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# Transiting to a New Development Pattern? A Conceptual Analysis of New Dynamic Hypotheses Governing Development

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Globalization and a shift in the dominant type of capital investments from physical to knowledge forms, emerging since 70's had a major influence on industrial development pattern. This paper examines the dynamics of their impact, aiming to derive insights about modifications in the corresponding sustainability context. Introducing changes as new operation hypotheses in a dynamic model exhibiting industrial development pattern, it accesses conceptually their effects on the functions controlling capital accumulation and regulating capital intensity level that dominate its identity. Showing that model's growth property alters, it induces that development pattern is changing and a new form of limits-to-growth emerges.

## INTRODUCTION

The global financial crisis exploded in 2008, evolved gradually to a public debt crisis followed by a still lasting economic recession or at best by a sluggish growth. Its impact on the growth process is reflected in IMF's (2012) assessment of the magnitude of the risks threatening global recovery. Identifying these risks in the ongoing euro-area crisis and the fiscal "cliff" facing USA, it justifies the assertion that this impact exceeds any other postwar manifestation of business cyclicality. Even more, the evaluation of the current financial and economic crisis as the biggest in the last 80 years (Carmassi *et al.*, 2009) comes along with the persistently alarming trends of the under going global population growth and that of environmental load.

Considering that the course of economic development is determined by the dynamic interaction of economic, demographic,

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environmental and social structures (Forrester J., 1971) this coincidence unmasks serious inefficiencies lying in the development process. These inefficiencies manifest themselves with the explosive rise of unemployment and the soaring of income inequalities in the social aspect of development, as well as, with the progressing climate change and non-renewable natural resource shortage in the environmental one. Acting backwards on the economic and demographic structures of development, they exert pressures on its course. Raising forces that counteract the growth dynamics and threaten in the long-term the attainment of standards of living, they are challenging the sustainability context of development associated to its postwar path. This path is attributed in literature to the pattern of development assigned to industrialization. Characterized by the dominance of neoclassical (industrial) growth pattern and national economies of scale (Solow, 1956), it has already been identified by a dynamic model exhibiting in its behavior the course of development followed and its long-term sustainability options (Forrester, N., 1973, Forrester, J., 1971, 1973).

Since 70's major changes have evolved in the development process mainly attributed, as discussed in section 2, to the globalization and to a shift in the dominant type of investments from physical to knowledge forms of capital. It is remarkable that although they affect critically the industrial development pattern, they have not been cohesively integrated so far in its context. More specifically, it has not been yet strictly evaluated if their impact on its dynamic structure induces a change to its dominant properties or not. These properties, being defined by its functions that are most relevant with the industrial development process, dominate its identity as a dynamic system. The identification of induced change in these properties is capable of revealing the structural or coincidental nature of the inherent reasons dictating the intensity of the currently observed pressures to development. Thus, it entails critical policy implications for their address in the context of a development policy aiming to exit crisis, sustaining in the long-term the standards of living. In particular:

If this impact does alter these properties, it rather suggests a structural change in the industrial development pattern, implying that development path is currently under transition to a new pattern distinct fromthe industrial one. Currently observed divergences from equilibrium should be attributed then to a not yet fully established structural readjustment of the development process underlying transition to a new development pattern and entailing the emergence of new forms of limits-to-growth. Hence, for their long-term address in a sustainability context, a novel development policy agenda is required.

If it does not, induced changes may alter the magnitude of material flows within the industrial pattern, but not its structure. Currently observed disturbances may be considered then coincidental, requiring for their address a change of policy mix, thus without altering the industrial sustainability context.

This paper examines the dynamics of the change in industrial development pattern, with a view to deriving insights about modifications in the sustainability context associated with it.

## ECONOMIC DEVELOPMENT, SUSTAINABILITY AND DYNAMIC MODELING

In postwar years, western economies following the industrial development pattern performed a firm progress in productivity, growth and standards of living. The initial appearance of current pressures in 1970's, as it was manifested with the emerged stagflation and the two global oil shocks, raising the cost of capital erected novel obstacles in this course of development. A public debate was initiated then about the long-term options available to development after the end of the "golden age" of industrialization that introduced, among other new considerations, the sustainable dimension of development.[1]

The policy response originated from System Dynamics (SD) introduced the limits-to-growth approach to development. Defining sustainable development as the policy sustaining in the long-term the standards of living, it argued that in a strategic time horizon they may not be sustainable in the context of industrial development pattern due to the emergence of environmental and social limits to growth. Identifying industrialization as more harmful than population growth in sustaining development, it provided for a cohesive sustainability policy agenda focusing on a strategy of self-restraining growth as a means to control the intensity of arising pressures (Forrester, J., 1971, 1973, Meadows *et al.*, 1972, Forrester, N., 1973).

The response of public policy had an opposite direction. It was targeting the re-enforcement of growth with the adoption of two major policy vehicles: (i) the acceleration of technological progress towards addressing the emerging environmental pressures and (ii) the enlargement of economies from national to a global scale (Dornbusch and Fischer, 1978, p. 572). An approach to sustainable development was introduced only in early 1990s, after it had been defined in the context of the Brundtland report 'Our common future' (Report of the

World Commission on Environment and Development, 1987). As a major requirement for its achievement it was set in this report for the first time the idea that, the economic growth is necessary for the conservation and the improvement of the environmental quality (Stern, 2003, p. 4). The neoclassical approach to sustainability is focused solely to the environmental aspect of development, ignoring the social one (Grossman and Krueger, 1995, 1994, 1991, Shafik and Bandyopadhyay, 1992). Its foundation lies on the environmental curve of Kuznets and it argues that as the income increases, the demand for improvements in the environmental quality will rise, raising the available funds for investments (IBRD, 1992). The sustainable development is defined thus, as the contemporary stage of development for advanced economies, following the fifth stage of the Rostow's (1960) neoclassical pattern, that of massive consumption. The new stage is characterized by the accelerating rates of economic growth ensuring the sustainability of the environmental aspect of development.[2]

The policies adopted in line with this agenda produced major changes in the development process, as presented in section 2, that are directly related with currently observed threats.

As the origins of current threats stem from a multidimensional domain consisting of economic, demographic, social and environmental structures, their address in a sustainability context involves a structural and functional complexity. In coping with it, SD based analysis offers in general a suitable study framework (Lane *et al.*, 2012). Providing a systemic approach to development process, it allows for the integration of the economic, demographic, social and environmental structures determining its course into a dynamic model. Addressing by means of computer simulation the non-linearity of involved social processes represented by high-order differential equations, it allows formulation of existing interrelations among these structures. Hence, a dynamic model may provide a complex definition of development content.

A complex framework for the industrial evolution of economic development is provided by a SD model proposed by Forrester, N. (1973). It is presented in section 3 and serves in this paper as benchmark model. It interrelates, economic, demographic, social and environmental structures that are endogenously producing with their dynamic interaction the path of development followed by a national typically industrialized economy in its full life-cycle (Forrester, J., 1977). This cycle, explained in more detail in section 3, is even longer than the long wave or Kondratiev cycle (1925).

The changes assumed here as affecting the industrial development pattern, may be addressed in the context of this model as new dynamic hypotheses introduced in its operation. The model's identity as a dynamic system is determined by the properties of its dominant functions producing its industrial development behavior. Assessing the effect of new hypotheses on these functions, conclusions may be derived for the nature of their impact on its behavior and hence, for the nature of change induced in the sustainability context of development.

The aim of this paper is triple. At first, to formulate conceptually assumed changes as dynamic hypotheses that extend the benchmark model. Secondly, to evaluate the impact of new hypotheses on the industrial development pattern by examining the nature of their effects in model's dominant functions producing it; in particular the functions controlling the capital accumulationand regulating the capital intensity of the production process, that generate the growth process. Thirdly, to identify the nature of the change induced in the sustainability context of economic development, providing the directions for further research required for its dynamic address.

