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## Alternative theories on economic growth and the co-evolution of macro-dynamics and technological change: A survey

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# LEM

## Working Paper Series

### **Alternative Theories on Economic Growth and the Co-evolution of Macro-Dynamics and Technological Change: A Survey**

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# Alternative Theories on Economic Growth and the Co-evolution of Macro-Dynamics and Technological Change: A survey\*

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## Abstract

This paper aims to propose an approach to endogenous growth considering the relationship between macro-dynamics and technical change. We draw upon two streams of literature: Cumulative causation and its macroscopic view of economic dynamics, and Evolutionary economics and its focus on micro-determinants of technical change. This paper presents a survey of the formal representation of the growth process and identifies the possible bridges between these two approaches. Our claim is that merging these two distinct theories might offer a framework to consider the co-evolution of macro-dynamics and technical change.

**JEL Classification:** O30, O40

**Keywords:** Economic Growth, Technical Change, Cumulative Causation, Evolutionary Theory

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# 1 Introduction.

To analyse the relationship between technical change and macro-dynamics, one would directly refer to growth theory. And over the last years, batteries of models were developed in order to consider and to sustain that the emergence and diffusion of technical change affects but also drives economic growth and employment dynamics, among others.

Among all these models, the New Growth Theory (NGT) is dominant in the literature. It stresses the importance of technical change and increasing returns (which mainly drive the first one) in growth dynamics. More recently it also considers the effect of skilled biased technical change on employment and income distribution dynamics. In other words this literature mainly and clearly focuses on the effect of technical change on macro-dynamics.

However, the NGT rarely considers explicitly the reverse causality, meaning here the possible effect of macro-dynamics on technical change. One should rather say that its analysis, only considers the influence of macro-parameters on the emergence of technical change. The behavioural parameters of a representative consumer affect firms investments, along the balanced growth path. But these macro-influences are set once-for-all through the resolution of dynamic optimizing problems by these representative agents. It seems rather a specific way to speak about the influence of macro-dynamics on technical change. Unless one accepts that every economy grows and will always, as it has always grown, along this balanced growth path deduced from dynamic optimisation.

Our aim is to explore another route, to propose an approach to the endogenous growth processes. To do so, we examine two of the alternative approaches to growth theory in the literature. We focus first on the Post-Keynesian or Kaldorian approach to economic growth also known as Cumulative Causation growth theory, and second on the Neo-Schumpeterian or Evolutionary theory developed starting from the work of Nelson and Winter (1982). This choice was guided, on the one hand by the rather complete analysis performed by Kaldorians, including Kaldor himself, on growth as a self-reinforcing process linked to the strong interconnections between macro-dynamics and technological dynamics. On the other hand, we choose to consider the evolutionary approach, for to its focus on technological dynamics, their micro-foundations and their effect on macro-dynamics. As we argue later in this paper, even if these two approaches only propose partial analysis

of the interactions between macro-dynamics and technological change, they nevertheless seem to complete each other providing then room for building an integrated framework.

The paper is organised as follows : Section 2 is devoted to the review of Kaldor's work on growth and the formal developments of cumulative causation theory. Section 3 focuses on the foundations on Evolutionary theory and the recent development in evolutionary modelling of economic growth. The last section is devoted to the discussion on the complementarities among these two approaches, the possible connections for providing a more complete framework to analyse the cross-effects of macro and technological dynamics and the few formal attempts to be found in the literature.

## **2 A Macroscopic Approach of Growth and Technical Change**

### **2.1 N. Kaldor : Towards 'Cumulative Causation' Growth.**

Along his career, the scope of issues considered by N. Kaldor covered a wide range of economic questions, from imperfect competition to monetary macro-economics. However we concentrate here on his contribution to the theory of economic growth and development of capitalist economies. If Kaldor's influence on the latter is undeniable, his contributions were scattered along his diverse works without, as he acknowledged himself, ever fully elaborate a 'general theory' based on his diverse contributions.

