observation of intense transactions between firms in the same space (with a mobile local workforce so that the increased flexibility allows a reduction of costs) to the observation of untraded relations, often conventional, neither fixed nor present in all times and all places but able, when present and positive, to enhance collective action and learning and, in this way, make the system more efficient.

The influence of institutions, rules and routines on competitiveness has been emphasised by many authors (e.g. Cooke and Morgan, 1998) in contributions that we could call "neo-institutionalist" and which are applied with success to a large number of cases of local production systems.

Finally, some authors focused on the mechanisms of diffusion of knowledge and of learning within and among territories, instead than with respect to organizations or people. The term "learning region" (Florida, 1995) has even been introduced to define these mechanisms.

3 The System Dynamics approach

The System Dynamics was born in the late 50s and early 60s, with Forrester, who published in 1961 his book "Industrial Dynamics". Then, the founder and other followers have improved the methodology and applied it in a large number of fields, from economics to society, to the environment; this last aspect was especially developed in the 70s with Dana Meadows and the "Club of Rome". Today the System Dynamics has a Society, a review (the System Dynamics Review), an annual world research conference and is mainly applied to business policy and strategy problems (Sterman, 2000), even if it is not rare to find contributions in other fields as economics (Smith and van Ackere, 2002).

The system dynamics approach has been synthesized by Wolstenholme (1990) as "observing and identifying problematic behavior of a system over time and creating a valid diagrammatic representation (or model) of the system capable of reproducing (by computer simulation) the existing system behaviour and of facilitating the design of improved system behaviour". The most interesting feature for the purpose of studying the mechanics of a local production system is the complexity allowed by this simulative approach, in particular the possibility to represent loops and feedbacks.

We chose to use the SD, instead of other simulative approaches, because it allows to separate two different phases of the modelling process: the first one is the design of the structure of the model according to the relationships which are considered most important by the modeller. The second one is the formalization of the equations according to the relationships that are specified in the first phase. This two step mechanism becomes very useful when the problems to be analyzed are very complex, as is the case of the mechanics of a local production system.

To go into further detail, the first step of the modelling process begins with the detection of which variables are the *stocks*; the stocks represent the inertia of the system and are persistent in time, i.e. maintain their value after each run of the simulation, apart from the modifications induced by the *flows*. There exist mono and bi-directional flows, depending on their value. Positive flows are called *inflows*, negative flows *outflows*, but it is also possible to have bi-directional flows. Since the whole model is a system of difference equations, stocks and flows are linked in this way:

$$stock_{t+1} = stock_t + \beta stock_t + \gamma$$

The flow is therefore the part of equation which changes the value of the stock in time ($\beta stock_t + \gamma$) and, when it always has the same sign, either is an inflow or an outflow, depending on the sign. In order to simplify the study of causal relationships, often the positive and negative component of the flows are represented separately with an inflow and an outflow. In the diagrams of the various system dynamics simulation softwares existing, the stocks are represented with boxes and the flows with thick arrows, sometimes featuring a sort of hydraulic tap.

All the rest of the variables are re-calculated at each run of simulation and then enter inside β and γ as appropriate and can either be parameters or functions of other variables, parameters stocks or flows. It must be remembered, however, that the only type of variables to have 'memory' are the stocks; this issue will be of paramount importance when, in section 4.6 we will deal with the resilience of the system. All the variables which are neither stocks nor flows are usually represented with circles. The thin arrows, in the diagrams, are used to indicate that a variable is used in the calculation of another. Finally, if a variable appears in the diagram as a number of boxes or of circles overlapping, it is to indicate a vectorial variable.

The second step is to enter the actual equations, which it is possible to do only according to the diagram previously designed, choosing the best mathematical form for each equation. In this phase, other parameters can be added and entered as simple numbers, but these parameters can never change in time and cannot be tracked in the study of the dynamics.

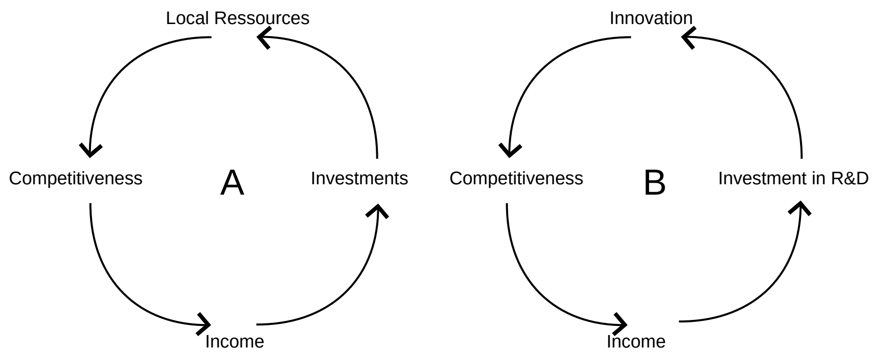

Figure 1: Two virtuous circles at the base of regional competitiveness.

4 Characteristics of the model

When writing the model, a number of general features were used throughout. Not all the possible relevant endogenous variables were included; this first because the focus is on the development of the two virtuous circles in which we will go more deeply below, and then to avoid the "verisimilitude trap" (Gilbert and Doran, 1994) that consists in adding too many details not because needed but simply because plausible. Because parsimony is a quality in a model, the number of exogenous variables has been limited too: the addition of parameters has decreasing returns in terms of realism, and, if if the model expands too much, it becomes too complicated and impossible to read.

However, the methodology of the System Dynamics allows to give the model the precious characteristic of the interrelation: each sector is linked with all the others (see Fig. 2), and this is important since the analysis of a territorial production and innovation system has to be holistic.

When entering the equations, we followed a few general procedures: first, most stock nodes have a dissipative mechanism, justified by the existence of deterioration and obsolescence, or by the normal turnover (through births and retirements) of the population; the Environment is the only node that instead has a conservative mechanism which is justified by the possibility of nature to regenerate itself, even if in the long run. The local technology node is not dissipative, but must confront itself with a continually growing external technology; for this reason it also needs to receive inflows at any period, to maintain competitiveness.

Throughout the model, the single equations have decreasing returns to scale, as it is more plausible to be in the real world, but the interaction of all equations give rise to dynamic increasing returns to scale so that the model has a central unstable equilibrium, in which it was calibrated and with all possible nodes equal to 1, and two stable, one upper and one lower, equilibria. This issue will be further developed in section 5.

Whenever possible the equations are in multiplicative form so that the elasticity of a variable with respect to another can be easily set up. Once decided that the returns are statically decreasing and dynamically increasing, the choice of the actual value is not relevant for a theoretical exercise. In fact, the elasticity parameters can be significantly changed without qualitatively altering the functioning of the model; moreover, the elasticities actually used in the simulations are deliberately intermediate, so that, even if it is possible for many researchers to disagree on them, it is not possible to collect general consensus on the direction of the possible modification.

4.1 Theoretical focus of the model

The competitiveness of a region, in the model as in the theories of reference, is the result of the good working of two virtuous mechanisms: first (Fig. 1-A) there is the more traditional circle of the accumulation of local resources (infrastructure, services, etc.), these have positive effect on competitiveness, and in this way a larger monetary output can be produced and part of this reinvested into the accumulation of local resources. The second circle (Fig. 1-B) is less traditional and is the one of innovation: by innovating, the system is able to continuously generate technology and in this way remains competitive in the markets (Porter, 1998); competitiveness generates value added which can be reinvested in learning and R&D, and hence allows to continue the innovative process.

To make the model able to cope with the 2 virtuous circles, it is made of four main blocks, corresponding to the 4 main components of a local production system (plus an additional block for the final indicator and control variables, Fig. 2): (1) the local government, which drains resources from the territory and can use these to provide infrastructure and services necessary to make the territory competitive. (2) The firms, the agent which, according to the heterodox theories are agents belonging to the territory instead of seeking the best location; they produce value added by using the inputs available, moreover they can reinvest part of the profits in innovation and human capital, and create networks; (3) The workers, also strictly linked to their territory; these are very important because the learning mechanisms are embedded in the people living in the places. (4) The innovation dynamics, comprising both the creation of new technology or the imitation and diffusion of existing one, that is fundamental for competitiveness in a region belonging

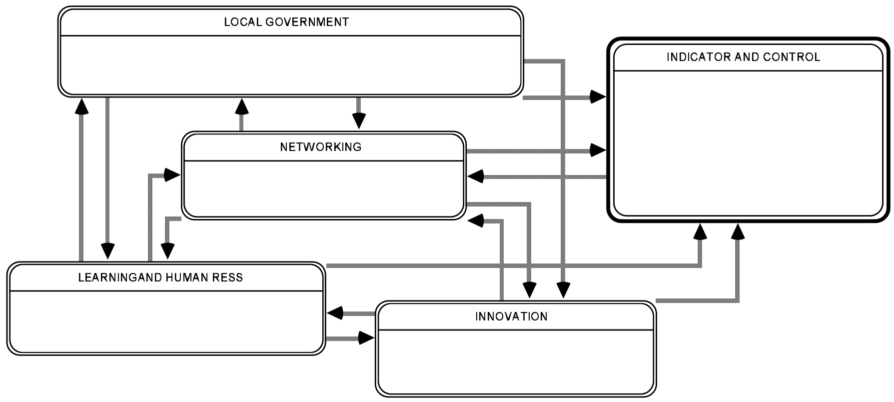

Figure 2: The four building blocks of the model.

to the advanced world. Each sector will in turn be illustrated in the following pages.

This schema has its predecessors in the work of Freeman (1987) who, in its analysis of Japan, indicated in the central government (since its analysis was at the state level), in the education system and of professional qualification, in the R&D strategies and in the relationships among firms and between these and the central government the key sectors to investigate.

More recently Bramanti (1999) designated as the four focal points of the emerging paradigm of the relational development and of territorial competition the innovative processes, the network relations, the learning mechanisms and the governance mechanisms.

4.2 Learning and human capital

The learning mechanisms are represented in two of the sectors of the model. As it is in the literature, which distinguishes between information and knowledge, with the first belonging to all which can be blueprinted and the second that, together with active understanding "[...] resides in the heads of individuals" (Simmie, 1997, p.7). The modelling of information is in the Innovation block, whereas knowledge is in the Learning one, which, with the use of a population dynamics, embodies the fact that "in each technology there are elements which cannot be written down in blueprint form or are difficult to verbalize and can therefore not be diffused easily" (Carlsson and Jacobson 1997).

Tacit knowledge (basically but not only know-how), is incorporated in the people, for this reason the learning and human capital sector is the one with the largest inertia.

In traditional economic growth models in the wave of Solow (1956) and also in more recent endogenous growth models (Lucas, 1988) labour is basically treated as a production factor, not differently from capital; its productivity is consequently determined by the technology and the amount of capital per head. In these analysis economic growth is also determined by the growth of population. On the contrary, in modern economies, the demographic pulse has arrested and global competition is not only on the cost of production factors but on that complex set of factors that stimulate and generate permanently the innovation (Maillat and Kebir, 1998).

In the model, therefore, there are three stocks of workers. The *unskilled*, workers without any particular ability who in the model constitute a residual class and are not a factor of competitiveness. The *skilled*, workers that, holding or not a formal qualification, have the skills needed for the job they are doing. The presence of a larger quota of skilled workers in the system has its positive effects on the costs of the firms (Wiig e Wood, 1997), but also on the easiness of imitation of external technologies. Beyond the assumption of no growth of population, there is the further assumption that both these groups of workers are not mobile outside the local system. This fits very well the European case where workers are rarely mobile internationally, nor inter-regionally.