## AN OVERVIEW OF THE SOURCES OF THE CHANGE IN INDUSTRIAL DEVELOPMENT PATTERN

There is a broad consensus in recent economic literature and among public policy makers that economic system has changed since 70's, due to the emergence of globalization and to a shift in dominant type of investments from physical (productive) to knowledge forms of capital, in following respects: (i) its structure is considered nowadays common in all developed and fairly developed economies with just a couple of non-significant exceptions (Galbraith, 2004) and (ii) the role of knowledge has been upgraded in the growth process (Brinkley, 2006; Foray, 2000; EC, 2000). The empirical evidence of the ongoing transformation in this direction is provided by the emergence of a new global pattern of production and trade that alters the traditional rule of comparative advantage. On theoretical grounds it is argued with the introduction of a new growth theory that modifies the traditional neoclassical (industrial) growth pattern.

The new pattern of specialization in production and trade worldwide indicates that raw material processing and heavy manufacturing shifts from industrial to developing countries (with low labor cost and loose environmental legislation); the former turn their focus towards knowledge intensive products and services (Saeed, 1998;

EU, 2007). Global labor division also changes. Developing countries tend to specialize in the production of outputs with high resource content and low added value in knowledge, while the industrialized countries in outputs with low resource content and high added value in knowledge (UNCTAD, 1996, 1998, 1999; Saeed, 1998; EU High Level Group chaired by Kok W., 2004).

In respect to the growth process, the endogenous growth theory shifted the focus away from the physical content of capital that was the dominant form of capital in neoclassical (industrial) growth model (Solow, 1956), towards its knowledge content (Romer, 1986). Emphasizing on human capital and on Research and Development (R&D) as endogenous sources of innovation and therefore economic growth, the new growth theory inaugurated knowledge as the key source of economic growth (Lucas, 1993; Grossman and Krueger, 1991).

The evolution of economic system in this direction is associated with changes recorded in the economic activity structure, being attributed in general to the emergence of a new technological revolution and to the adoption of a new set of public policies worldwide.

The revolution in information and communication technologies (ICT) considered having as starting point 1971, introduced a new pattern of technological change, distinct from the industrial labor – saving one (Perez, 1983, 1985, 2002; Dosi, 1982; Cimoli and Dosi, 1995). Its impact is demonstrated, on the one hand, in the launching of a new technology improving the efficiency of non-renewable natural resources per unit of output, in both respects (a) reducing gas emissions to environment (b) decreasing their inflow as inputs in production outputs (Fiddaman, 2007). On the other hand, in facilitating technically the globalization of money and capital markets as well as the split of production process in geographically distant locations (Strange, 1996).

The new public policies adopted were originated by a set of policies proclaimed in 1989 by the three major economic institutions located in Washington DC, USA, thus referred in literature as "Washington Consensus" (Williamson, 1989). Among other reforms they are targeting fiscal discipline and control of the state budget deficits, deliberation and deregulation of the financial markets, privatization of public entities and trade deliberation in the context of uniform external trade regulations imposed by World Trade Organization (Steger, 2003). Their initial scope was restricted to serving as a framework for the design of the structural adjustment programs financed by IMF and World Bank in Latin America economies. However their implementation was gradually generalized, as seen in

Eurozone South debt financing programs or in recent EU Treaties and Agreements. The institutional reform they are driving at, consolidates globalization and facilitates diffusion of a knowledge based economy (Fisher, 2007).

The structure of economic activity and the underlying growth process are major determinants of the path of economic development. Thus, emerging globalization and knowledge economy acting on these determinants, affect industrial development path.

## INDUSTRIAL DEVELOPMENT PATTERN: BENCHMARK MODEL

In literature, both economic activity structure and neoclassical growth pattern are dynamically interrelated in the context of the benchmark model (Forrester, N., 1973). The model represents the life-cycle of development of a national typically industrialized economy (Canada). This cycle, occurring in the span of a few hundred years, is divided into the phases of growth, transition to equilibrium, and, equilibrium, defined as follows: "During the growth phase, population, production and industrialization increase exponentially. During the transition phase, growth encounters mounting negative pressure from environmental and social limits to growth. During the equilibrium phase, the forces producing and restraining growth are in balance." (*op. cit.*, p. 1). The model deals with a 250-year period of the cycle. Aiming to explain how pressures being latent in growth phase can emerge later to suppress growth it focuses on changes occurring during the transition phase between growth and equilibrium.

The model deals with the shifting allocation of labor and capital between production sectors to balance the needs of the population during the life-cycle of development. Its structure incorporates a demographic and an economic activity section consisting of five production sectors: agriculture, goods, services, capital and natural resources. Within each production sector, capital accumulation is controlled by the relative marginal productivities of capital and labor. The material flows among model sectors are shown in Fig. 1. The process of economic development is controlled by causal feedback loops formed by its economic, demographic, environmental and social structures that interact continuously to produce its course. A causal feedback loop is any circular chain of causally related variables. The model is a system of approximately 162 mathematical equations, tying together its elements in a classical and neoclassical economic context and in a fully dynamic feedback structure.

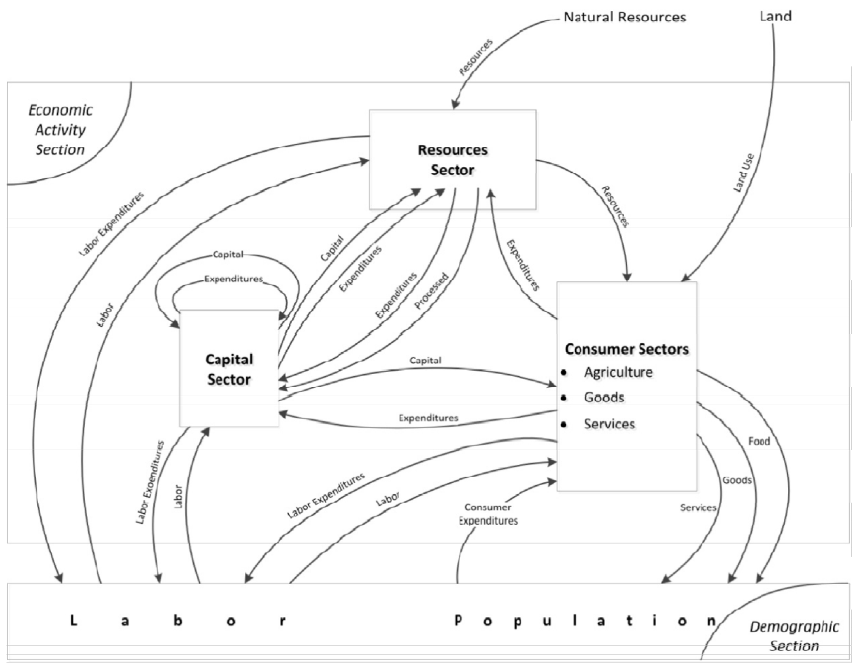



**Figure 1:** Generic overview of the benchmark (original) model

Simulating with a computer the development process for the period 1900 – 2000 identified as the growth phase, the model produces endogenously in its behavior the neoclassical growth pattern of industrialization as shown in Fig. 2. The model allows the examination of relative time of events and signs of shift from one development phase to another in advance of actual occurrence. Assuming that over the next 150 years (2000 – 2150) identified as the transition phase, development is likely to encounter serious obstacles threatening economic and demographic growth the model examines the impact of different sets of emerging environmental and social restrictions. Among them is chosen, as most likely one to occur in transition phase for the given country, the behavior mode in which development is limited by resource shortage and population overcrowding. In order to address these limits, various development policies are tested aiming to appraise their long-term impact on standards of living. Evaluating the model behavior exhibited by the corresponding modes, the policy of recycling non-renewable natural resources results as the most efficient one; it holds standards of living high for a longer time period than the other tested growth policies.