As far as this survey is concerned, one can point three major statements to be found in Kaldor's work on economic growth:

First economic growth is an historical process. In this respect Kaldor reported a set of statistical regularities (i.e. 'stylised facts') concerning long-run growth, observed along history. Second, the undeniable influence of technical change and increasing returns on growth, have to be considered as endogenous processes. Finally he considered aggregate demand as necessary to insure a self-sustainable growth process.

These three components of Kaldor's growth analysis will be the basis for his verbal development of a 'cumulative causation' approach to economic growth, as we detail in the next section.

Introducing his 1957 growth model, Kaldor pointed out clearly the importance of modelling and understanding the economic growth process as an historical process:

“A satisfactory model concerning the nature of the growth process in a capitalist economy must also account for the remarkable historical constancies revealed by recent empirical investigations.” Kaldor (1957)<sup>1</sup>

In this respect, he underlines the following set of statistical regularities, or stylised facts, characterising the economic growth history of capitalist economies :

1. Industrialised economies face continuous growth in GDP and continuous increase in labour productivity.
2. Industrialised economies face continuous increase in the ratio capital per workers.
3. Profits rates on capital are regular.
4. Ratio capital over GDP is constant and regular over periods.
5. Income distribution is constant over time. The share of labour income over GDP is constant over time, this implies that the wage growth rate will be proportional on average to productivity increases.
6. There exist non-negligible differences among economies in growth rates of GDP and of labour productivity increases.

This set of stylised facts were probably the most influential contribution of N. Kaldor to the analysis of economic growth, cited by most of growth theorists, from the ‘New Growth Theorists’ to ‘Evolutionary economists’, including naturally his direct followers.

For Kaldor these facts challenge directly the Neo-classical approach to economic growth, and the use of a traditional production function and stress the need to consider technical change as an economically driven process (see Kaldor (1957)). He then considers technical change as related to investment,

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<sup>1</sup>p. 260, as reprinted in ‘Essays on Economic Stability and Growth’

and to the renewing the production capabilities, rejecting at the same time the concept of 'stock of capital' in favour of a more disaggregate conception of production capabilities (closer to the idea of capital vintages). The accumulation of newer, and therefore more effective production capacities, implies gains in labour productivity. In this respect he introduces the concept of '*technical progress function*' (Kaldor (1957), Kaldor and Mirrlees (1962)). The latter links the rate of growth of labour productivity to that of capital per worker (i.e. investment in capital goods) in an increasing but concave function.

In the mid-sixties, and starting from his Inaugural Lecture in Cambridge (1966), Kaldor's increasing interest towards applied economic growth also modifies his conceptualisation of technical change. This pushes him to go beyond the 'technical progress function' to capture the effect of technical change on growth. From the mid-sixties on, in Kaldor's view, technical change, at the heart of the growth process, is directly linked to the existence of increasing returns. The latter can be static and/or dynamic (Kaldor (1966,1972)). As static increasing returns, one has to understand the 'classic' concept of increasing returns to scale, mainly at the firm level. They emerge in large scale production systems due to labour specialisation and learning-by-doing.<sup>2</sup> Dynamic increasing returns are the combination of two distinct processes. The first one is directly linked to the 'technical progress function'. It implies that the resources generated are invested in production capacities, allowing for larger production scales, but also more efficient ones due to the accumulation of more recent generations of machinery. The second effect refers directly to Young (1928), and relies on a macro-level extension of the idea of division of labour to be found in the Classics analysis. Note that according to Young the existence of a macro-level division of labour generates a self-sustaining economic growth process. In this respect, dynamic increasing returns occur at the macro (or meso) level. For Kaldor, these increasing returns are the main engine for productivity increasing, but remain mainly confined to the manufacturing sectors. This leads him to present the manufacturing sector as the main engine for growth (Kaldor (1966)), and competitive advantage in international trades (Kaldor (1981)).