Finally, there is a separate stock of workers, these mobile not only nationally but also internationally: the *R&D personnel*, called as in the Research and Development Annual Statistics of Eurostat. These constitute usually less than 2% of the total population and are not only mobile but also usually concentrated in the capital cities areas or in specific advanced regions. The factors that are assumed to affect the location of these are not only the level of instruction infrastructure in the region, but also the level of Research and University, the specific investments done by the firms to attract them and also the level of amenities in the territory, to which they also appear to be sensitive. The R&D personnel has an own retirement system and is modelled apart of the two other stocks of workers which, on the contrary, are strictly linked.

In fact the total number of skilled and unskilled workers is fixed and normalized to 1, with a retirement mechanism that in each period substitute workers with new entrants, whose skilled % is determined by the level of instruction in the system. During their working age the skilled workers can become inapt to their duties because they do not automatically follow the evolution of the modes of production and therefore become unskilled; this obsolescence mechanism can be contrasted by a training mechanism, which is either public, through instruction, or financed by the firms. All these mechanisms are represented in the model by appropriate flows.

4.3 Innovation

The dynamics of explicit knowledge is drawn in the Innovation block. This is the real engine of growth and competitiveness of all the system, where internal factors and interactions with the external environment determine the positioning of the region with respect to the technological frontier.

The importance of innovation for growth was known long ago, but before the 80s its mechanics was still rarely made explicit and seen rather as a "black box" (Aghion and Tirole, 1998) of which both the inputs and the outputs were known but not the inside functioning. The part of growth not explained by the accumulation of physical or human capital and therefore due to technological progress, constituted the so-called "residual" (Solow, 1957).

With the re-discovery of Shumpeter, the evolutionary theories and the focus on innovation in endogenous growth theory, starting with the Romer (1990) model, the innovative process has become central to any economic growth investigation. Moreover in most heterodox theories, as rapidly mentioned in the introduction, innovation is a local (in a national or regional regional scale) process. For this reason, in the model, coherently with the heterodox theories outlined in the introduction, technological knowledge is shared among all the actors of the territorial system, and the innovative process is the outcome of a collective effort of which all firms can benefit. This fits very well to the 'innovative milieu' case, where knowledge is in large part shared, but also fits the learning regions and all these cases of local systems of production (that are prevailing today in the developed world) in which technology is vital for competitiveness and the level of overall technology is at the basis of the performance of the system taken as a whole.

The definition of innovation used in this block is that of Edquist and Johnson (1997, p.42) according to whom "technological innovations are [...] regarded as the introduction into the economy of new knowledge or new combinations of existing knowledge" is best suitable. There is a large agreement (Teece, 1998) on the following characteristics of innovation, which were taken into account in the modelling process: uncertainty, so that the modelling has to involve stochastic variables; path dependency, due to the difficulty of escaping from technological trajectories; cumulative nature, because most of what is found is built on what already existed and moreover draws on tacit knowledge; irreversibility, not only because of the large investments that new technologies often need, but also because of market failure as the lock-in that makes difficult to change a standard with a superior one once it is widely diffused; the presence of interrelation between sub-systems, with other users and developers, necessary for the success of an innovation; a large degree of tacitness, i.e. knowledge impossible to codify and therefore difficult to transmit; a certain degree of appropriability, which has influence on the propensity of the economic agents to invest in innovation so that there is often a trade-off between static efficiency, which would claim for as less as possible appropriability to increase welfare and dynamic efficiency, which is due to the stimulus to innovate coming from the possibility to retain the profits.

What role for the territory in such process? In the words of Porter and Solvell (1998, p.446), it is "central to the question of how easily knowledge embedded in one local cluster can be imitated by outside actors. If diffusion is indeed rapid and can be accomplished at low cost, globalization forces would override earlier locally confined innovation. If, on the other hand, diffusion effect is sluggish, costly and involves long lead times, then localized innovation processes will remain essential". The model allows both cases to be simulated, since it is endowed with a intentional local innovation, a costly imitation and a free diffusion mechanisms, whose parameters can be adjusted according to the opinions of the user.

The case that is more interesting, however, is the one of sluggish diffusion that allows for the space an extended role in which (Bramanti and Maggioni, 1997) there is co-ordination of industrial decisions, the political choices on localization, creation and repartition of resources are taken, there is the formation and evolution of un-traded interdependencies and actors learn technologically and organisationally, technology and innovation are created generating a process of collective building of resources.

In building the model, the suggestions of Nelson and Rosenberg (1998) were followed wherever possible: first they suggest to consider technological investment in large part as product of investment intentionally decided and directed toward it; second, parsimony does not allow to exclude a role for public and not proprietary research as that in universities and public R&D institutions; third unavoidable point is the inclusion of uncertainty, different from risk because it is not calculable in advance. In addition to these features, innovation has been considered, for the reasons explained before, a process radically embedded into the territory.

To encompass all these issues the innovation block is built on the interaction of two stocks of knowledge (called local and world technology) with the influence of the stock of R&D institutions in the territory.

The mechanism best suitable to the evolution of world technology is an exponential one, in which at each simulation period the stock of world knowledge grows of a percentage p, so that the cumulative nature is taken into account. The parameter can be kept fixed in the simulations for simplicity reasons but is assumed to be stochastic so that technology can be submitted to unpredictable cycles and shocks. The local stock of knowledge also grows at each simulation period, but under the composite effect of three forces: a spontaneous and not costly diffusion and a costly imitation make external knowledge also available inside the territory; the third is the local capability to innovate that is built cumulatively on the local stock of knowledge again with a stochastic exponential parameter, but now this parameter depends on the endowments of the system itself. The confront of local and world knowledge then creates an index of "technology gap" which is at the basis of the competitiveness of the local system, since our focus is on relative competitiveness.

A number of exogenous parameters and endogenous stocks influence the three mechanisms: diffusion is influenced by the openness of the system and the presence of a skilled workforce; imitation by the previous two plus the spending of firms (in particular those of the ring sector that don't spend on own innovation); innovation is determined by the stock of Research and University institutions of the system, with this stock being affected by obsolescence as all infrastructure but more rapid and with input coming from public spending, firm investment and R&D personnel presence.

When the local system approaches the technological frontier, an increasing part of the knowledge produced locally can be thought to be completely new worldwide, so that its effect is to increase the stock of world knowledge as long as the local one. This mechanism adds realism and avoids the explosion of the system, but is also the reason because the model is suitable to explain relative growth (competitiveness) instead than absolute one. Moreover, this feature is helpful in a multi-regional framework as the one of section 6.

The model was calibrated in an equilibrium in which the summed effect of the three inflows of local knowledge produces locally the growth rate of the world knowledge: both stocks grow exponentially but the gap remains stable; in simulations, the system has the possibility to start virtuous circles and reduce the technological gap but also to start vicious circles and lose ground; this will be more extensively discussed in section 5.

4.4 Market and enterprises (networking)

At the core of any local production system there is a web of firms which represent a key factor for the development of the territory; if this web is not dynamic and diffused enough, the lack of entrepreneurship can be a constraint on local development that is hard to overcome, even with the most appropriate policy.

The block of the model which includes the market, the firms and their relations is called Networking. The assumption of the model, coherent with the reference theories, is that production is a local process for which the firms use extensively immaterial resources (like knowledge and skills) that are available at sub-national level. Since the model scale is the region, the market is instead mostly external and the demand for the firms of the region is more dependent on national and international factors than on internal, even if both effects are included in the model.

In the literature there exist many possible classifications for the firms (according to age, size, property, etc.) but the most interesting one, when dealing with the innovation capabilities of the local production systems of the advanced economies, is the one between *core* and *ring* firms. The classification used here is similar but not coinciding to the one used by Storper and Harrison (1991) in their taxonomy of the governance mechanisms in the local production systems, (all core, all ring no core, core-ring with lead firm, core ring with coordinating firm) and also similar to that between "leader" and "indotto" of Folloni and Maggioni (1994). For our purposes we define as "core" the firms that compete on the markets with their dynamic ability to propose innovative products; the firms of the "ring" are not only the furnishers of the first group but, more extensively, all the firms that renounce to compete with always new products and locate themselves in the manufacture of more mature products. The behaviour of the two groups of firms, as was already previewed when illustrating the innovation block, is differently modelled.

An assumption allows to represent the firms as continuous variables: since all the establishments of the different sectors are in general of different size, the total of the production capability is not made of a number of quantums of equal size, but can be treated as if it was the "quantity of firm" of the local system; to see it differently, it could be a proxy for the "entrepreneurship" available in the system, once it is assumed that this has a direct relation with the amount of entrepreneurial initiatives in the region.

The amount of core and ring firms can change, but not as much as other variables, and this is realistic because, coherently with the 'heterodox' theories, we consider the firms generated by the people living in the region and, therefore, it is not plausible that the production capability of a single place can grow more than a certain amount, with the exception of the productivity growth due to technological advancements, which is however modelled apart (section 4.3).

The cost function for the productive plants is also unique for each group; this does not need to assume that all firms face the same costs, only that the overall average effect can be modelled. And the costs of a plant are very dependent on the endowments of the region of location (Porter, 1994).

The variables that are thought to have influence on production costs are similar for the two groups but not coincident: both have the quantity of infrastructure per firm, the quota of the skilled workforce and the technology gap (with a lower parameter for the ring firms); the core firms' costs are also influenced by the presence of R&D personnel and, positively, of ring firms in the territory: some of them can be sub-contractors.

Firms are mobile in the model: the net effect of mobility depends on profits, the openness of the system, the interaction between the two groups of firms (so that the core firms take advantage from the presence of ring firms and vice versa) and the congestion/concurrence effects (so that both the core and the ring firms are hampered by the excessive number of firms of the same type, even if there exist indirect positive effects of co-localization), and on the reproducibility (a synthetic indicator of the endowments of the territorial system that will be discussed later on). The net mobility allows a number of interesting policy experiments as the one of Fig.8, which will be illustrated in section 5.

The market mechanism, not central in this paper, has for this reason been chosen as simple as possible: a demand function with constant elasticity of price, makes the tax rate influence the profits but not the gross mark-up and the prices of the firms. The demand is then affected by a number of variables and parameters: among the latter an important role is played by the openness of the system which has negative effect on the ring and reversed U effect for the core; the technology gap has an important effect (negative for both types of firms), since products with more technological content are either more demanded or less sensible to price than other less advanced (Campisi et al., 1997); the level of services provided by the public administration is important and positive because of their role in the model of increasing the capacity to penetrate the market (Onida et al., 1992); the concurrence between firms of the same type has negative effects for both types, but the quantity of core firms has indeed a positive effect on the quantities demanded to the ring (since a part of their supply is provided locally). An exogenous "market cycles" variable is added to allow the simulation of external shocks and cycles which may affect the local system.

The profits of the firms, calculated as multiplication between the difference of unitary prices and costs per the amount of firms, constitute the value added of the system that is the major output of the networking block. This value added is in part levied up by the public administration by the mean of taxes, in part constitute net profits (that are supposed to go to the local inhabitants and so are a welfare indicator), in part is reinvested by the firms in innovation and in human resources in the way that was described when analyzing the previous blocks.

The quotas of profits reinvested in each option, as long as the taxes, are important parameters that can be changed to simulate policies and reactions.

4.5 The role of local government

The fourth block of the model is called government because it includes all the variables that are controlled by the local government in addition to other organizational variables that are not relevant to the networking block.