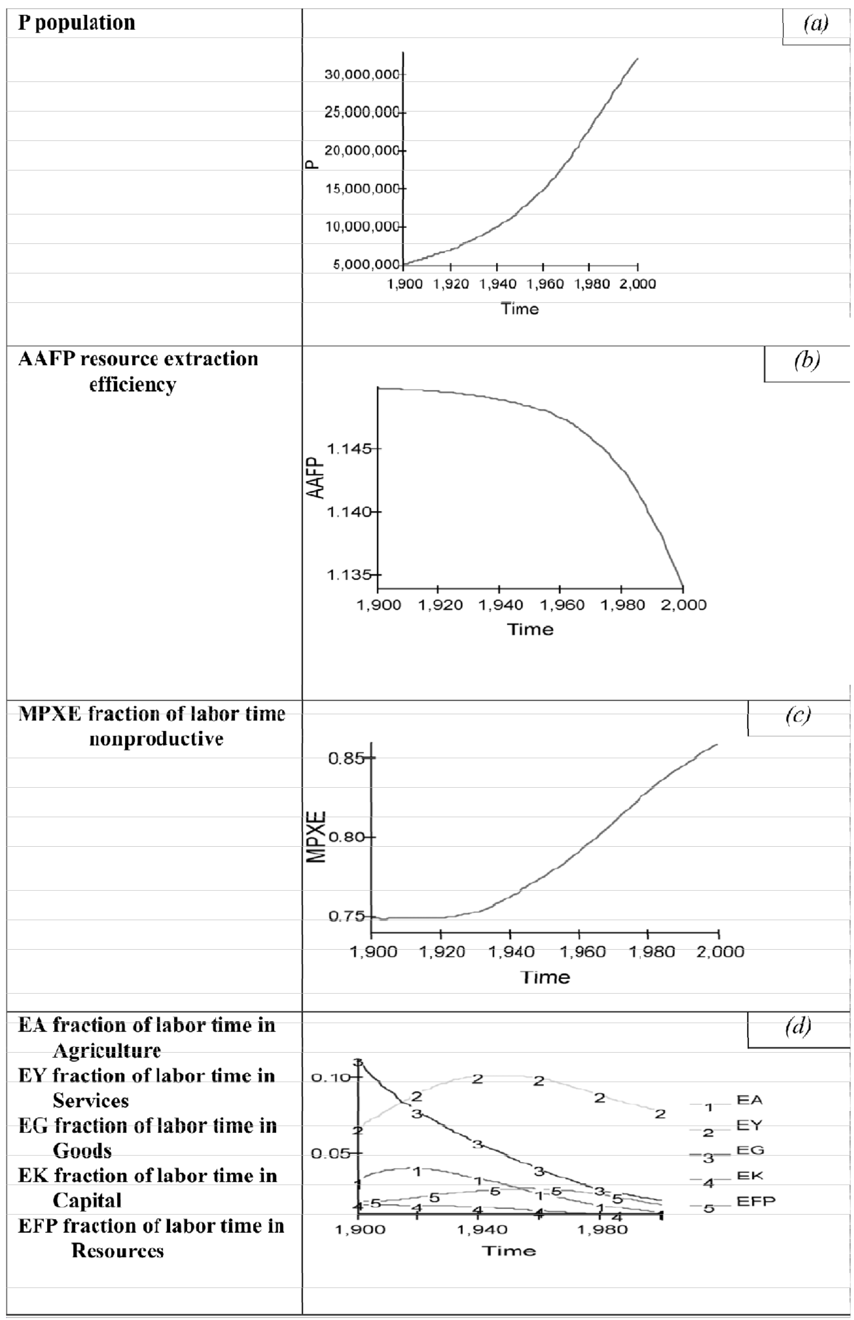



**Figure 2 (a-d):** Simulation of benchmark model variables in the mode of industrialization (Canada 1900-2000)

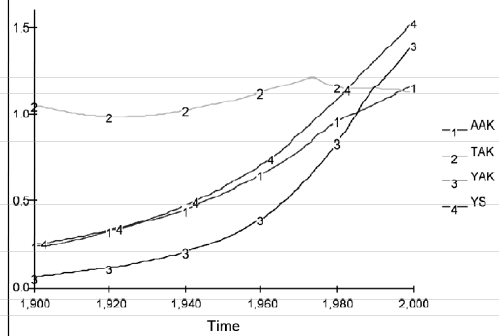
**AAK Goods per capita**

**TAK Food per capita**

**YAK Services per capita**

**YS Population crowding**

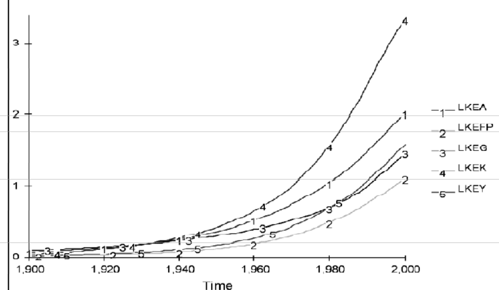
*(e)*




**Capital/labor ratios:**

**LKEA in goods**
**LKEFP in resources**
**LKEG in agriculture**
**LKEK in capital**
**LKEY in services**

*(f)*




**EKFP Labor cost of resources**

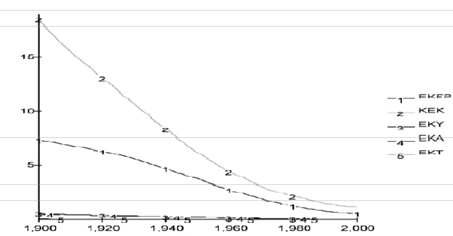
**KEK Labor cost of capital**

**EKY Labor cost of services**

**EKA Labor cost of goods**

**EKT Labor cost of food**

*(g)*




**AGA Need for goods**

**AGMPX Need for nonproductive time**

**AGT Need for food**

**AGY Need for Services**

*(h)*

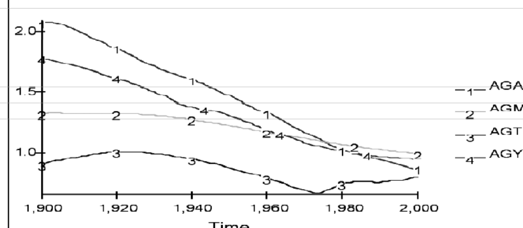



**Figure 2 (e-h):** (continued) Simulation of benchmark model variables in the mode of industrialization (Canada 1900-2000)

## DYNAMIC HYPOTHESES FOR MODEL EXTENSION

The model contains the generic structures producing or restricting development for almost any industrial economy (Forrester, N., 1973). It doesn't include structures generating the business cycle or other shorter-term behavior patterns. The values of particular variables derived from it do not exactly match with historical values recorded in county's data. However, as shown in Fig. 2, it captures the major trends observed in the country's past: the population growth in Fig. 2(a); the falling resource extraction efficiency in Fig. 2(b); the reallocation of labor in Fig. 2(c) and Fig. 2(d); the rising standards of living in Fig. 2(e) and Fig. 2(h); the increasing capital intensity of production process in Fig. 2(f) and Fig. 2(g). The closeness of its behavior with the real one as historically observed serves as a criterion of the model validity or confidence. Considering its versatility in representing with a structural elaboration any development content related withthe industrial one, the model allows for its extension, so that later changes, as those assumed here, may be incorporated in its structure. These changes - attributed to the globalization and to a shift in the dominant type of investments from productive to knowledge forms of capital - are introduced by formulating the responding dynamic hypotheses in its context.

### Globalization Hypothesis

This hypothesis represents the globalization of the economic activity. Globalization is defined here as a process regarding the simultaneous opening of national economies. As the movements of capital and financial transactions are the first and foremost deliberated sectors, this opening leads to a global integration of money and capital markets. The creation of a global financial market facilitates the integration of goods, services and natural resources markets in a global scale and shapes a new global economic context characterized by a more or less dense interdependence of national economies (Fisher, 2007).

In this respect, globalization has two major effects on the model structure:

(a) It extends the scale of production process enlarging economies from national to a global scale. Extension implies that (i) the theory of economic growth and efficiency may now be applied in a global context (Saeed, 1998) and (ii) the economic activity structure assigned to industrial economies may now serve as a pattern for the global structure of economic activity.