The formalisation chosen to represent these increasing returns effects refers directly to the work of Verdoorn. The equation is nowadays known

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<sup>2</sup>Note that the latter will constitute one of foundations of the NGT, but twenty years later.

as the Kaldor-Verdoorn law. It links linearly the productivity growth rate to the growth rate of output via the Verdoorn coefficient, plus a constant term. This equation will be at the heart of the cumulative causation growth models.

The undeniable role of increasing returns in generating a sustained growth in production capacities of the economies is not sufficient for N. Kaldor to explain growth processes. He considers, in this respect, Young (1928) or Myrdal analysis as incomplete. He stresses the necessity to consider the demand factor in the analysis of economic growth<sup>3</sup>. Demand provides the missing link between increases of production capacities due to increasing returns and the generation of income growth.

Demand induces a ‘chain reaction’ along the economy. The rate at which industries grow is related to the rate at which the other grow. Hence dynamic industries generate income, then demand spreads across the entire economy:

“[T]he increase in demand for any commodities [...] reflects the increasing in supply of other commodities, and vice versa ” (Kaldor (1966) p.19)

The nature of this ‘chain reaction’ is rooted in the demand structure of the economy. The demand structure relies on three distinct but interrelated processes: Internal consumption, capital investment and external demand.

First the internal demand structure is defined by the “changes in the consumption structure associated with the rise in real incomes per head”. This is linked to the income elasticities of each sector’s demand. The latter directly influences the distribution of growth impulses within the economy:

“The chain reaction is likely to be more rapid the more the demand increases are focused on commodities which have a large supply response [i.e. increasing returns], and the larger demand response induced by increase in production.” (Kaldor (1966) p.19)

Income elasticities are directly connected to the social structure of the economy. Hence Kaldor (1966) distinguishes three income classes affecting the nature of income elasticities:

1. Low income levels whose consumption is directed towards food and primary goods.

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<sup>3</sup>See Kaldor (1966, 1970, 1972).



2. High income levels whose consumption is rather concentrated on services.
3. A middle income class whose consumption is concentrated on manufactured goods.

The nature of income elasticities at the aggregate level depends on the relative importance of these groups in the economy. The higher income elasticity, the more efficient the ‘chain reaction’, economic growth mechanisms rely on the importance of this middle income group.

The second component of demand dynamics is rooted in capital investment. It concerns the industrial sectors. This component explains how demand dynamics allow growth impulses to diffuse across the economy in ways specific to the properties of production technologies in each industries, and the ways in which sectors are interrelated. The rate of growth of products demand triggers investment expansion. Investments affect economic growth through two distinct channels, first as exposed above by providing dynamic increasing returns (i.e. the renewing of production capacities) and second by constituting an outlet for the industrial sectors.

External demand is the last component of aggregate demand. For Kaldor, to sustain growth, economies have to reach the stage in which they become ‘net-exporter’ of manufactured consumer and capital goods. In advanced stages of development, self-sustained growth relies on the combination of growth impulses linked to external demand with the self-generated growth of domestic demand:

“both rate of growth of induced investments and the rate of growth of consumption become attuned to the rate of growth of the autonomous component of demand, so that [the latter] will govern the rate of growth of the economy as a whole.” (Kaldor (1970))<sup>4</sup>

For Kaldor the whole growth process is driven by this autonomous component of demand, function of the world income growth.

## 2.2 Cumulative Causation: From Thoughts to Models

From his diverse contributions Kaldor derives what he calls ‘the principles of cumulative causation’, according to which economic growth is a self-reinforcing phenomenon generating the necessary resources to sustain itself

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<sup>4</sup>As quoted by Boyer and Petit (1991)

over the long-run. The cumulative nature of the growth process relies on a circular conception of the growth process and the co-evolution of two major dynamics: increasing returns and increasing aggregate demand.

Dynamic increasing returns ensure the long run growth of production capacities. These increasing returns are directly related to technical change. Technical change is itself generated within the economic system, through the intermediate of investment and the effect of division of labour<sup>5</sup>.