The fundamental role for this block is the allocation of public spending among the different needs of the territory. The local government can get resources from taxes, borrowing and the central government and spends these resources through the vectorial variable "expenditure". According to Cooke, Uranga and Extebarria (1998) there are three main systems in the creation and use of public resources locally: the case of decentralized spending, in which the central government takes the decisions that are afterwards implemented by the local authorities for efficiency reasons; the possibility of autonomous spending, when the local government has the rights to decide how to allocate the resources which still come from the centre; the presence of taxation authority, when the local governments can also levy the amount they chose of taxes. The model can simulate all the three cases, but it is the third one that is more interesting since it allows to better distinguish the effects of the local policies and because it is the one supported by most local authorities today.

There is no absolute best scale for local economic policies, it depends on the efficient scale for decisions and implementations; however it is important to remark that the services that are more important for the firms are those available locally because of their accessibility.

Lundvall and Johnson (1994) assert that the market mechanisms works well enough in the allocation of existing knowledge, but that in the learning economy (as that of this model and of the advanced world now) the mechanisms of learning and of innovation are also fundamental so that the intervention of government is necessary according to five aspects: (a) it can provide the means of learning, i.e. increase the capability of learn and innovate through investment in education and training; (b) it can give incentives to learn, with a policy apt to encourage innovation; (c) it can increase the capability to learn, using policies apt to favor the organizational change inside the firms; (d) it can promote the access to the relevant knowledge not only with high-level academic institutions but stimulating the transfer of knowledge and the co-operation between these and the firms, especially those in the high tech; (e) it has also to create the premises that allow the agents to learn to forget, that is to abandon all these skills that are obsolete. In the evolutionary literature, therefore, we observe that support to innovation and creation of new resources are added to the traditional government task of optimal allocation (Belussi, 1997).

The government, in this model, performs all these roles: through the vectorial variable "expenditure" it provides local services to the firms, it invests in education and in R&D, it heals the environment and provides infrastructure. The last two roles, never mentioned earlier in the paper, deserve some description.

The model features a stock called Environment, which represents the level of physical amenities that are present in the system. From the standardized initial level it deteriorates under the burden of economic activity and of population; it can be improved with public expenditure (we assume for simplicity that no private agent would do so) and has a mechanism of "bio-persistence" that makes nature tend to return to its standard level in the long run.

Infrastructure, the third stock under direct government control, is the nucleus of the Social Overhead Capital, and its effects on development have been at the centre of an intense debate following the works of Aschauer (1988). Here infrastructure is indivisible, non-proprietary and generic, but not a public good strictu-sensu since the number of firms that use it matters and induces congestion. Infrastructure in the model is different from "services" because it needs some time after the investment before becoming operative (and this is easy to model in a system dynamics framework). Infrastructure, as all the features of the systems, is subject to wear off and obsolescence.

A number of exogenous parameters are included in the sector for simulation purposes, as the level of adequacy of the government (represented as the amount of expenditure that really goes to its duties), of corruption, of associationism. Moreover, there is the possibility for the local government to get extra-resources from the central government and to borrow at a settable interest rate; these features allow the simulation of a extensive number of policy experiments.

4.6 A suitable synthetic Indicator

The simple per capita value added, even if very important, appears insufficient by itself as final indicator of a complex system as this one. This because it is static, and in fact you can observe a high level of value added in a period simply because of a favorable temporary shock when the system overall is badly working and in this way losing ground with respect to competiting localities. In addition to this, the role of environment as an indicator of quality of life can not be neglected; for these two reasons the final synthetic

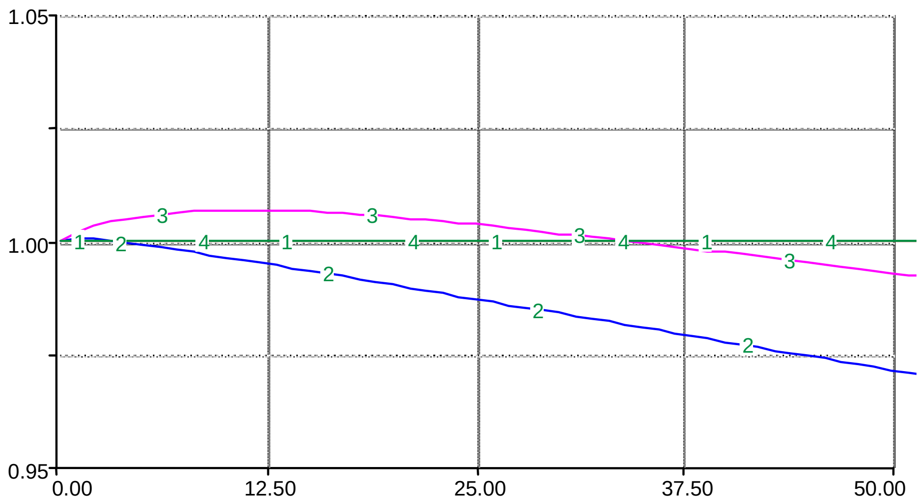

Figure 3: The outcome on the final indicator of 4 different policies. Notice that the outcome of policies (3) and (4) are not directly comparable with the Pareto criterium and some utility function has to be explicited.

indicator of this model is built ad-hoc to include static as well as dynamic factors, economic as well as environmental variables

Two of the parts of the synthetic indicator are undebatably the net profits per capita (that is the part of value added that goes into citizens' consumption) and the environment level; the third part has to be a dynamic indicator: this has to represent the "sustainable advantage" of the system, that is its ability to produce and reproduce in time the factors of economic performance, or, to use the words of Florida (1995, p.535), the ability of "re-creating, maintaining and sustaining the conditions to be world class performers through continuous improvement of technology, continuous development of human resources, the use of clean production technology, elimination of waste, and a commitment to continuous environmental improvement".

A solid productive fabric can be an insurance for the future since for example (McCann, 1995), a place with a solid fabric of infrastructure and skilled workers, due to the presence of a district of firms in a sector, can experience a crisis due to the crisis of the sector; but, after a few years, the same place could experience fast re-growth of its industrial activity due to the birth or arrival of firms in different sectors which benefit not of the externalities they create but of the skills of the workforce that had been created by the previous activity.

The variable that represents this long term sustainable advantage, has to take into account all the factors of the model that will affect its future performance and that are, at least to a certain extent, persistent over time: the technology gap, the quota of skilled workers, the quota of R&D personnel, the amount of infrastructure and of services, the amount of Research and University, that of instruction, plus the Environment itself, for the role it has in capturing the mobile R&D personnel. All these are put together in a multiplicative form of the type:

$$\prod F_i^{\alpha_i}$$

Where F_i are the factors and $\sum \alpha_i = 1$

The weights of the factors are empirically calculated by comparing the rapidity of the system to react to a change of them. The outcome is with a very good approximation the "resilience" of the system (Bramanti and Ratti, 1997) i.e. its capability to confront negative shocks and come back to virtuous growth paths.

Finally, the three basic components are put together in another multiplicative form as the one above to form the final indicator, but this time the exponents weights, still summing 1, are completely arbitrary: in fact they depend on the preferences, the aversion to risk and the temporal horizon of the decisor, hence on a political decision.

A first interesting conclusion that can be drawn from the model is, therefore, that no policy is the best in all cases. In fact, when running the simulations, different weights in the final indicator give different classifications of the group of policies that are compared. The advisor to the government should always try to reveal the preferences of the decision body, and then design the policy that is optimally fitted to these (Fig 3).

5 Simulations with the model

A model created coherently with the schema illustrated in section two (Fig. 4), must have at least one equilibrium to be studied in its dynamic properties. Two options were available: the first one was to run the model with plausible parameters and discover towards which equilibrium it would finally converge; this would be easier but would also bear the limit of not being able to understand how many stable equilibria exist and the impossibility to discover possible unstable equilibria; the second option was to decide a 'point' and 'calibrate' the dynamic system so that this point represent an equilibrium. All those which will hereafter be called 'points', for the sake of simplicity, are actually 13-dimensional vectors with the values corresponding to the 13 stock

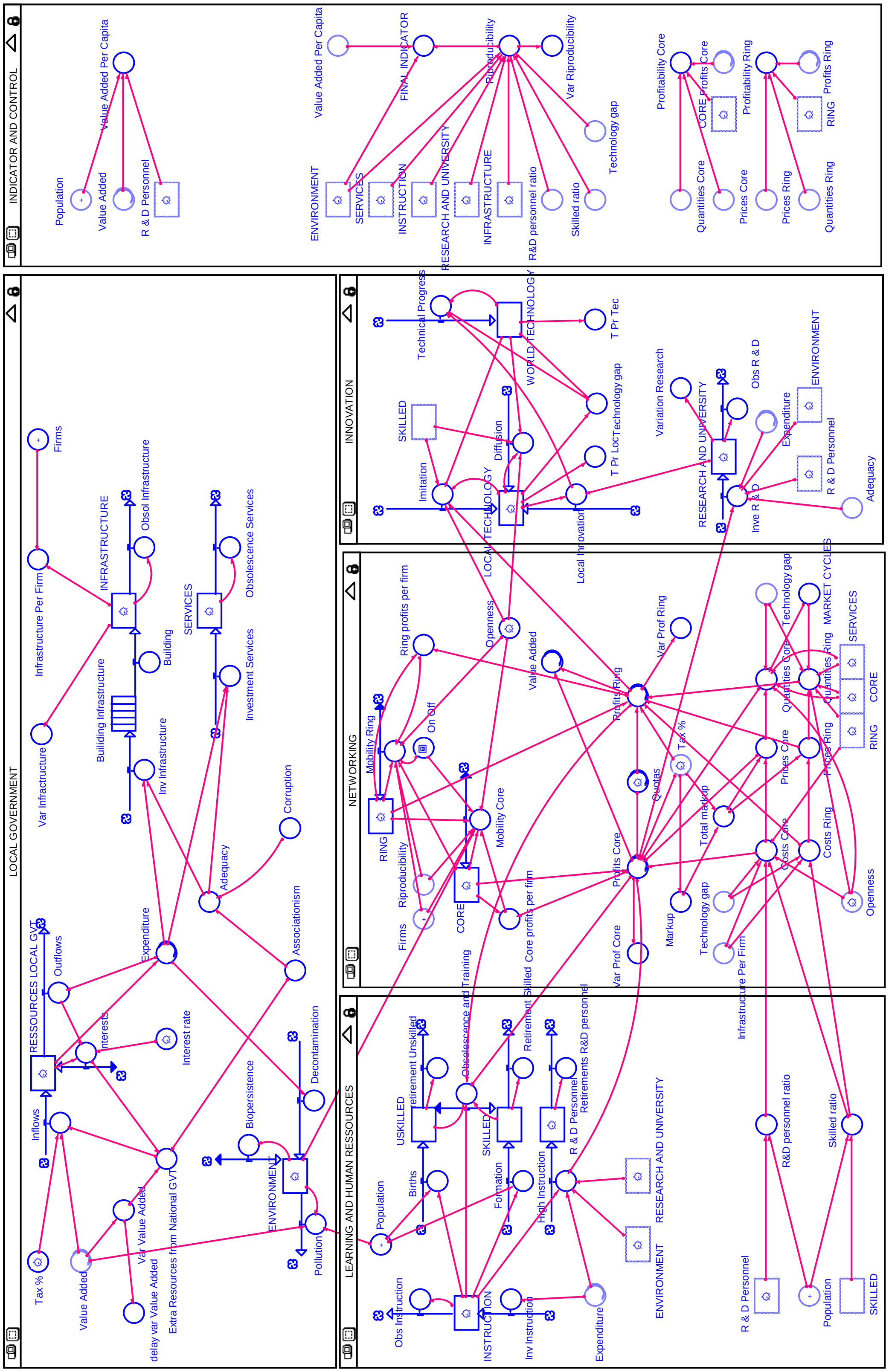

Figure 4: Diagrammatic representation of the model.
(Some variables appear more than once because their symbol is replicated elsewhere to shorten the arrows and improve readability.)

variables of the model. Among all the possibilities, for concrete advantages which will be evident below, the point chosen to represent the calibration equilibrium was the one with all stocks with the standardized value of 1, except the skilled and unskilled workers (whose sum is 1), the R&D personnel (which has the plausible value of 0.02, i.e. around 2% of the population), and local and world technologies (whose ratio is relevant instead of absolute values). To make of this 'central point' an equilibrium, all inflows and outflows have been multiplied by appropriate constants so that each stock would persist at the same level of 1 in absence of shocks (again with the exception of technologies, which would grow forever at the same pace, without altering the gap).