(b) It increases the capital intensity of the production process. This is attributed, on the one hand, to the radical increase of the level of capital leverage succeeded with the global integration of capital and money markets (Strange, 1996). Its order may be seen in the growth of world's financial assets (the value of equity market capitalization, corporate and government bonds, and loans) as well as in the rise of financial depth (measuring these assets relative to GDP), from 1980 to 2007: the first grew from around $12 trillion to $206 trillion; the second rose from 120 percent to 355 percent of global GDP (McKinsey Global Institute, 2013). In general it is estimated that the leverage level of financial capital during last years has over-tripled as, from a previous level of 10:1, has exceeded 30:1 nowadays. In European Union the banks of Germany and France may serve as a clarifying example, as their capital leveraging is reported to exceed their capital size by 32 and 26 times, respectively (Brown, 2012). This increase of the capital leverage level increases radically the inflow of capital in economic system.

On the other hand, labor markets as it is argued, have remained persistently national in respect to both, free movement of labor and income convergence (Castaldi *et al.*, 2004; International Labour Office, 2008). Further, the introduction of new technology, leading to an even greater substitution of labor, affects in a negative way both employment and the share of labor income in GDP (Krugman, 2013). Thus, the radical increase of capital inflow, assumed to result externally in the model as the outcome of the financial globalization, implies an ordinal increase of the capital/labor ratio of the production process that, in the model, represents the level of the capital intensity in the production process.

Both effects imply changes in the values of the benchmark model parameters (constants) imposed externally which alter the magnitude of material flows within model but do not affect its structure and its properties.

### Knowledge Economy Hypothesis

This hypothesis represents the shift in the dominant type of investments from productive to knowledge forms of capital. Since knowledge of productive techniques and capital goods are both classified in the benchmark model structure as capital, this shift is implemented endogenously with a shift of domination within capital, from physical (productive) to its knowledge content. Its emergence is attributed to the assumed impact of a new technology improving the efficiency of natural resources on production process, introduced in the model exogenously. In particular, since the model does not include an emission sector, its aim is identified here with the reduction of the natural resources' consumption per unit of output. Thus, the rise of importance of the knowledge content of capital responds to the emerging need to upgrading technological status in the production process, so that the resource content per unit of output is reduced. This shift in the content of capital affects directly, among production sectors, the capital and the goods sectors that use the natural resources as inputs. It also affects (a) the cost of capital and (b) the definition of 'natural resources content per unit of output' variable.

In terms of the capital cost, as it is argued, the formation of a unit of the knowledge capital is more expensive than a unit of productive (physical) capital (Foray, 2000; Forrester, N., 1973). Therefore, the dominance shift within capital presupposes an increase in the capital intensity level of the production process. This requirement introduced exogenously, is fulfilled by the globalization hypothesis. Thus, the adoption of the 'capital intensity increase' hypothesis stands for the exogenous condition allowing the introduction in the model of assumed new technological status.

In terms of the 'natural resources content per unit of output' variable, its definition now alters: being assumed in the benchmark model as a fixed constant (determined exogenously), it now becomes an endogenous variable and even more, inversely related with the capital intensity of the production process. In particular, its rate of decline depends on the rate of the capital intensity increase. The decreasing resource content of capital as the capital intensity is increasing, represents the changing form of capital from physical to knowledge forms (Forrester, N., 1973, p. 159). This definition change, from an exogenous constant to an endogenous variable taking continuous values that depend on capital intensity, allows resources to be treated now equally with capital and labor as variable production inputs (Forrester, N., 1973, p. 159).

Knowledge economy hypothesis, altering dynamically the resource content of the goods and capital outputs, implies a model modification entailing a structural extension. Its adoption appears to serve the aim of enforcing growth dynamics addressing the downward tendency of material standard of living (i.e. food/per capita, services/per capita, goods/per capita) observed at later stages of development in resource and crowding limited mode of benchmark model operation. As shown in Fig. 3, it reverses this trend, by altering the polarity linking capital/ labor ratio with the resource content of output. Thus it aims to offset the negative impact of the declining resource extraction efficiency on standards of living. This impact is negative because, when development is limited by resource shortage and population overcrowding, as it is showed in the corresponding behavior mode, declining resource extraction efficiency raises the cost of physical capital goods and retards accumulation of capital and productivity in resource and consumers sectors. The resulting decline in the standards of living reduces the ability to regenerate knowledge capital. The difficulty in supporting R&D accentuates productivity loss in the resource sector and causes further decline in the standards of living (Forrester, N., 1973, p. 53).

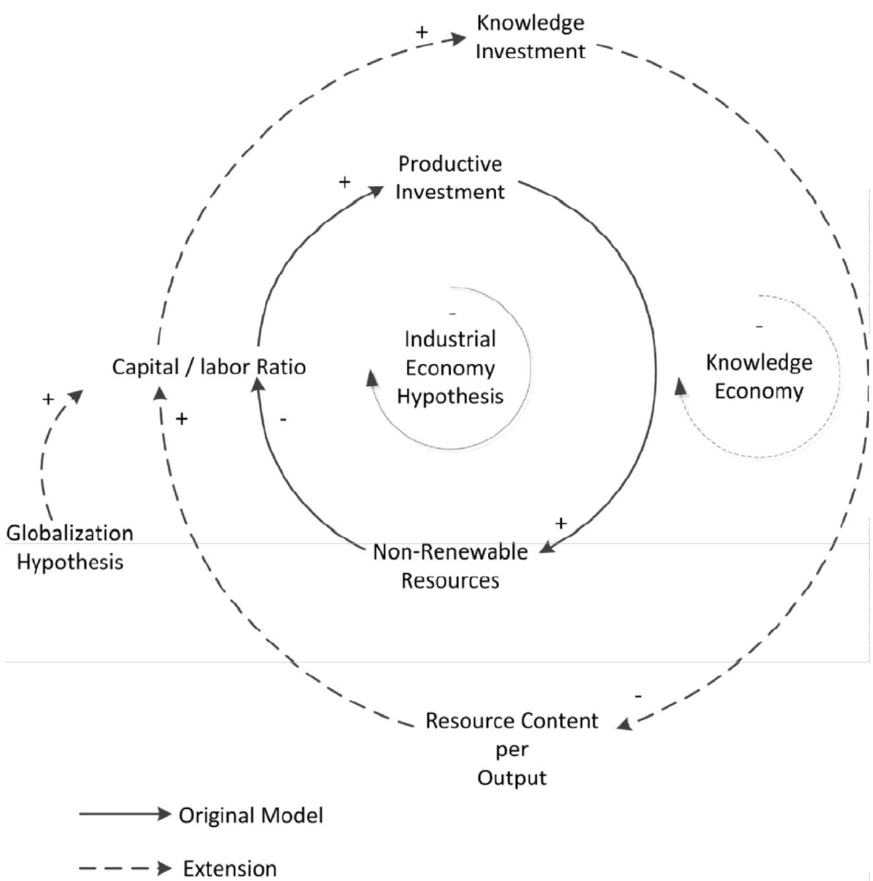



**Figure 3:** Dynamic hypotheses; Benchmark model and extension

In conclusion, provided that the capital intensity (capital/labor ratio) is raised exogenously due to the globalization hypothesis, the shift in the dominant form of capital investments is caused endogenously according to knowledge economy hypothesis. The latter transforms the resource content of goods and capital to a variable production input and even more, declining as capital/labor ratio is increasing. As shown in Fig. 3, capital investment is now primarily in the form of knowledge requiring little resource input, as opposed to physical capital goods. As resource consumption per output decreases, capital/labor ratio increases, tending to raisethe standards of living.

## THE IMPACT OF THE NEW DYNAMIC HYPOTHESES ON THE MODEL STRUCTURE

The basic model's structural element is the feedback loop. Its dynamic behavior is generated by the causal feedback loops formed by the individual structures controlling with their interaction the process of economic development. These loops function simultaneously but each one has a separate purpose. Depending on the importance of their individual purpose in economic development, in terms to their critical role in producing its distinctive industrial content, some loops are more important than others in interpreting the model behavior (Forrester, N., 1973, p. 7). Exemplifying the dominant qualities of this content prescribed in theory as the major economic functions assigned to the industrial development process, they provide a broader information base for understanding the dynamic behavior exhibited. Their structure represents the dominant properties of the underlying system. Hence, they may serve as the adequate domain for examining the nature of induced change in the model's identity due to the adoption of new dynamic hypotheses. Evaluating their impact on the loops of the benchmark model that are most relevant with the industrial development content and identifying the potential changes induced in their structure, the nature of the model's change can be shown.