Following the Keynesian tradition, Kaldor considers economic growth as a demand driven process. Increases in aggregate demand will drive economic growth absorbing the increases in production capacities. Aggregate demand dynamics are related by a multiplier effect to the increases in its ‘autonomous’ component (i.e. exports), stressing at the same time the importance of international trade.

These two main dynamics are interrelated. In generating income, aggregate demand dynamics create the resources to sustain investment and then sustain dynamic increasing returns. This effect is synthesised by the Kaldor-Verdoorn law. Second, dynamic increasing returns sustain the competitiveness of the economy on international markets. The latter sustain aggregate demand dynamics through the multiplier effect. Economic growth is then a circular and self-reinforcing process, in the sense that “growth creates the necessary resources for growth itself” (León-Ledesma (2000)).

This cumulative vision of the growth process leads Kaldor to consider two possible growth path:

1. Growing among a ‘virtuous circle’ : Dynamic increasing returns and the multiplier effect are such that, respectively, competitiveness, and then a sufficient aggregate demand, can be sustained among time. Aggregate demand generates the resources allowing to sustain dynamic increasing returns.
2. Diving in a ‘vicious circle’ : Dynamic increasing returns are not sufficient to sustain competitiveness and/or the multiplier effect does not allow demand to sufficiently sustain dynamic increasing returns.

The gate to one or another path resides in the structural characteristics of the economies (i.e. among others, industrial and sectorial specialisation).

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<sup>5</sup>In this respect N. Kaldor recognized almost two decades before what will become the driving forces of growth for the New Growth Theory

These two growth schemes, and the cumulative nature of the growth process recalls the grip of history and the undeniable historical nature of growth analysis. It offers theoretical foundations to the existence of continuous, but significantly different, GDP and labour productivity growth rates among industrialised economies as reported in the 1957 paper's set of stylised facts.

At the heart of the literature founded around these principles, Dixon and Thirlwall (1975) present one of the first attempt to formalise Kaldor's analysis. Faithful to Kaldor's verbal exposition of the cumulative mechanisms laying under economic growth, they develop a simple model of regional growth around the following relationship.

GDP, is represented, following the Keynesian tradition, by aggregate demand. Its growth rate ( $y_t$ ) is linearly function of the exports growth rate ( $x_t$ ) through a multiplier<sup>6</sup>. The latter is directly inspired by Hick's 'super-multiplier' principle.

$$y_t = \varepsilon x_t$$

Exports represent here the only 'autonomous' component of aggregate demand. The growth rate of exports is linearly linked to foreign income growth rate ( $y_t^*$ ) by income elasticity on the one hand. The latter is considered by the authors as a proxy for non-price competitiveness. This argument could represent the degree of specialisation or of integration of the economy in world trades. On the other hand exports growth rate is linearly related to the growth rate differential between domestic ( $p_t$ ) and 'world average' prices ( $p_t^*$ ) by price elasticity. This second component captures the effect of price competitiveness dynamics on the dynamics of external demand.

$$x_t = \alpha y_t^* + \beta (p_t^* - p_t)$$

Domestic prices are set applying a mark-up on unitary production costs. Price dynamics are then determined by the difference between an exogenous wage growth rate ( $w_t$ ) and an 'endogenously' defined labour productivity growth rate ( $a_t$ ).

$$p_t = w_t - a_t$$

Note that Dixon and Thirlwall made the implicit assumption that labour supply perfectly respond to labour demand itself driven by growth.

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<sup>6</sup>Equations are ours. They aim at clarifying the argument so might not exactly reproduce the equations in Dixon and Thirlwall (1975).

Technical progress implies labour productivity growth rate ( $a_t$ ). It is formally represented by the so-called ‘Kaldor-Verdoorn law’. Hence increase in productivity will be function of economic growth ( $y_t$ ).

$$a_t = \lambda y_t + \epsilon$$

The model as defined by Dixon and Thirlwall (1975), is compatible with the stylised facts concerning the structure of income distribution among production factors, capital intensiveness and profit rates on capital. It generates continuous growth rates in GDP and labour productivity. It is also easy to show with this model that for some values of the structural parameters the economy enters into a virtuous growth circle, while falling in a vicious growth circle for some other values.