The first advantage of this procedure consists in the fact that one could easily and immediately confront any value of the system with the benchmark of 1. The second advantage is that, given the multiplicative form of most equations, a modification of the exponents (which represent the elasticities) does not move the calibration equilibrium but only affect the dynamics[1].

The issue of stability of this equilibrium has to be discussed in the light of the assumptions on returns of section 4.

Any single equation of the model has decreasing returns (i.e. the sum of all the exponents is less than 1) by assumption; this because we don't believe that a single mechanism can be at the basis of competitiveness and, therefore, that all the advantages gained in just one aspect fade out during the development process. At the same time, if the coefficients of the single equations, even if remaining below 1 in any single equation lie above a certain level, the interaction between the various equations generates a dynamic equation with increasing returns. On the contrary, if the coefficients are lower, the dynamic equation has decreasing returns. Unfortunately, due to the complexity of the model, it is not possible to explicit the reduced form of the reduced form equation, however, its dynamics can be studied with a simulative procedure. We will call the first case "dynamic increasing returns to scale", as in Boyer (1988b), since there is a mechanism in which the positive growth of a variable induces positive growth on the others.

If the dynamic returns are decreasing, the model has just 1 equilibrium, the central point in which it is calibrated. If the dynamic returns are increasing, the calibration standardized equilibrium is unstable and an upper and one lover equilibria exist. From a theoretical point of view, the first case is uninteresting for two reasons: first because the model would in be unable

[1] In addition to this, it has to be remarked that, since all variables are standardized, a multiplication of the inflows and outflows of a stock by the same value only changes the speed of adjustment.

to represent the multiplicity of development levels which is observed in reality and, second, because the heterodox theories evidence that the virtuous interaction of all the mechanisms in a territory can give rise to trajectories which make sustainable in time the advantage on competitors. For these two reasons, the second case have been chosen for the model.

Then it can be added that the two stable equilibria are far enough to allow a large number of policy simulations in the interval between them. For this reason, a small shock can make the system in the central unstable equilibrium start its slow path towards the upper or lower equilibrium, but the most interesting feature is that structural changes, as appropriate structural policies, can more effectively put the system on the right growth path and also move higher and lower equilibria.

The change of the obsolescence parameters (section 4), when combined to the corresponding change in the inflows, is also able to change the speed of adjustment without changing the central unstable equilibrium.

The simulations confirm that, when an economy is in a stable growth path or in a declining path (both considered as relative concepts), a shock can not usually change its long run trajectory and its final equilibrium status (Fig.5), but structural policies (as a better balancing of government spending or a more intensive investment by the firms) can change the path. A permanent shock, affecting for example the demand, can more often than a temporary one change the trajectory of the system from positive to negative, but its magnitude has to be considerable. The introduction of cycles, on the other hand, does not affect the long run path of the system. (Fig.6).

When the model is simulated stochastically, with uncertainty in the growth of technology (but with the stochastic parameters depending on the values of the relevant features of the local economy, Fig.7), the growth paths generated by the model are very differentiated; this is a feature that we usually find in real economies, in which it is not always clear if the system is performing some way because of the internal processes of because of the external occurrences, since the external situation can hide the internal capabilities.

The model can be used to simulate the effect of a large number of possible development policies, whose effects can be much more easily observed when the simulation is run non stochastically, in fact, as already mentioned, it is not easy to disentangle the effect of the shock and that of the policy. The following policy experiments, therefore, can be viewed as the results expected on average by a policy maker, before knowing the actual values of the stochastic factors.

A first experiment concerns the installation of a large industrial plant, built with national resources. This is an expensive and top down policy; in fact the model shows that in the short run there is a crowding out effect on

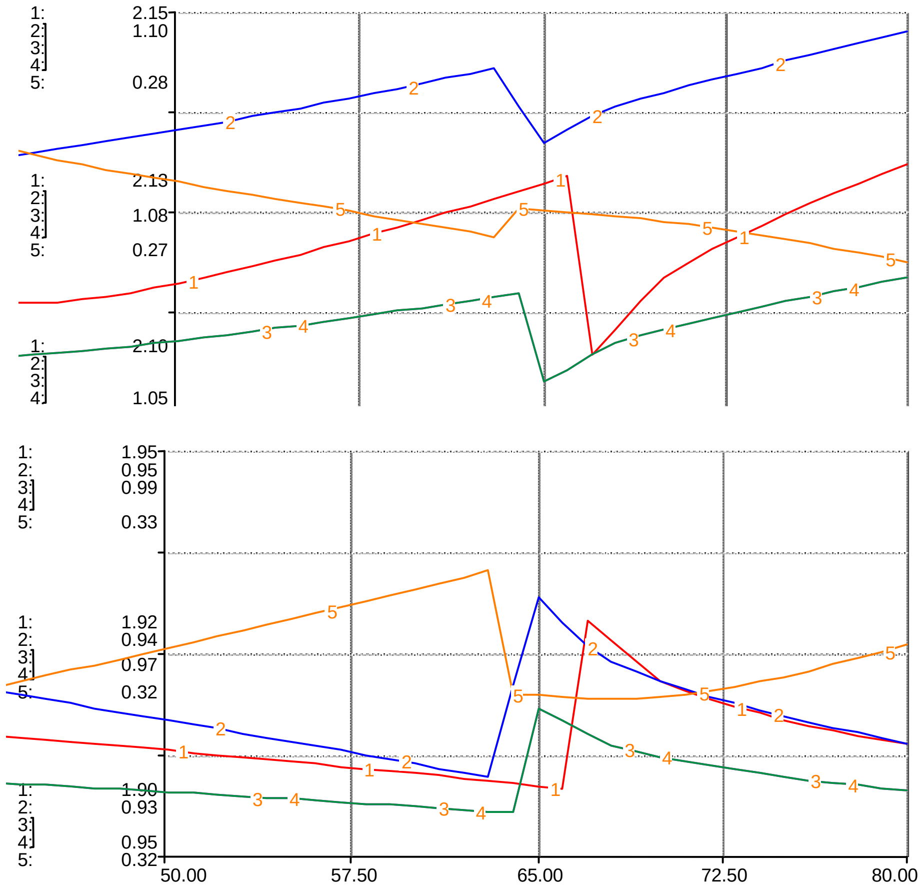

Figure 5: The effect of a temporary shock on four stock variables of a growing (top) and a declining (bottom) economy: infrastructure (1); research and university (2); services (3); instruction (4); technology gap (5).

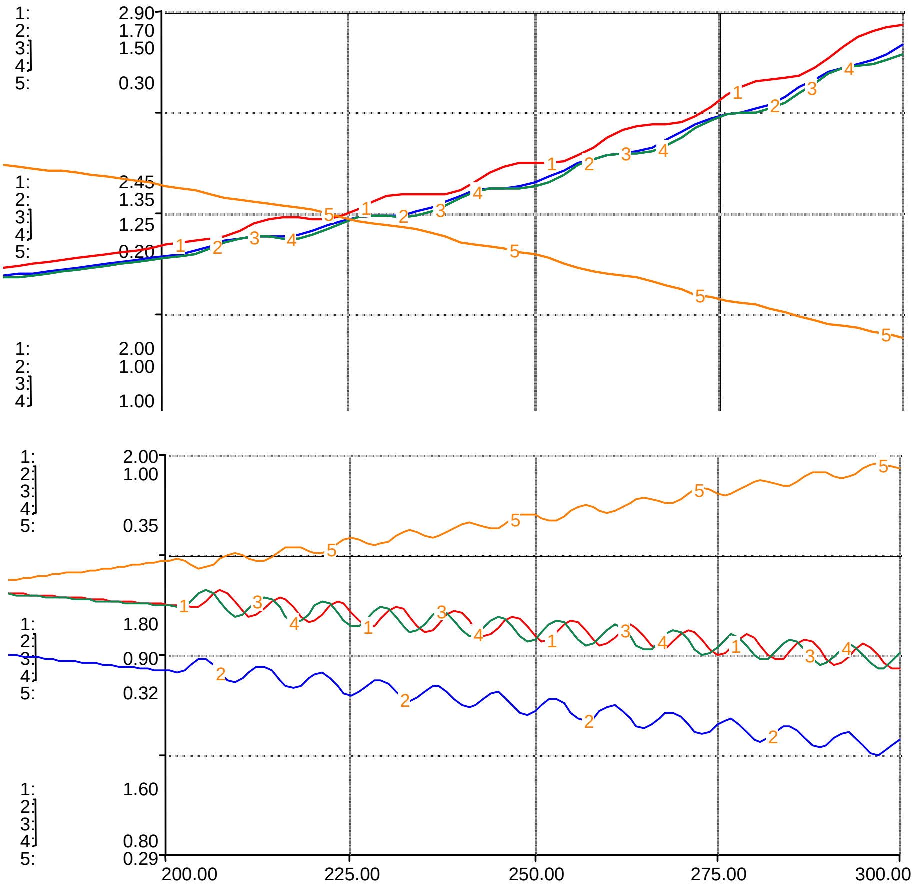

Figure 6: The effect of the cycle on four stock variables of a growing (top) and a declining (bottom) economy: infrastructure (1); research and university (2); services (3); instruction (4); technology gap (5).

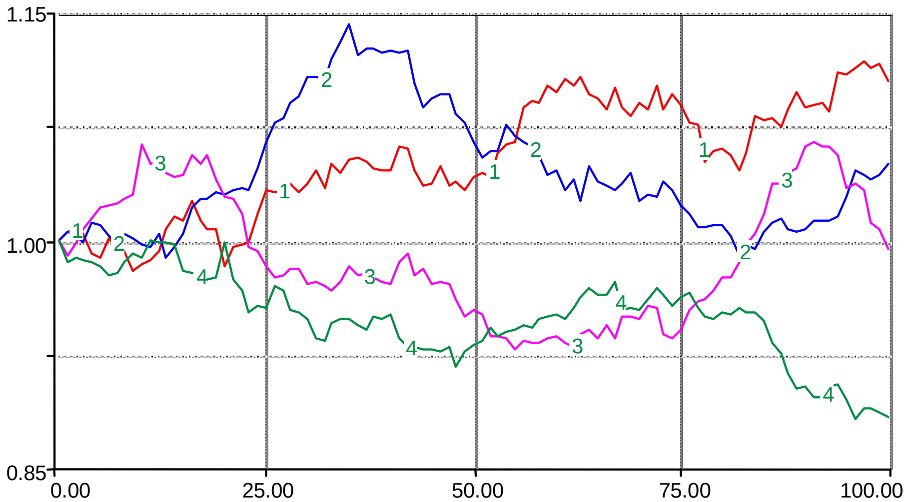

Figure 7: Four different development patterns of economies submitted to random shocks, as synthesized by their final indicators (1 to 4).