Top standing among these loops are, the loop controlling capital accumulation in model's capital sector, that represents the capital accumulation process, and the loops regulating the capital/ratio in each sector, that determine the capital intensity level of the production process. Capital accumulation loop, described in original model as playing "a very important role in economic development", causes capital accumulation in capital sector and yet, the declining cost of capital (Forrester, N., 1973, p. 21, 29). Capital accumulation loop plays a dominant role in the process of economic growth (op. cit., p. 23), since it represents the process generating wealth in the form of capital. The loops regulating the capital/ labour ratio in each production sector constitute a major component of this process, since, as explained below in par. 5.3, functioning in opposition to the capital accumulation loop, determine the level of capital intensity of production process (op. cit., p. 26). Therefore these three loops, exhibiting in model structure the dominant qualities assigned to the industrial process of economic growth, are dominant determinants of the industrial content of economic development.

Globalization hypothesis alters properties of the underlying system, but without affecting its structure and implying a parametrical change.

In distinction, knowledge economy hypothesis entails a structural extension. The nature of its impact on the model's structure may be evaluated by examining its causal effects on the capital accumulation loop in the capital sector and the loops regulating capital/labor ratiointhe capital and goods sectors.

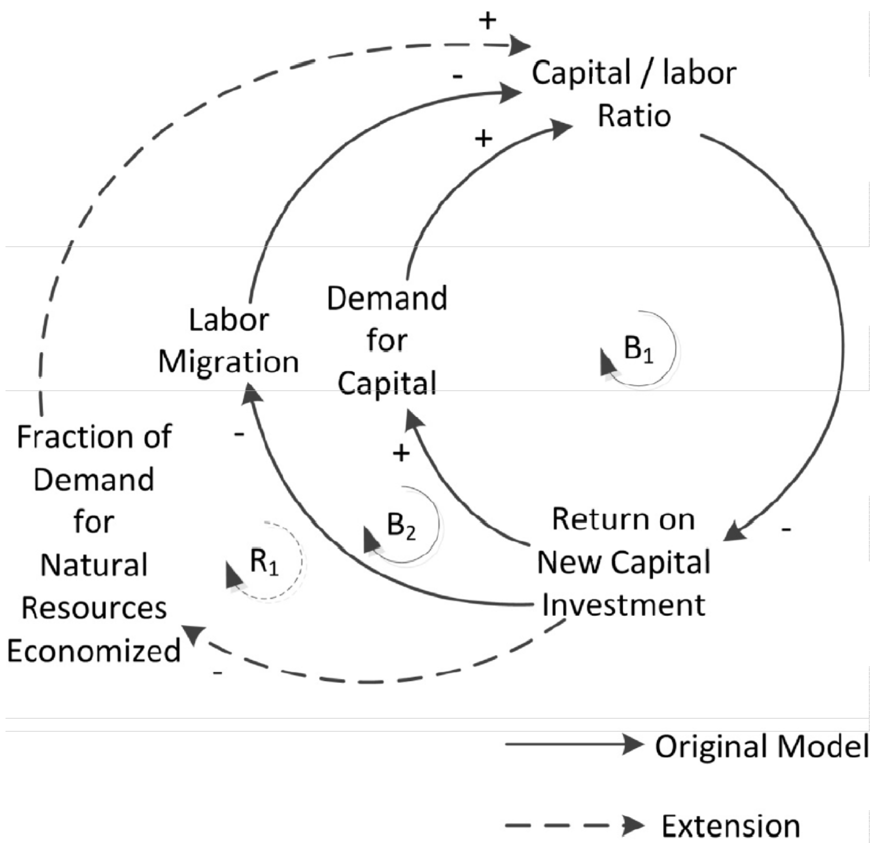
As mapping tool for showing this impact, from now on, causal loop diagrams are used. In SD methodology, the causal loop diagrams play two important roles. Firstly, during model structuring they serve as preliminary sketches of causal hypotheses and, secondly, they provide a simplified overview of a model. The arrows (causal links) represent the relations among variables. The direction of causal links displays the direction (polarity) of the effect. Signs "+" or "-" at the upper end of the causal links exhibit the sign of the effect. When the sign is "+", the variables change in the same direction; otherwise they change in the opposite one.

Feedback mechanisms are either negative feedback loops (balancing loops, denoted as B) or positive feedback loops (reinforcing loops, denoted as R). A negative feedback loop exhibits a goal-seeking behaviour: after a disturbance, the system seeks to return to an equilibrium situation. In a positive feedback loop, an initial disturbance leads to further change, suggesting the absence of equilibrium.

For clarity purposes, the names of the variables forming the feedback loops examined here are written below in italics. The analysis of causal links connecting them follows the branches tying them together within these loops.

### The Impact on Capital/labor Ratio Loops in Goods and Capital Sectors

In the original model, the *Capital/labor ratio in* each sector is regulated by two balancing feedback loops denoted as B1 and B2 in the causal loop diagram shown in Fig. 4. Loop B1 limits *Capital/labor Ratio* by




**Loop B1:** *Capital / labor Ratio→ Return on New Capital Investment→ Demand for Capital*
**Loop B2:** *Capital / labor Ratio→ Return on New Capital Investment→ Labor Migration*
**Loop R1:** *Capital / labor Ratio→ Return on New Capital Investment→ Fraction of Demand for Natural Resources Economized*

**Figure 4:** The impact of new dynamic hypotheses on loops regulating Capital / labor Ratio in goods and capital sectors

decreasing *Demand for Capital* in sector. Loop B2 limits *Capital/labor Ratio* by increasing *Labor Migration* to sector. Their joint action slows the accumulation of capital in sector when *Capital/labor Ratio* becomes high.

Knowledge economy hypothesis implies the introduction in the model structure of a mechanism allowing the resource content of the goods and the capital units to be reduced when the cost of the resources is rising, that is, allowing its substitution with capital and labor as a third variable production input. This mechanism, reported as an omission from the original model structure (Forrester, N., 1973, p. 53), may be applied with the activation of a new branch forming a new feedback loop (reinforcing loop R1) in goods and capital sectors. In particular, through loop R1, *Capital/labor Ratio* in sector is influenced now additionally by Fraction of Demand for Natural Resources Economized. The function of new loop is triggered with the introduction of the new technology improving the efficiency of natural resources as production inputs. The causal links among loop variables are explained below.