In its 1979 paper, Thirlwall introduces in this framework an explicit balance of payment constraint.<sup>7</sup> To achieve this, the authors introduce an explicit formulation for imports dynamics, modelled on exports dynamics as in Dixon and Thirlwall (1975), and exchange rate dynamics.

Considering an explicit import growth function combined with the balance of payment constraint, allows to explicitly construct a trade multiplier in the Harrodian tradition. The latter is computed as the ratio between income elasticities to external demand and to internal demand for foreign goods. Hence the structure of demand will directly influence growth dynamics. Also the exchange rates dynamics might absorb partially competitiveness differences. It then neutralise any voluntary decrease in wages to accelerate growth through external demand channels linked to price competitiveness.

Introducing this constraint tends to limit growth rate differentials but does not eliminate them. Moreover the model seems to show the importance of short-term macro-economic conditions for growth (i.e. exchange rates).

Amable (1992) develops the non price competitiveness dimension of demand dynamics in the balance of payment constrained cumulative causation framework. Imports and exports dynamics representations become also linearly dependant on the ‘quality’ competitiveness of the economy. Quality increases through a learning by doing process, function of the accumulation rate of GDP. This specification reinforces at the same time the cumulative nature of the growth process and its path dependency.

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<sup>7</sup>See Thirlwall (1979) and Mc Combie and Thirlwall (1994).

## 3 Evolutionary Theorising on Economic Growth:

### 3.1 Evolutionary Thinking and the Work of Nelson and Winter.

Evolutionary approach to economic change develops around Nelson and Winter work. Their book, “Evolutionary Theory of Economic Change”, published in 1982, is considered as the major foundation of modern evolutionary theorising on the economic analysis of technical change. Part IV of their book concerns directly the analysis of economic growth, and has provided the foundations of the evolutionary modelling approach of economic growth.

Evolutionary theory places itself in the direct line of Schumpeter writings about long run economic development. It gives a central position to technological change, whether radical or incremental, due to the single entrepreneur or institutionalised R&D activity. Moreover, evolutionary theory places the source of technical change at firms level, in their investment behaviours, and their learning capacities.

Following Schumpeter’s idea, economic systems evolve out of equilibrium. The existence of turbulence led by technical change cannot be understood in an equilibrium framework; as quoted by Andersen (1994):

“[T]here was a source of energy within the economic system which would of itself disrupt any equilibrium that might be attained.”

This source of energy is technical change. Thus evolutionary modelling does not assume a priori existence of equilibrium. If it exists, it has to emerge from economic dynamics.

Moreover, evolutionary theory will prefer population dynamics to the representative agent assumption typical from Neo-classical theories. Concerning agents behaviour, this heterogeneity can only be insured, if these behaviours are not based on substantial rationality. If it was the case, this type of behaviour would lead to behavioural homogeneity, and then to representative agent assumption. The evolutionary approach is an out of equilibrium analysis, focused on dynamic processes, based on heterogeneous and rationally limited behaviours.

From the modelling perspective, evolutionary economics directly refers to its namesake in natural sciences. The dynamics of economic systems rest on three major processes:

1. *Heterogeneity*: Economic agents can differ, in term of behaviour, history, learning capacity among others, parallel to genetic characteristics in natural sciences.
2. *Mutation*: Agents characteristics can be subject to evolution. This mechanism of mutation may concern behavioural patterns, or technological patterns among others.
3. *Selection*: This process allows to differentiate between heterogeneous agents. It defines survival or extinction of agents on the basis of given characteristics (i.e. competitiveness, profitability and so on...)

These three processes governing evolutionary dynamics are strongly interrelated. The selection process could only occur in a heterogeneous environment. But selection process tends to limit heterogeneity. To survive the selection process, heterogeneous agents have to mutate. And it is because a selection process exists that agent mutates. Then an evolutionary modelling cannot be considered without these interrelated processes.