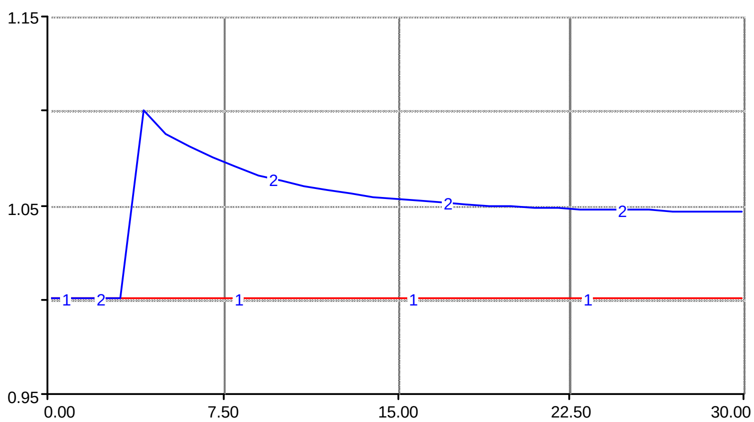

Figure 8: Effect of the introduction of an exhogenously financed large plant (2) with respect to the benchmark path (1).

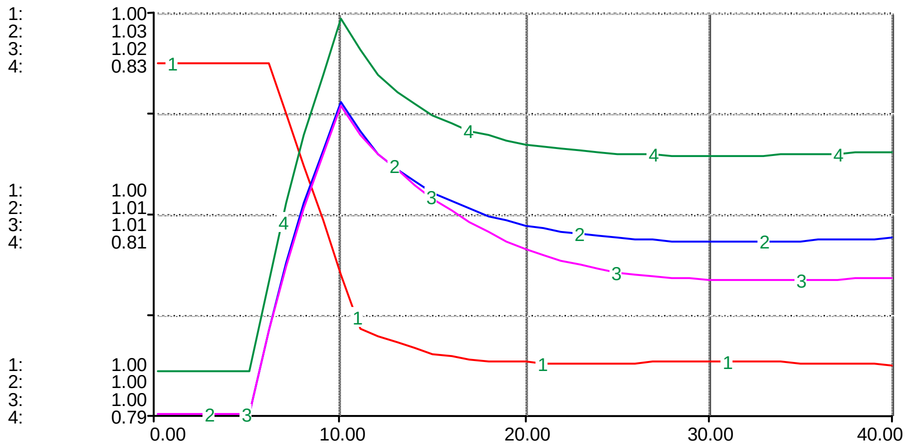

Figure 9: Effect of the introduction of an exogenously financed large plant on four stock variables of an economy: environment (1); final indicator (2); reproducibility (3); value added per capita (4).

local firms, even if the total long run effect is positive, as already noticed in Fig.8.

Another possible top-down policy experiment is an increase in infrastructure exogenously financed. This increase has positive effects, but the short run effects are larger than than the long run ones when the local government has to maintain the new built infrastructure using only local taxes. In fact the model and the reference theories assume static decreasing returns to scale and it is reasonable that doubling infrastructure can not by itself double the tax revenues (Fig.9).

The effect of state aid on the regional economy can also be simulated: for instance a general increase of resources for the local government (e.g. through state aid); this can be the start of a positive growth path, but need to be considerable and last for some time to be really effective (Fig.10).

The model also allows to simulate the effect of the changes of the exogenous parameters; for example an increase in the efficiency of the use of public funds (through adequacy, for example), brings important positive effects (Fig.11). The model does not say how such an increase can be obtained, but, if the central government, or some supra-national body as the EU commission, achieve to improve the abilities of the local governments, the results can be important and lasting.

Coming to bottom-up policies, another way in which the local government becomes more effective, is by better allocating its funds among the different axes; this is allowed and simulated in the model with a modification of the

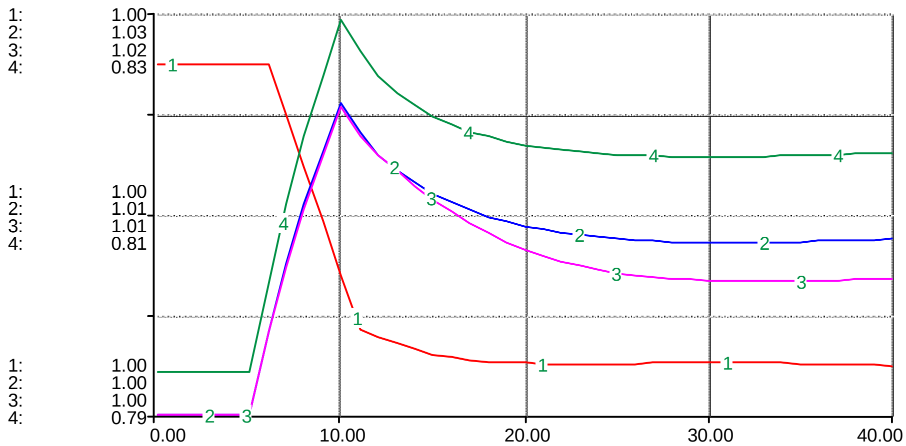

Figure 10: Effect on a stagnating regional economy of the gift of an amount of exogenous financial resources without reimbursement. The four stock variables represented are: environment (1); final indicator (2); reproducibility (3); value added per capita (4).

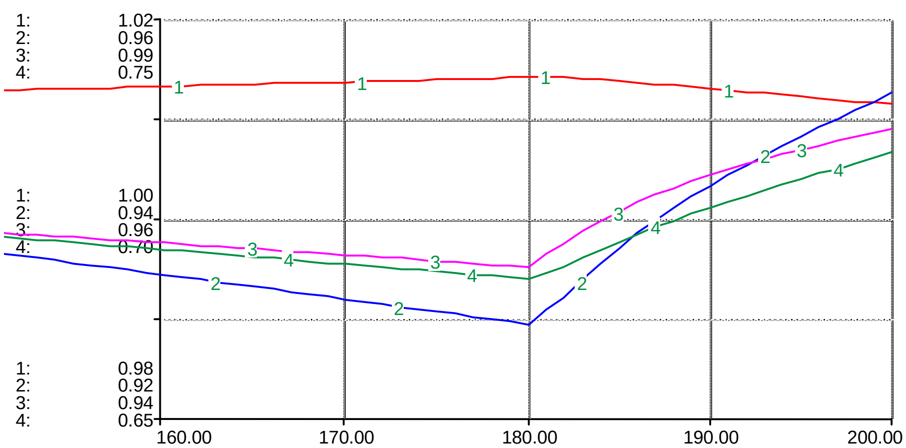

Figure 11: Effect of a permanent improvement in government efficiency (through the variable "adequacy") on four stock variables of a declining economy: environment (1); final indicator (2); reproducibility (3); value added per capita (4). The declining pattern can even be reversed.

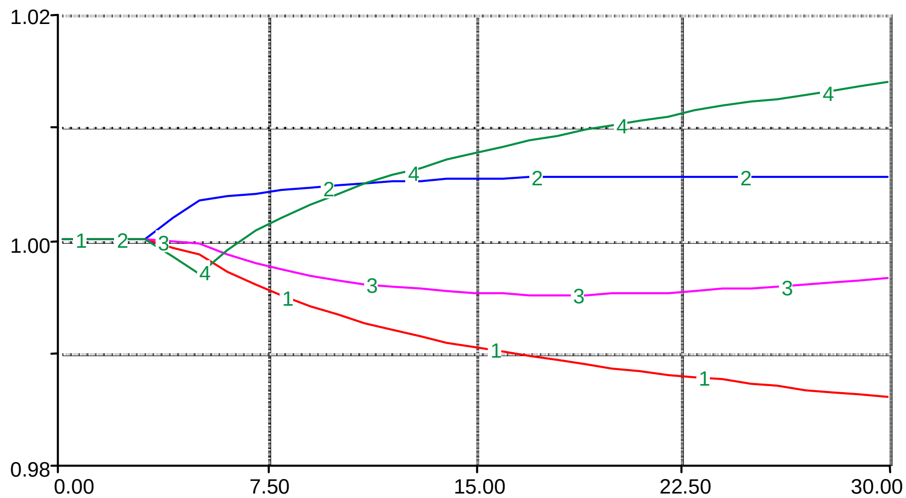

Figure 12: Four different patterns (represented with the variable "final indicator") of economies which change their public policy expenditure distribution. The patterns can be very different.

policy mix through the change of the expenditure quotas (Fig.12). The effect can obviously be positive or negative, depending on if the new mix is better balanced for the present situation or not.

A modification of the tax rate can also be introduced in the model: in general this has short run negative effects on the welfare of the population (since the value added which goes into consumption is part of the final indicator) but, if well spent, can lead to higher growth in the long run.

To complete the list of development policies which are illustrated, the implementation of local government borrowing, which has positive effects if done in a period in which the returns of public investment are superior to the interest rate (which is exogenous to a local production space) (fig.13) and the implementation of anti-cyclical policies through public deficits in recessions and surpluses in expansion (Fig.14).

The model also allows to simulate the effects of variations in the behaviour of the actors of the system: for example, if the firm decide to re-invest a larger quota of their profits, this diminishes the income of citizens (the shareholders) in the short run, but usually pays off in the longer run, especially if the local production system is not yet in a definite equilibrium position with respect to the others (Fig.15).

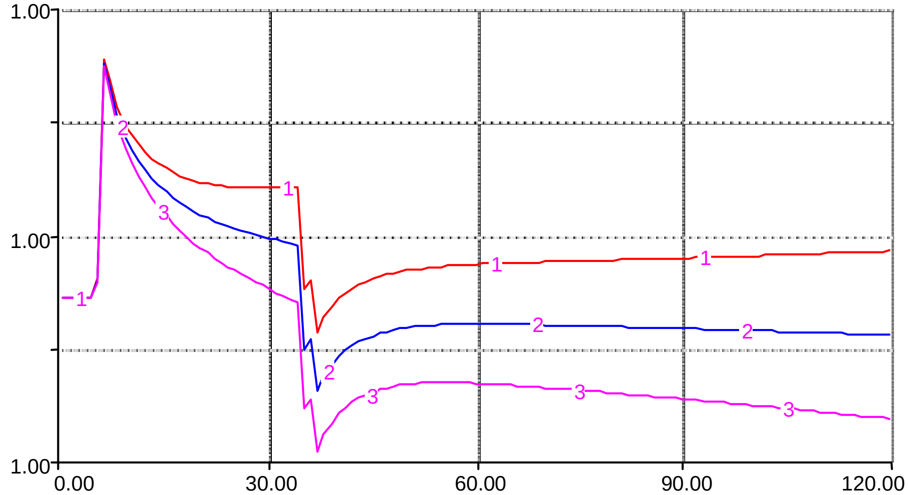

Figure 13: Four different patterns (represented with the variable "final indicator") of economies in which the government borrows to invest. The different patterns of this figure depend on the interest rate, but the timing and the structure of expenditure are also important.