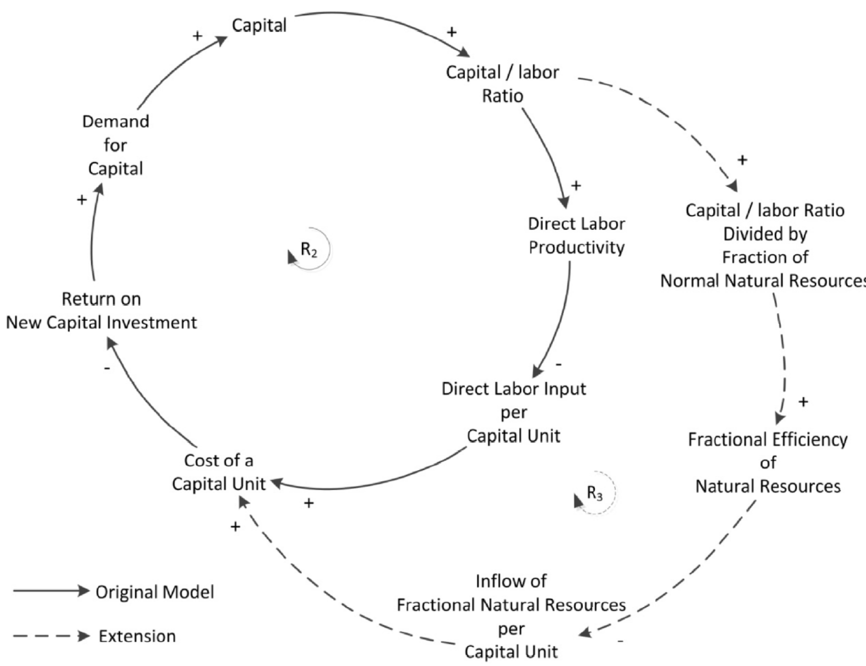
The causal links connecting *Capital/labor Ratio* in goods and capital sectors and *Return on New Capital Investment* in both goods and capital sectors remain negative as in the original model, despite the introduction of the new efficiency technologies; as *Capital/labor Ratio* increases, *Return on New Capital Investment* decreases. Capital investment is subject to diminishing returns, because it is now in the form of financing R&D, which is assumed to subject to diminishing returns of scale. Acceleration of technological progress in the long term is not sustainable in overall economy, because total financing of R&D may not surpass in the long run the rate of growth of economy itself (i.e. GDP). This may be seen in the relationship connecting public expenditures in R&D aiming carbon emissions reduction and the decline of carbon intensity ($CO_2$ emissions/GDP) in U.S. economy. Carbon intensity (declining 0.4% per year) is declining more slowly than GDP is growing. Emissions will continue to rise, albeit more slowly (Fiddaman, 2007). This assumption is opposed to conventional wisdom that increases in R&D spending will increase in the long term the rate of technology improvement. As contributed by historical evidence, the most likely outcome of an increase in technology financing is, at first, a one-time boost of growth and then its stabilization around the same rate of improvement as before the increase (Fiddaman, 2007). As it is argued, this is happening, on the one hand because problems to be solved get gradually harder, since as technology progresses their complexity increases as well, as seen in the US policy to invest heavily in R&D in order to create options for future reductions of greenhouse gases (op. cit.); in spite the large increases in national R&D funding for this purpose and the rapid progress of relevant particular technologies, the energy and carbon intensity trends observed in US economy remain regular for many decades. On the other hand, the success of new technologies in improving efficiency of natural resources as production inputs triggers opposite effects on growth. Since it lowers the cost of resources per unit of output, allows the production and consumption of larger amounts of output, as seen, i.e. in respect to the reducing emissions per unit of output, in energy services. Being now cheaper it is desirable to consume more of them, thus offsetting partly the improvement succeeded in efficiency. Contributing in this way to acceleration of economic growth, it puts further pressure on resource extraction and gas emissions in other sectors. Although these side effects are generally regarded as insignificant, they are important over long time horizons (op. cit.).

The polarity linking *Return on New Capital Investment* and *Fraction of Demand for Natural Resources Economized* is negative because as *Return on New Capital Investment* is declining, the need for economizing natural resources per unit of output is growing, so that the cost of capital is decreased. As long as the need for economizing natural resources per unit of output is growing, the same is occurring with the *Fraction of Demand for Natural Resources Economized* in the goods and capital sectors. However, as *Fraction of Demand for Natural Resources Economized* moves upwards, the *Demand for Natural Resources* is declining according to knowledge economy hypothesis. This decrease results to a rise in the *Capital/labor Ratio*, which leads to further decrease in *Return on New CapitalInvestment* in sector, thus closing the reinforcing loop R1.

### The Impact on Capital Accumulation Loop in the Capital Sector

In the original model, the cost of a capital unit in the capital sector is measured by the man-hours of direct and indirect labor required for the production of a capital unit. In capital sector, the direct labor input per unit of capital is the man-hour spent for the production of capital, while the indirect labor input per unit of capital is the man-hour required in resource sector, for production of the quantity of natural resources used for the formation of a capital unit. Indirect labor per capital unit is a constant since the resource content per unit of output remains constant i.e. the man-hours required for the production of natural resources used in the formation of a capital unit is constant. Therefore, capital accumulation is caused by a positive feedback loop R2 that acts through direct labor input as shown in Fig. 5.

Knowledge economy hypothesis implies that the indirect labor is no longer a fixed exogenous parameter but it becomes now an endogenous variable representing the varying quantity of natural resources that inflows in each capital output unit. The quantity of natural resources that inflows now in each capital unit is a fraction of the constant quantity of natural resources contained in each capital




**Loop R2:** *Capital → Capital / labor Ratio → Direct Labor Productivity → Direct Labor Input per Capital Unit → Cost of a Capital Unit → Return on New Capital Investment → Demand for Capital*

**Loop R3:** *Capital → Capital / labor Ratio → Capital / labor Ratio Divided by Fraction of Normal Natural Resources → Fractional Efficiency of Natural Resources → Inflow of Fractional Natural Resources per Capital Unit → Cost of a Capital Unit → Return on New Capital Investment Demand for Capital*

**Figure 5:** The impact of new dynamic hypotheses on capital accumulation loop in capital sector

unit in the conditions prevailing in 1970, considered hereafter as normal, and indicating industrial conditions. Therefore, the resource content of capital is now a fraction of the resource content of capital in normal conditions. The shift from a fixed to a variable resource content of capital is applied in the original model structure with the activation of a new branch forming the positive feedback loop R3. This loop causes capital accumulation through the indirect labor inflow in the capital sector i.e. the varied quantity of natural resources that inflow as input in each capital unit. Thus, capital accumulation is now caused by the joint interaction of loops R2 and R3 shown in Fig. 5. The causal influences are further explained below.

In the capital sector, the relation between *Capital* and *Capital/labor Ratio* is positive. As long as the stock of capital increases, the same is happening with *Capital/labor Ratio* by definition of the ratio. The justification for the positive polarity of the causal link between *Capital/labor Ratio* and *Capital/labor Ratio Divided by Fraction of Normal Natural Resources* is as follows: in contrast to normal conditions, the fraction of normal natural resources in capital sector represents the fractional proportion of the natural resources that are used for the formation of a capital unit and not a constant quantity. According to the knowledge economy hypothesis, as the capital intensity of production processes (*Capital/labor Ratio*) increases, the *Fraction of normal natural resources* in the capital sector decreases. The positive polarity is justified on the assumption that as capital intensity of production process increases, the knowledge content of capital dominates over its physical (productive) content (increases as well). Thus, it allows economization of the quantity of natural resources required for the formation of a capital unit, as it decreases in respect to the one used for this purpose in normal conditions. Natural resources per capital unit are economized because knowledge content of capital, the dominant now form of capital, requires less inflow of natural resources in comparison to its physical content. According to globalization hypothesis, capital intensity of the production process has been now radically increased compared to its level in normal conditions. Thus, new capital investment is assumed to represent now generally the introduction of new technology improving the efficiency of natural resources in the production process. In conclusion, as long as *Capital/labor Ratio* is raised the denominator (*Fraction of Normal Natural Resources* in capital sector) is decreasing. This results to an increase of *Capital/labor Ratio Divided by Fraction of Normal Natural Resources*, and hence the relationship is positive.

The relationship between *Capital/labor Ratio Divided by Fraction of Normal Natural Resources* and *Fractional Efficiency of Natural Resources* is positive. This is justified as follows: *Fractional Efficiency of Natural Resources* represents the productivity of indirect labor in the capital sector that is economized and expresses the fractional increase of efficiency of natural resources proportionally to its value in normal conditions. However, due to the knowledge economy hypothesis, an increase of capital intensity of the production process enlarges the knowledge content of capital and decreases the resource content of a capital unit. Enhancement of knowledge capital, on the one hand triggers demand for more capital (for financing R&D) in the capital sector. On the other hand, it decreases inflow of indirect labor because the amount of man-hours required now in the resource sector for the production of the natural resources used for the formation of a capital unit, is declining. The decline of the resource content of a capital unit equals with the decrease of the indirect labor in the capital sector, that is, the decrease of labor required in the resource sector for the extraction of natural resources used in a capital unit. Thus, the productivity of indirect labor increases. Incurred efficiency improvement of natural resources is a fraction of (fixed) efficiency characterizing natural resources in the capital sector, in normal conditions. Thus, as fast as *Capital/labor Ratio Divided by Fraction of Normal Natural Resources* is increasing and the inflow of natural resources in a capital unit is decreasing, so much bigger is the improvement of *Fractional Efficiency of Natural Resources* and, hence, the relationship is positive.