Beyond these theoretical conceptions of economic dynamics, Evolutionary growth models share a common willingness to reproduce historical growth patterns. As stated by Nelson and Winter (1982):

“The challenge to an evolutionary formulation [is to] provide an analysis that at least comes close to matching the power of the neo-classical theory to predict and illuminate the macro-economic patterns of growth”. (Nelson and Winter (1982) p. 206)

Evolutionary growth modelling does not try to represent a balanced or stable growth path, but aims at reproducing, using theoretical models, some set of regularities and facts to be observed and emerging from the long-run growth patterns found along history.<sup>8</sup> The seminal Nelson and Winter (1982) work explicitly aimed at reproducing and explaining Solow (1957) data on total factor productivity for the United States. Their main target is to model growth process in an evolutionary way, generating “*considerable diversity of behaviour at the level of firm*” as well as an “[...] *aggregative time path of certain variables [...]*”, staying consistent with history but also compatible with Solow’s results.

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<sup>8</sup>Evolutionary growth models being, in fact, the outcome of a large empirical literature developed often by the same scholars. Even if we choose not to review this literature here, this fact deserves to be stressed.

As a reminder, one can briefly sketch Nelson and Winter (1982) growth model as follows :

First, heterogeneity is considered at the firms level. Each firm is characterised by its own production process (that can differ from others). Firms produce using a Leontiev type of production function. This excludes any substitution between capital and labour for a given technology. Technologies (i.e. production factors' productivity levels) are drawn from a given and finite 'pool of existing techniques'. The latter represents the state of advancement in scientific and technical knowledge. At any point in time, only some of the production techniques are known and used, while other remain to be discovered.

Second, selection occurs through market mechanisms. Hence at each period, aggregate demand (assumed exogenous) and aggregate supply (defined by firms production capacities) clears the market for homogeneous goods. At each period, market clearing defines the price level. The latter combined to wage level, technological parameters and capital stock defines each firms' profitability level. When firms profitability level no more exceeds a given threshold, they exit the market.

Finally, mutation concerns here the changes in technological characteristics (i.e. the production function parameters), due to technical progress as resulting from a formal R&D activity. This research activity is of two distinct types :

- 'Local search' consists in the development of unused and undiscovered sets of techniques within the pool. The local nature of this process resides in the concentration of the probability distribution of the possible new techniques around the existing ones. This reflects in a way the increasing cost of changing existing routines to adopt more distant techniques.
- 'Imitation' consists in the adoption of other firms techniques. The probability of success in imitating is proportional to the spread of a given technology in the economy.

All the macro-economic dynamics resides in the micro-dynamics of competition and technical change. Hence in their formal approach, the authors consider economic growth as driven at the micro-level.

## 3.2 Evolutionary Modelling of Economic Growth.

The seminal Nelson and Winter (1982) gave birth to an entire branch of evolutionary economics dedicated to the formal modelling of the economic growth process. But the undeniable relationship with this canonical work does not prevent this stream of literature to be conceptually and formally highly heterogeneous. We choose here to consider three major families of models, with respect to some of their main distinctive characteristics.

A first group of models is to be found in the works by Chiaromonte and Dosi (1993), Dosi and Fabiani (1994) and Dosi, Fabiani, Aversi and Meacci (1994). These models, in direct line with Nelson and Winter, share, among other, a disembodied conception of technical change, that distinguishes them from other evolutionary growth models. The production process is represented by a Leontiev production function. Chiaromonte and Dosi (1993) consider a two sector model with a capital good sector and a consumption good sector. The capital good is used in the production process of the consumption good. While in Dosi and Fabiani (1994) and Dosi, Fabiani, Aversi and Meacci (1994), labour constitutes the only production factor.