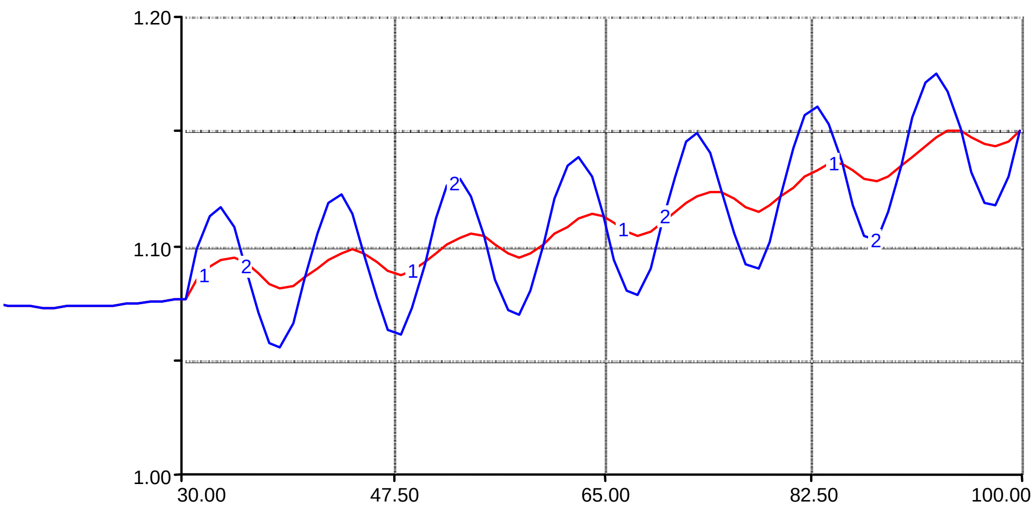

Figure 14: With the implementation of anti-cyclical policies and perfect foresight, the development pattern of a region can become less exposed to the cycles (2 vs 1).

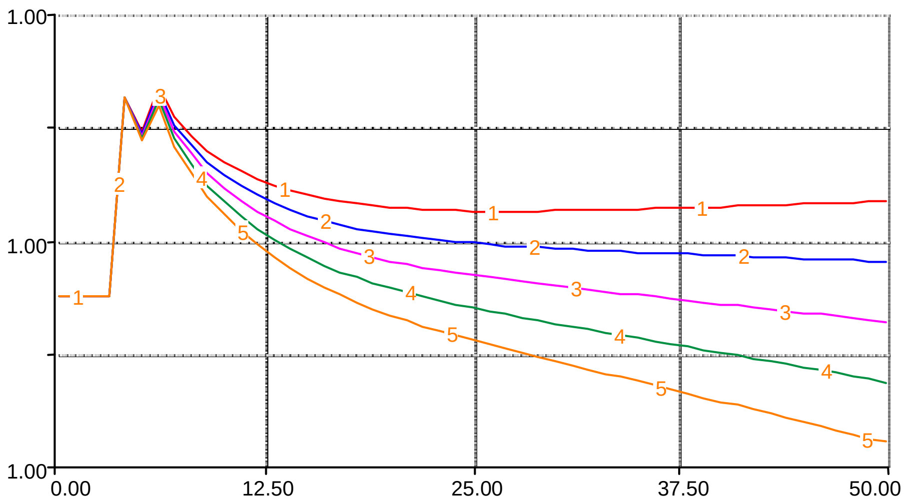

Figure 15: Five different patterns (represented with the variable "final indicator") of economies in which the firms decide to reinvest an additional quota of income, instead of distributing it to the shareholders (the inhabitants of the region).

6 Economic disparities

The issue of why and when economic activity concentrates in space is diffused across disciplines: in particular it is at the centre of regional economics and regional science, but mainstream economics and business science are, especially after the 1980's (Storper, 1995) experiencing a renewed interest for the question.

The most diffused theoretical reason for the concentration of economic activity lies in some sort of increasing returns to scale. These can be internal to the firm (and they will bend to sectorial concentration), internal to the sector (the localization economies) or external to the sector but belonging to some local economic space (Hoover, 1937). The latter case is known as urbanization economies, which arise for example because of the possibility for firms which cluster to take advantage of specialized services, of infrastructure which has a minimum scale for provision, of a skilled workforce in the labour market or of strict interaction with other firms that makes them more efficient.

In the real world, however, comparative advantage still plays an important role, since "geographic concentration by itself does not imply the existence of spillovers" (Ellison and Glaeser, 1997, p.891). But in a theoretical contribution like this one, the explanation of different levels of development through natural comparative advantage is not appealing. In fact, if we give importance to the natural advantage of places, the model loses its generality and explicative power.

For this reason, the most interesting aspect of the new economic geography models is that they allow regions initially equally endowed to finally show agglomeration and/or different levels of welfare. This usually happens through cumulative effects caused by the fact that the firms (through the labour market, the variety of inputs, their interactions or other mechanisms) benefit of the presence of other firms and, through the mobility of some factors towards the richest region, the agglomeration is reinforced.

Since, probably, the most important point of advantage for the regions of advanced economies remains the presence of the relevant knowledge and the capability to renew it in time through the process of innovation (Ratti et al. 1997), it is more interesting to see if different levels of income can take place without assuming different local production systems and without any movement of people or capital.

If, in fact, we assume that knowledge bears some of the characteristics of a local public good (Grossman and Helpman, 1991), then technological competition between local spaces of production can give as outcome the attainment of different levels of economic development, and this despite of the fact that the internal functioning of these can also be the same. The cumulativeness of innovative activity, in addition to the increasing returns to scale engendered by the interaction of the various mechanisms of a local system, can in fact give a region a technological advantage that its competitors are not able to catch up. This despite the spontaneous diffusion of knowledge and the imitation processes, which may not be able to fill the gap.

The model of this article is structurally designed to be able to simply produce and simulate such a behaviour: all is needed is to place a number of identical models the one besides the other and then to link them through technology.

In fact, since all the factors are by assumption regional-specific and, as in occidental Europe, the workers are not mobile, the interaction between the various models (that is between the various production systems) will occur through technology. To accomplish this, the world level of technology is endogenized and becomes composed of all the technical knowledge available in all the production spaces of the model.

We assume, as we also did in section 1, that any knowledge present in a place will be part of the world knowledge, but at the same time, we allow the possibility to have some pieces of knowledge shared by two or more regions. If there exist n regions, we represent with n sets the technologies embodied in all the agents of each given territories; coherently with what

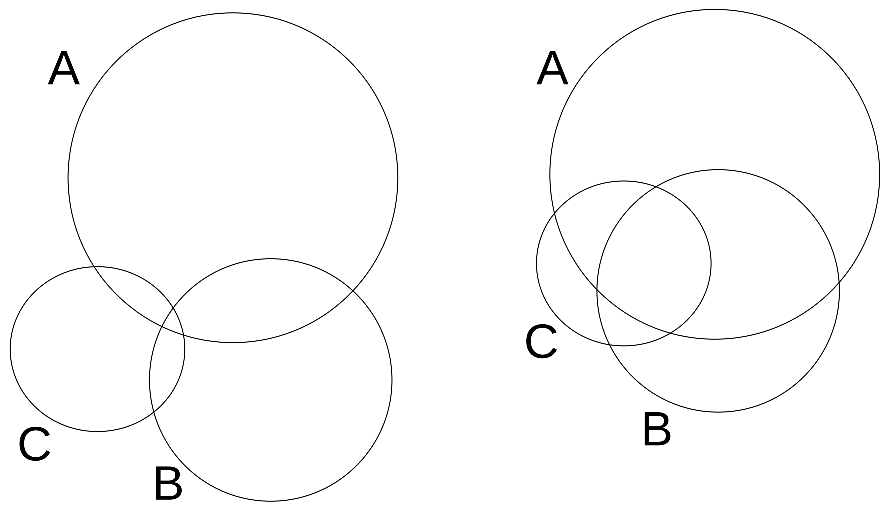

Figure 16: Three regional sets of technology with lower and higher overlapping of technologies.

stated above, we define the world technology WT as the union of the n local sets of technology LT_i; at the same time we also make the simplifying assumptions that first no intersection of two or more sets is empty and, second, that no set is included in the union of all the others. With these hypotheses it is possible to represent WT as in Fig. 16 depending on the high/low degree of subsitutability/compementarity.

The world technology is in both cases the union of the sets, no intersection is empty and the technology gap of, for example, region A, is given by:

$$\frac{\bigcup_i^n LT_i - LT_A}{\bigcup_i^n LT_i}$$

.

A simple c.e.s. type function allows to calculate the world level of technology coherently with these hypotheses:

$$WT = (\sum_i LT_i^{\delta})^{\frac{1}{\delta}}$$

Where WT is the word technology and LT_i are the local ones. The parameter δ depends on the degree of overlapping between the regional knowledge bases; this is for simplicity supposed equal among the regions and has

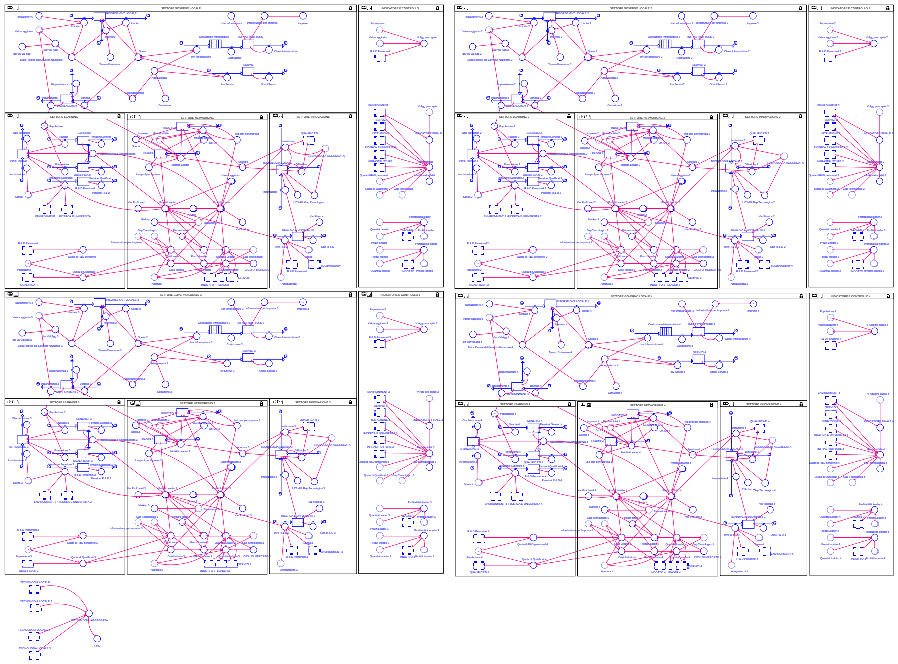

Figure 17: A four regional model obtained linking 4 identical regional systems.

to be higher than 1 to respect the hypotheses. A higher δ corresponds to economies in which the technological bases are more similar and, therefore, the blueprints possessed in one region are more rarely different from those possessed by the other region; the opposite is true for a lower δ (Fig.16). The existence of multiple equilibria also depends on the size of δ: the higher, the more divergent the model. It is not necessary to have the same degree of complementarity of knowledge for all regions (in the real world this parameter is likely to be higher for regions which are more similar and/or closer) but this realism, if implemented, would add complexity to the model without qualitatively changing the results and therefore without affecting its explicative power.

Stochastic simulations (i.e. with innovation being a random outcome dependent on the effort devoted to it) produce patterns which are different one replication from the other and highly realistic, but which also are difficult to interpret. For this reasons the mathematical properties of the model have been analyzed using the deterministic form.