The relation between *Fractional Efficiency of Natural Resources* and *Inflow of Fractional Natural Resources per Capital Unit* is negative by definition of these variables. The *Fractional Efficiency of Natural Resources* (fractional productivity of indirect labor) is defined as the fractional quantity of a capital unit that corresponds to the quantity of natural resources economized (or to indirect labor inflow economized in the formation of a capital unit) in respect to the resource content of a capital unit in normal conditions. The *Inflow of Fractional Natural Resources* (of fractional indirect labor) *per Capital Unit* represents the man-hours quantity required now for the extraction of natural resources used in the formation of a capital unit. It is a fraction of man-hours required for this purpose in normal conditions and, thus, it is a fraction of the quantity of natural resources inflowing in each capital unit in normal conditions. The fractional quantity of capital units that may be formed by the quantity of natural resources economized is inversely proportional to the quantity of man-hours required now for the extraction of natural resources used in the formation of a capital unit. As long as the former is increasing, the latter is decreasing. Thus, the causal link is negative. As long as *Inflow of Fractional Natural Resources* (of indirect labor) *per Capital Unit* is decreasing, due to the decline of resource content in capital sector, the cost of indirect labor is decreasing, as well. Thus, the causal link between *Inflow of Fractional Natural Resources per Capital Unit* and *Cost of a Capital Unit* is positive.

In the original model, the *Return on a New Capital Investment* in the capital sector is measured with the gain obtained in total productive capacity from a man-year devoted in the formation of capital. For a given amount of man-years invested in the formation of capital now more capital units may be bought since the *Cost of a Capital Unit* is decreasing. Thus the causal link relating *Cost of a Capital Unit* and *Return on New Capital Investment* is negative. The relations between *Return on a New Capital Investment* and *Demand for Capital* as well as between *Demand for Capital* and *Capital* are positive, as described in the original model.

Hence, capital accumulation is now self-driven by loops R2 and R3 that act both individually and jointly.

### The Impact on Model Identity

In the original model the balancing loops B1 and B2 regulating capital/labor ratio in the goods and capital sectors act in the opposite direction with the reinforcing loop R2 causing capital accumulation in the capital sector.

Loop R2 determines the process of economic growth in all the production sectors: tending to reduce the cost of capital goods it increases the return on new capital investment for all five sectors; in response, the demand for capital in these sectors is increasing, causing increasing capital accumulation and rising sector labor productivity; the resulting raising of capital/labor ratios in all five sectors generates higher material standard of living for the entire economy (Forrester, 1973, p. 23). When these ratios rise high enough, then loops B1 and B2 are activated. With their function they can stop further accumulation of capital in each sector: causing decrease of the return on a new capital investment in sector, the demand for capital is reducing and labor migration is increasing; the resulting substitution of capital investments by labor investments tends to reduce capital/labor ratios in sector, retarding capital accumulation; when capital accumulation ceases, productivity stops and the material standard of living reaches at equilibrium (*op. cit.*, p. 26).

Knowledge economy hypothesis is activated as the production process becomes highly capital-intensive. It aims to respond to the threat raised to material standard of living at high levels of capital/labor ratios by re-enforcing the process of economic growth. This goal is addressed with structural extensions serving two purposes: (i) to offset the restrictive action of balancing loops B1 and B2 on capital accumulation and (ii) to re-enforce capital accumulation with a new channel raising capital stock. These structural extensions are introduced with the activation of new branches forming two reinforcing loops, R1 - regulating capital/labor ratios in the goods and capital sectors through decreasing demand for natural resources, and, R3 – causing capital accumulation in capital sector by decreasing the natural resource content.

Loop R1, raising capital/labor ratios in the goods and capital sectors, holds high the level of capital intensity of the production process. Offsetting this way the tendency of balancing loops B1 and B2 to limit the capital intensification of the production process, loop R1 allows capital accumulation to grow.

Loop R3, introducing a new source causing increase of capital stock in the capital sector, through the decrease of the natural resource content per unit of capital, re-enforces accumulation of capital caused by loop R2 through direct labor input.

The new loops, acting both individually and jointly, denote a structural rather than a parametrical readjustment of the process of economic growth. Allowing labor productivity to rise in all sectors and efficiency of natural resources – the newly introduced productivity measure- to grow in the capital and goods sectors, they re-enforce economic growth in all production sectors. Consequently, material standard of living is now expected to be raised along with the capital intensification of production process. Thus, the structural model extensions underlying new loop functions affect dominant qualities of development content, as those assigned in benchmark model to industrial economic growth process.

In SD context, structural extensions do not suffice for forecasting technically the model explicit behavior change, since formulation of the corresponding mathematical equations and model simulationis required. However the status of incurred change in its behavior may be induced conceptually, by examining the impact of the new qualities introduced in model operation due to these extensions, on the identity of underlying system. Since it is a growth system, the growth of its condition (level) attributes its main property (Forrester, J., 1961). Thus the properties of the system's particular growth pattern followed, define its identity.

Model's behavior is produced by dynamic interaction of the economic demographic, environmental and social structures comprising the elements of the underlying system. Among these structures, the growth property is attributed only to the economic and demographic ones. The mode of behavior produced by model simulation depends on the mode of its structures interaction. Interaction modes may be discriminated by changes induced in the properties of either, the corresponding patterns of system's growth or, the other parts of the system. In the first case of discrimination, distinct interaction modes produce in its behavior distinct development patterns, while in the second case they produce distinct development modes within a particular development pattern. System's growth pattern, showing how the system is growing, is determined by interaction of both, the structure producing the process of economic growth in the model's production sectors and the structure producing population growth in the demographic section. Assuming that the properties of the latter remain unaltered in all interaction modes, the properties of system's growth pattern defining its identity are dictated by the dominant content of economic growth corresponding to the former.

The industrial behavior mode of the original model, representing the pattern of development during the 100 years (1900-2000) of industrialization, is produced by the mode of interaction determined by the dominance of industrial (neoclassical) content of economic growth in system's growth pattern. The new qualities introduced in the process of economic growth, as projected with the new loops activation, altering its structure, at the same time they are altering qualitatively the industrial content of economic growth, as discussed previously. The qualitative differentiation incurred in this content, points out a structural modification of the properties assigned to the growth of the original system. Indicating changes in the interactive relationships linking economic and demographic structures with environmental and social ones that alter their overall interaction within model, it demonstrates a change of model's growth identity. Shifting its operation to a new interaction mode, the model's simulation is most likely to exhibit in its behavior, as verified exclusively by theoretical consistency, a new development pattern demonstrating altered dominant (growth) qualities.

## DIRECTIONS FOR FURTHER RESEARCH AND IMPLICATIONS FOR THE SUSTAINABILITY PROSPECTS OF ECONOMIC DEVELOPMENT

Since the introduction of globalization and knowledge economy hypotheses in the benchmark model is likely to modify the development pattern exhibited in its behavior, the long-term sustainability prospects of development have to be explicitly readdressed technically, in the light of its new growth properties. In this direction further work is required aiming at the dynamic identification of the new development pattern. The impact of adopted hypotheses on other important model's causal feedback loops describing additional aspects of development has to be specified and mapped. Next, the mathematical equations representing the new hypotheses have to be defined, so that the simulation model is formulated. The extended in this way dynamic model can demonstrate then the discrete qualities of the new development content. Allowing the evaluation of alternative development policies in terms of their impact on the sustainability of the material standard of living in a strategic time horizon, it can serve as an effective tool for the design of a long-term policy sustaining development and providing for the crisis exiting.

However, the conceptual formulation of the new dynamic hypotheses governing development and the preceded assessment of their impact on the dominant feed back loops of the benchmark model allows a theoretical appraisal of their implications for the sustainability prospects of economic development.

As assumed in the benchmark model, at the end of the growth phase in development life-cycle a set of endogenous environmental and social pressures is arising, posing long-term limits to growth. These limits are strictly associated with the neoclassical (industrial) pattern governing its growth, since their origins stem from the mode of interaction of, environmental and social structures with economic and demographic ones, dictated by this pattern. The formers, not having the property of growth, interacting with the latter generate forces resisting growth, when their augmentation, in line with this pattern, goes too far. When their strength is intensified, limits are approached.

The new dynamic hypotheses activate the two new reinforcing loops R1 and R3, as shown in Fig. 4 and Fig. 5. Increasing the level of production capital intensity they are altering the benchmark model's growth pattern. The structural differentiation induced in the growth process, strengthens the growth enforcement and upgrades the level of capital intensification in the production process. This growth process change implies a heavier reliance of development on capital investments, an acceleration of system's growth pace and a more complex system's structure. The new growth pattern of model's economic structures changes the mode of their interaction with the environmental and social ones, and thus it imposes on these a new way of augmentation. Their augmentation according to the new growth pattern entails a differentiation of the form of environmental and social pressures arising in the new development context. Since the form of pressures determines the kind of limits that may emerge in its behavior, the limits-to-growth have to be reconsidered.

Limits lie dormant in the system and their erection implies the activation of feedback loops that, being latent during industrialization, dominate the later stages of development and suppress growth (Forrester, N., 1973). In a growth system like the one underlying benchmark model, change is equivalent to growth (Forrester, J., 1961). Negative feedback loops, indicating the action of forces resisting growth, tend to produce equilibrium (equilibrium loops). Positive feedback loops tend to reinforce growth (growth loops).The changing dominance in model operation, between growth and equilibrium loops during the development life-cycle, serves as a criterion for classifying projected behavior pattern in a phase of this cycle. During growth phase of the cycle, growth loops are dominant. Transition to equilibrium phase implies that dominance is rendered to equilibrium loops (Forrester, N., 1973).

Among growth loops of the benchmark model, dominant role in the system's augmentation during the growth phase is playing, as already mentioned, the reinforcing loop R2, controlling capital accumulation in the capital sector. Its reinforcing action in increasing capital accumulation and consequently system's growth, is limited though by the balancing loops B1 and B2 regulating the capital/labor ratios in each sector, as shown in Fig. 4. Since these loops are activated at high levels of production capital intensity, loop R2 dominates over loops B1 and B2 during the growth phase characterized by a limitless growth in population, production and standard of living. Domination means that the return on a new capital investment generated by loop R2 is raised faster than the pace that loops B1 and B2 can suppress it, so that the net effect of three loops is to maintain a return on new capital investment greater than the return on new labor hiring (Forrester, N., 1973, p. 35, 36). However, when equilibrium loops B1 and B2 are activated, they are capable of dominating over reinforcing loop R2, reducing the return on a new capital investment and the capital intensification of production process.

The activation of reinforcing loops R1 and R3 and the increase of capital intensity introduced by the new dynamic hypotheses are strengthening the capital accumulation process caused by reinforcing loop R2. They are also offsetting the restrictions posed by equilibrium loops B1 and B2 to capital intensification of production process. Although the overall dominance between growth and equilibrium loops in model's operation may not be technically verified by the implied structural changes, however, an even stronger domination of growth loops in the functions determining model's growth property must be anticipated. On the other hand, it can be directly induced that the impact of reinforcing loops R1 and R3 on social and environmental structures' augmentation encounters the emergence of new pressures to growth, introducing high risks to development process. In particular:

As the capital intensification (capital/labor ratio) of production process is enforced to accelerate without any constraint balancing its level,so that the resource content of the goods and capital outputs can be constantly diminishing, labor productivity has to increase in an accelerated pace as well. A constant acceleration of labor productivity implies that the variable 'fraction of labor time nonproductive' measuring the amount of leisure time available (i.e. un employment), in the long-term will rather radically rise. Thus a radical increaseinthe intensity of social pressures must be anticipated.

The improvement in the efficiency of natural resources per unit of output achieved with the capital intensification of production process, in the long-run may be offset by a cumulative increase of production output in total economy, thus it can finally result in an increase of environmental load. This outcome is attributed to the so called 'boomerang effect' of new technology in the scale of production, as already explained in par. 5.1. Although the new technology in the short-run slows down the environmental burden, freeing resources for other productive activities, in the long-run it is likely to increase environmental pressures (Radermacher, 2011, Fiddaman, 2007).

In the short and medium-term the new risks arising are identified with the permanent necessity to accelerate financial capital leverage, so that the pace of the capital input increase is constantly accelerated, while at the same time the labor input increase is constantly decreasing. Their emergence, as seen in the current global financial crisis and in its consequences, can have a major impact on the growth process threatening the development prospects. The global financial crisis attributed to the overleveraging of financial capital that resulted to a huge financial debt due to the mounting non performing subprime loans, was soon diverted to a development crisis in a global scale.

## POLICY CONCLUSIONS

Based exclusively upon the conceptual analysis of the properties of the new development model, recommendations can be formulated now for the planning of a long-term policy of sustainable development.

The transition to the new development model appears to serve the scope of reinforcing the growth dynamics. The new development model, being yet in the preliminary stage of its evolution, seems to aim strategically at the address of the intensity of the environmental pressures encountered at the later stages of industrial development.

This pursuit is served with the adoption in the production process of a new technology improving the efficiency of natural resources and thus decelerating environmental load. The launching of new technology and its application, upgrading its role as production input, requires however, a radical increase of the capital intensity of the production process, since it is more expensive than the industrial labor saving one. Globalization contributes in increasing the capital input inflow, as the global money and capital markets integration allow the radical increase of capital leverage. At the same time, labor input inflow is decreasing, as on the one hand, labor markets remain persistently national and divergent, and, on the other hand, labor is substituted in a faster pace by technological improvements.

This development strategy, relying solely on a new more capital intensive technology to address the environmental challenges to development created by growth, envisages the gradual restriction of the alternatives being available in the industrial one. Trade-offs is appearing in the development process where choices were unnecessary during industrialization (Forrester, N., 1973, p. 72).

In particular, trade-offs develop between population growth and the quality of life, between total production and per capita production, between present and future high standards of living.

In general, as the technological advancement of production process has to always keep ahead of the rising environmental demands, the production capital intensification has to be continuously accelerated. Thus, the option of regulating growth is eliminated and its self-regulation appears as the only viable choice for the public policy. Under these circumstances, it has no available alternatives for the address in the long-term of the constantly increasing intensity of social pressures to development. Therefore,the choice of new development strategy to focus on the address of environmental pressures with the introduction of a new more capital intensive technology just transfers all the pressure to growth to the social dimension of development, without eliminating the risks originated by its environmental one.

In this context and in distinction to the conventional wisdom, the long-term sustainability of economic development seems to lie in a departure from the imperative of exponential growth, foremost for the industrial Northern economies, with a controlled de-escalation of productivity growth. Then, environmental pressures may be addressed with labor intensive policies (i.e. the increase of free time from work) rather than, solely, capital intensive ones (i.e. innovation and entrepreneurship). A desirable future entails a regulation of the new development model towards a more austere and equitable prosperity paradigm. As seen in the sovereign debt crisis of the Eurozone, its adoption is already enforced violently and unfairly exclusively to the weaker economies of the South. As long as the Northern economies remain in the growth imperative, the intensity of social pressures is expected to rise, threatening further the global prosperity. As Krugman (2012) states it, the conventional wisdom that the future of development will resemble the past is very likely to be wrong.

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### *Notes*

1. An outline of this debate is presented in Topalides (2012). A neoclassical approach is presented in Samuelson (1976, p. 814) and Dornbusch and Fischer (1978, p. 572); a System Dynamics approach and its neoclassical response in Forrester J. (1971, 1973) and in Nordhaus (1973), respectively; a systemic-evolutionary approach and its neoclassical response in Georgescu-Roegen (1975) and in Solow (1974), respectively.
2. For a criticism of the validity of the Kuznets' environmental curve, see: for the theoretical grounds, Stern *et al.* (1996), Arrow *et al.* (1995), Stern, (2003, p. 10); for the methodological grounds, Stern (2003, p. 3, 19).

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