For the sake of simplicity, the parameters of all the regional economies

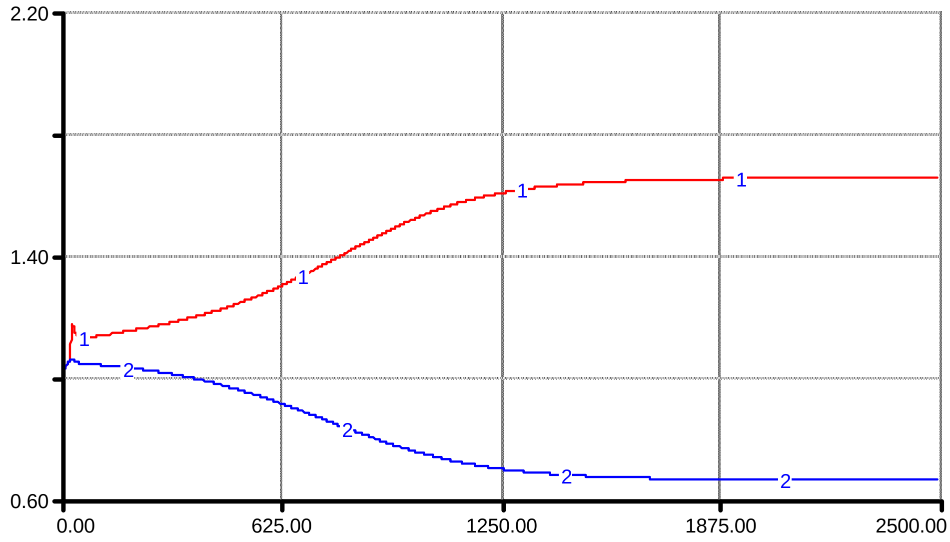

Figure 18: A bi-regional system reaches a stable income differentiation situation in the long run.

have been set so as to have, at the beginning of the simulations, all the regions in the same calibration unstable equilibrium where all stocks are equal to one (the same used with just one region); the short run elasticities were also kept equal among regions because we thought it was more interesting to confront different dynamic patterns of regions which are not different in their essence, even if these elasticities could be changed without moving the central unstable equilibrium. In fact, if different regions are simulated with different elasticities, it is like trying to explain the different performances by the mean of comparative advantage, an investigation which is more interesting in applied empirical research than in a theoretical model like this one.

The stable equilibria of the multi-regional models were searched by simulation: if the dynamic returns to scale of the single regions are increasing as assumed in section 5, starting with all the regions in the same unstable equilibrium, asymmetric (for example different in term of magnitude or timing) shocks put the regions on their way to stable equilibria which are reached in long run simulations (Fig.18).

With a world composed of more than one competing territory (four of them in Fig.17), there is the possibility of outcomes with different territories having different performances so that some stabilize themselves near the technological frontier (i.e. their technology is not far from encompassing

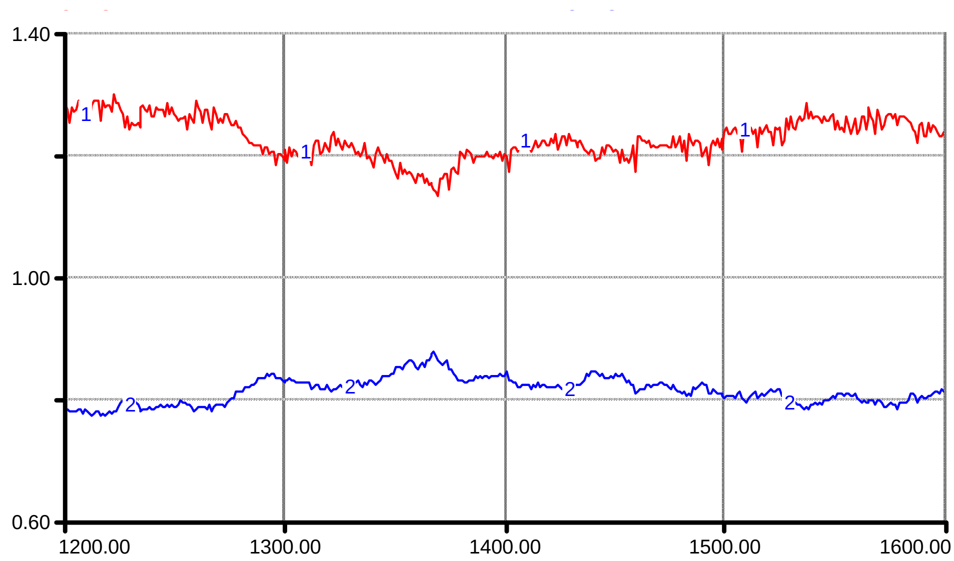

Figure 19: Exogenous random shocks on two regional economies are not generally able to change the rankings of the regions in term of the final indicator.

all the world technology), and other in lagging positions; we observe in fact multiple equilibria, a feature which is common to most of the spatial economy literature of the '90s.

This adds to previous literature that multiple equilibria can be obtained in a different manner: in fact the model uses the traditional c.e.s. function, but, instead of implementing a model coherent with mainstream economics, generates endogenous economic disparities having at the very basis a model of economy consistent with the heterodox theories of the new regional science and innovation. It is also important to observe that agglomeration is obtained without any mobility of factors with the exception of knowledge, on the contrary, mobility is essential to generate agglomeration in a bunch of models in the wave of Krugman (1991).

To summarize the steps followed to obtain this outcome, (1) we have represented the regional economy coherently with heterodox economic theories; (2) we have assumed short term decreasing returns and dynamic long term increasing returns inside every region, with all regions being identical; (3) the regions are put in competition the one with the others on technology and no factor mobility is allowed; (4) because knowledge is cumulative and helps maintain an environment propitious to innovation, it is possible to observe multiple equilibria.

If the model is simulated stochastically, its mathematical properties obviously become less visually evident, depending on the degree of randomness. Stochastic simulations make the model able to replicate the patterns of relative growth of the regions and in particular the observed persistence of regions in their welfare ranking (Fig.19).

The policy experiments of section three can be attempted also in this extended settings, and their results, for the single region in which they are implemented, don't have different results. The same conclusions hold true and are reinforced: with structural policies it is easier to change the path of the regional economies than with simple injections of money. Moreover structural policies, to be really effective, should target the mechanisms the regions use to create/imitate/use innovation.

7 Advantages and limits of the approach

Before drawing the conclusions, it is useful to assess advantages and limits of the approach, as well as the main achievements.

The use of the System Dynamics allows to build a representation of the mechanics of a local production system keeping into account both the complexity and the feed-backs, two things which are difficult to represent with the standard analytical instruments of economics. This difficulty often leads, on the one side, mainstream economists to opt for models much simpler than reality, and, on the other side, regional scientists and geographers to opt for descriptive models.

The approach of this contribution is instead intermediate and can represent a satisfactory compromise between the two above: it is able to deal well with both a large number of variables and interaction and allows to see the mechanisms while at work during the simulations; the model is also able to reproduce a large number of policy initiatives, which can in this way be understood more deeply.

The ample capability of replicating different policies and behaviours is in fact one of the most interesting features, and this compensates the fact that, differently from most economic models, not all the behaviours are optimizing (it is also debated if real behaviours are optimizing indeed, but this issue would go beyond economics and regional science to cognitive psychology).

The first limit is that this model is based on standardized values for the variables which are often (apart from the population quotas) not directly linkable to real world values; nevertheless, this feature is common to most theoretical economic models, and, moreover, since the focus here is on the mechanics inside a local system of production and innovation, it is important to see how the variables interact the one with the other more than how big, in absolute terms, are their values.

The second limit of this model is that it is not able to explain long run growth, since it has, when simulated with just one region, two stable equilibria, one upper and one lower, even if far apart; these roughly correspond to technological forerunners regions and to lagging ones. When the model is simulated with two or more regions, it still has multiple equilibria. We believe that the lack of endogenous long run growth is not enough to harm the significance of the results obtained, first because the stated purpose was to explain relative growth instead than absolute, and, second, since the model has to be applied to the regions of the advanced industrial world, relative disparities among these remain a very important policy issue indeed, especially because of their implications for social cohesion (EU Commission, 2003). To make an example, no European lagging region is poor in "absolute" (World) terms, nor is its population; however the gap with the most advanced ones is the reason of large efforts from national states and the EU to try to achieve convergence (Rodriguez-Pose and Fratesi, 2004). This despite, or even because, Objective 1 regions now appear to grow on average (Canova and Boldrin, 2001) at about the same pace of the rest of the Union.

8 Conclusions

This article justifies four main conclusions, two theoretical and two of policy.

From a theoretical point of view, the possibility to build a diagrammatic and equational representation of a territorial system of production and innovation, coherent with almost all the theories that in the introduction have been classified as heterodox, is a strong signal of the possibility to further integrate them: throughout the model, they appear more compatible than substitute, and the different focuses of one theory on one aspect, and of another theory on another aspect do not make them conflict. When a methodology is able to give space to more than one aspect at the same time (as the system dynamics is), all the aspects appear to integrate very well indeed.

The other theoretical conclusion is that different levels of development among regions can have pure technological causes. In this model's most interesting outcome, regions show different levels of production and also different prices for their productions depending on the level of technology embodied in them. For this reason the source of under-development or of scarce economic activity is shown to reside either in the inability of a territory to produce/imitate technology because of the malfunctioning of the internal socio-economic structure, or in the impossibility for the lagging region to catch up with the forerunners because of the cumulative nature of knowledge. We have in fact shown that when the creation of new knowledge is highly dependent on previously accumulated knowledge or when knowledge is very sticky, it may be not sufficient for the follower to have the same internal structure of the forerunner to catch up with it.

The first policy conclusion is that no economic policy it the "best" in an absolute sense. Various indicators of income and welfare have in fact to be taken into account as well as the time horizon of the decisor; all these will have to be combined according to a specific utility function so that the policy advisor will never be able to propose standard recipes.

The second policy conclusion is that, since more and more the competition between areas of the advanced world is on knowledge and technology, and since these are sticky and cumulative factors, radically embedded in the people living the territories, regional policies aiming at lagging regions, should not forget to target:

(a) The internal functioning of the production system of the under-developed regions, in order to make it produce knowledge more fluidly; these policies may target the presence of human capital, both in increasing the informal qualifications of the workers (the 'skills') and the formal level of instruction and also with the creation of a living and working environment able to represent a viable option for the more skilled workers (the only really mobile) when choosing where to live; the policies should also target the firms of the territory in their aptitude towards innovation and imitation, since every new investment, if the firm is not able to keep the pace of external innovation, is not by itself able to create long lasting development and may soon become obsolete; the policies should also target the public bodies, since they should be able to create an environment where innovation processes may happen: in this model the right 'mix' of public expenditure and the overall efficiency in the expenditure of funds are fundamental variables; concerning the role of infrastructure, if it has to be an effective mean of growth creation, it has to be well integrated in the knowledge creation process and, if exogenously added in quantity beyond the needs of the economy, it is not able by itself to create the economic activity which will use it.

(b) The inter-regional circulation of knowledge, so that the lagging regions could more easily acquire the technology through diffusion and imitation from the advanced ones; as we pointed out, this process is sticky and not easy to artificially produce because of tacit knowledge: the model's learning sector very well takes this into account.

All the available policy instruments (R&D support, education, training, business assistance, hard and soft infrastructure investment, etc.) have therefore to be mixed at their best (without forgetting to take into account the timing of policies), in order to create a system able to compete in the knowledge economy.

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Appendix A: Starting equations of the model

INDICATOR AND CONTROL

- FINAL_INDICATOR = Riproducibility ^0.4 * (34/27 * Value_Added_Per_Capita) ^0.4 *
- Profitability_Core = Profits_Core[Utili_Netti]/(Quantities_Core*Prices_Core)/CORE
- Profitability_Ring = Profits_Ring[Utili_Netti]/(Prices_Ring*Quantities_Ring)/RING
- Riproducibility = ENVIRONMENT^0.05 * (INFRASTRUCTURE * 0.5)^0.11 * INSTRUCTION^0.11 * (10/3 * Skilled_ratio) ^0.11 * RESEARCH_AND_UNIVERSITY^0.15 * (50 * R&D_personnel_ratio)
- Value_Added_Per_Capita = Value_Added[netto] / (Population + R_&_D_Personnel)
- Var_Riproducibility = TREND(Riproducibility,1)

INNOVATION

LOCAL_TECHNOLOGY(t) = LOCAL_TECHNOLOGY(t - dt) + (Diffusion + Imitation + Local_Innovation) * dt

INFLOWS:

- Diffusion = (WORLD_TECHNOLOGY- LOCAL_TECHNOLOGY) * Openness *
- Imitation = (WORLD_TECHNOLOGY-LOCAL_TECHNOLOGY)
- Local_Innovation = LOCAL_TECHNOLOGY * 0.03 * (EXPRND(RESEARCH_AND_UNIVERSITY)+EXPRND(RESEARCH_AND_UNIVERSITY)+EXPRND(RESEARCH_AND_UNIVERSITY)+EXPRND(RESEARCH_AND_UNIVERSITY)+EXPRND(

RESEARCH_AND_UNIVERSITY(t) = RESEARCH_AND_UNIVERSITY(t - dt) + (Inve_R_&_D - Obs_R_&_D) * dt

INFLOWS:

- Inve_R_&_D = ((Adequacy * Expenditure[Pol_R&D] + Profits_Core[Inve_Innovazione])/ 29.4

OUTFLOWS:

- Obs_R_&_D = RESEARCH_AND_UNIVERSITY * 0.2

WORLD_TECHNOLOGY(t) = WORLD_TECHNOLOGY(t - dt) + (Technical_Progress) * dt
INIT WORLD_TECHNOLOGY = 1

INFLOWS:

- Technical_Progress = WORLD_TECHNOLOGY * ((EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND (0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EXPRND(0.07)+EX

- Technology_gap = if
- T_Pr_Loc = TREND(LOCAL_TECHNOLOGY,1)
- T_Pr_Tec = TREND(WORLD_TECHNOLOGY,1)
- Variation_Research = TREND(RESEARCH_AND_UNIVERSITY,1)

LEARNING AND HUMAN RESSOURCES

INSTRUCTION(t) = INSTRUCTION(t - dt) + (Inv_Instruction - Obs_Instruction) * dt
INIT INSTRUCTION = 1

INFLOWS:

- Inv_Instruction = (Expenditure[Pol_Istruzione]/18) ^0.5 *2

OUTFLOWS:

- Obs_Instruction = INSTRUCTION*0.2

R_&_D_Personnel(t) = R_&_D_Personnel(t - dt) + (High_Instruction - Retirements_R&D_personnel) * dt

INFLOWS:

- High_Instruction = INSTRUCTION^0.2 * RESEARCH_AND_UNIVERSITY^0.3 *

OUTFLOWS:

- Retirements_R&D_personnel = R_&_D_Personnel*0.04

- 1 -

SKILLED(t) = SKILLED(t - dt) + (Formation + Obsolescence_and_Training - Retirement_Skilled) * dt
INIT SKILLED = .3
INFLOWS:
Formation = Population * 0.03 * ((exp(1)^(-LOGN(7)+LOGN(3)*INSTRUCTION)) /
Obsolescence_and_Training = - SKILLED*0.07 + 0.015 * USKILLED * INSTRUCTION^0.5 +
OUTFLOWS:
Retirement_Skilled = SKILLED*0.03
USKILLED(t) = USKILLED(t - dt) + (Births - retirement_Unskilled - Obsolescence_and_Training) * dt
INIT USKILLED = .7
INFLOWS:
Births = Population * Population * 0.03 * (1- ((exp(1)^(-LOGN(7)+LOGN(3)*INSTRUCTION)) /
OUTFLOWS:
retirement_Unskilled = USKILLED*0.03
Obsolescence_and_Training = - SKILLED*0.07 + 0.015 * USKILLED * INSTRUCTION^0.5 +
Population = 1
R&D_personnel_ratio = R_&_D_Personnel/Population
Skilled_ratio = SKILLED / Population

LOCAL GOVERNMENT

Builiding_Infrastructure(t) = Builiding_Infrastructure(t - dt) + (Inv_Infrastructure - Building) * dt
INIT Builiding_Infrastructure = 0.8
TRANSIT TIME = 2
INFLOW LIMIT = INF
CAPACITY = INF
INFLOWS:
Inv_Infrastructure = (Expenditure[Pol_Infrastrutture] * Adequacy / 0.144)^0.5 * 0.4
OUTFLOWS:
Building = CONVEYOR OUTFLOW
ENVIRONMENT(t) = ENVIRONMENT(t - dt) + (Decontamination + Biopersistence - Pollution) * dt
INIT ENVIRONMENT = 1
INFLOWS:
Decontamination = 0.065 * (Expenditure[Pol_Ambiente] / 0.18) ^0.5
Biopersistence = 0.05*(1-ENVIRONMENT)
OUTFLOWS:
Pollution = (0.02*Value_Added[lordo]+0.02*Population) * ENVIRONMENT
INFRASTRUCTURE(t) = INFRASTRUCTURE(t - dt) + (Building - Obsol_Infrastructure) * dt
INIT INFRASTRUCTURE = 2
INFLOWS:
Building = CONVEYOR OUTFLOW
OUTFLOWS:
Obsol_Infrastructure = INFRASTRUCTURE * 0.2
RESSOURCES_LOCAL_GVT(t) = RESSOURCES_LOCAL_GVT(t - dt) + (Inflows + Interests - Outflows) * dt
INFLOWS:
Inflows = Value_Added[lordo] * Tax_% + Extra_Resources_from_National_GVT
Interests = (RESSOURCES_LOCAL_GVT - Outflows) * Interest_rate
OUTFLOWS:
Outflows = ARRAYSUM(Expenditure[*])

SERVICES(t) = SERVICES(t - dt) + (Investment_Services - Obsolescence_Services) * dt
INIT SERVICES = 1
INFLOWS:
Investment_Services = Adequacy*(Expenditure[Pol_Servizi]/18)^0.5 * 10/4
OUTFLOWS:
Obsolescence_Services = 0.2*SERVICES
Adequacy = -(Associationism^2) + 2*Associationism -Corruption
Associationism = 1
Corruption = 0.2
delay_var_Value_Added = DELAY(Var_Value_Added,1)
Expenditure[Pol_Ambiente] = RESSOURCES_LOCAL_GVT * 0.2 + step(0.0,3)
Expenditure[Pol_Infrastrutture] = RESSOURCES_LOCAL_GVT * 0.2 +step(0.0,3)
Expenditure[Pol_R&D] = RESSOURCES_LOCAL_GVT * 0.2 +step(0.0,3) + pulse(0.0,2,1000)
Expenditure[Pol_Istruzione] = RESSOURCES_LOCAL_GVT * 0.2 +step(0.0,3)
Expenditure[Pol_Servizi] = RESSOURCES_LOCAL_GVT *0.2 +step(0.00,3)
Extra_Resources_from_National_GVT = 0 * ((IF(Var_Value_Added<0) then 0.3 *
Firms = RING + CORE
Infrastructure_Per_Firm = INFRASTRUCTURE/Firms
Interest_rate = 0.00
Tax_% = .4
Var_Infractructure = TREND(INFRASTRUCTURE,1)
Var_Value_Added = TREND(Value_Added[lordo],1)

NETWORKING

CORE(t) = CORE(t - dt) + (Mobility_Core) * dt
INIT CORE = 1
INFLOWS:
Mobility_Core = On_Off* (0.2 * (step(1,2)*(Core_profits_per_firm - delay (Core_profits_per_firm,1))) + 0.1 * (RING /CORE -1) + 0.02* (0.1 - abs(Openness-0.7))
RING(t) = RING(t - dt) + (Mobility_Ring) * dt
INIT RING = 1
INFLOWS:
Mobility_Ring = On_Off* (0.2 * (step(1,2)*(Ring_profits_per_firm - delay
Core_profits_per_firm = Profits_Core[Utili_Netti]/CORE
Costs_Core = (10/3 * Skilled_ratio)^-0.3 * (50 * R&D_personnel_ratio) ^-0.2 * RING ^-0.2 *
Costs_Ring = (10/3 * Skilled_ratio)^ -0.3 * Infrastructure_Per_Firm ^-0.3 * (10/3*Technology_gap)
MARKET_CYCLES = 0 * SINWAVE(1,10)
Markup = 1 - Tax_%
On_Off = 1
Openness = .6
Prices_Core = Costs_Core * Total_markup
Prices_Ring = Costs_Ring * Total_markup
Profits_Core[Utili_Netti] = (Prices_Core-Costs_Core) * Quantities_Core * CORE * (1-Tax_%) *
Profits_Core[Totali_dopo_le_tasse] = (Prices_Core-Costs_Core) * Quantities_Core * CORE *
Profits_Core[Inve_Innovazione] = (Prices_Core-Costs_Core) * Quantities_Core * CORE * (1-Tax_%)
Profits_Core[Inve_Risorse_Umane] = (Prices_Core-Costs_Core) * Quantities_Core * CORE *
Profits_Core[Lordi_pre_tasse] = (Prices_Core-Costs_Core) * Quantities_Core * CORE + 0*
Profits_Ring[Utili_Netti] = (Prices_Ring-Costs_Ring) * Quantities_Ring * RING * (1-Tax_%) *
Profits_Ring[Totali_dopo_le_tasse] = (Prices_Ring-Costs_Ring) * Quantities_Ring * RING *

- Profits_Ring[Inve_Innovazione] = (Prices_Ring-Costs_Ring) * Quantities_Ring * RING * (1-Tax_%) *
- Profits_Ring[Inve_Risorse_Umane] = (Prices_Ring-Costs_Ring) * Quantities_Ring * RING *
- Profits_Ring[Lordi_pre_tasse] = (Prices_Ring-Costs_Ring) * Quantities_Ring * RING +0* (1-Tax_%) *
- Quantities_Core = (6.4 + 1 * SERVICES - CORE - 4 *Technology_gap + MARKET_CYCLES - 2*
- Quantities_Ring = (3.9 + 1 * SERVICES - RING - 3 *Technology_gap +MARKET_CYCLES +CORE)
- Quotas[Tipi_Quote] = .2
- Ring_profits_per_firm = Profits_Ring[Utili_Netti]/RING
- Total_markup = 1+ Markup / (1-Tax_%)
- Value_Added[netto] = Profits_Ring[Utili_Netti] + Profits_Core[Utili_Netti]
- Value_Added[lordo] = Profits_Ring[Lordi_pre_tasse] + Profits_Core[Lordi_pre_tasse]
- Var_Prof_Core = TREND(Profits_Core[Utili_Netti],1)
- Var_Prof_Ring = TREND(Profits_Ring[Utili_Netti],1)

Not in a sector