Heterogeneity is considered at the firm level, representing the lowest level of analysis of these models. It concerns both firms technological capacities (i.e. productivity levels) and firms behaviours. Hence firms might differ in terms of technological strategies, by allocating resources (i.e. profits) to R&D activity (innovation or imitation), and in terms of market strategies, the mark-up pricing rule being function of ‘market share targets’ by firms (in Chiaromonte and Dosi (1993) and Dosi et al. (1994)) or using a fixed parameter (Dosi and Fabiani (1994)).

Selection operates through market mechanisms. Authors represent these mechanisms by a replicator equation. The latter links the market share dynamics to the competitiveness of firms relative to the average competitiveness. The formal definition of competitiveness slightly differs among models. In Chiaromonte and Dosi (1994), competitiveness is measured using prices and unsatisfied demand. In Dosi and Fabiani (1994) and Dosi et al. (1994) economies are open. Authors consider economies as submarkets. Hence when firms act on their domestic markets, competitiveness is the inverse of price. When they operate on a foreign market it also includes the exchange rate. Then entry and exit process resulting from selection is such that every entry corresponds to the exit of a firm. Exit occurs when the market share on a



submarket is lower than a given threshold.

Finally mutation operates, as in the Nelson and Winter model through technological change resulting from an R&D activity. Technical change induce productivity increases. In Dosi and Fabiani (1994) and Dosi et al. (1994), the latter results from innovation or imitation. These processes are stochastic, and quite similar to the one used in Nelson and Winter (1982). The success of R&D depends on the employment resources devoted to this activity. The same processes are found in Chiaromonte and Dosi (1993) in the capital good sector. In the consumption good sector, technical progress is deterministic. Firms constantly learn to use the capital goods.

Unlike Nelson and Winter (1982) in which the macro-dynamics are derived from micro-dynamics, these models consider an explicit macro-framework for the micro-dynamics exposed above. All these models adopt a Keynesian vision. Total firms output is derived, and constrained by aggregate demand. Dosi and Fabiani (1994) and Dosi et al. (1994) consider multi-sectorial open economies. Aggregate demand regroups domestic demand as a constant share of the total wage bill (the other share being devoted to imports), and external demand. Chiaromonte and Dosi (1993) consider a closed economy. Aggregate demand for consumption goods correspond to the total wage bill. The aggregate demand for capital goods is derived from the production (constrained by demand) level of the consumption good. In all these models wages are set at the macro level. Their dynamics is linearly related to labour productivity, employment and consumption price growth rates. Dosi and Fabiani (1994) as well as Dosi et al. (1994) introduce an explicit representation of growth rate dynamics of exchange rates, function of the trade balance and external debt. The latter compensates and can then absorb artificially competitiveness divergence through monetary channels.

The open economy models are used to consider the convergence/divergence patterns of growth rates among countries. The models generate a strong tendency towards divergence. According to the authors this in fact reflect the persistence of inter-firms asymmetries in productivity, profits and market shares, and is strongly related to micro-behaviours. Convergence remains possible under strong conditions on selection (replicator dynamic parameters) and on diffusion and appropriability of technological externalities. Chiaromonte and Dosi (1993) model is used to refine Nelson and Winter (1982) results.

A second group of Evolutionary growth model to be found in the literature

is the one developed around Silverberg and Lehnert (1994) and reconsidered in Silverberg and Verspagen (1994, 1995, 1998). This family of models share a common embodied conception of technical change. Technical progress is assumed to be incorporated in capital vintages.

The Silverberg and Lehnert (1994) model can be described as follows. Production techniques represent the lowest level of aggregation. Heterogeneity occurs at this level with respect to labour productivity embodied in the techniques. New techniques vintages are generated randomly, following a Poisson distribution. By assumption, Silverberg and Lehnert consider that each new techniques labour productivity is a multiple of that of the best-practice technique. This multiplicative relation is fixed and constant over time. Thus technological progress would lead to proportional improvements of labour productivity. Adoption of new technologies by producers then depends on the profitability of the techniques. Given wage rates (economy-wide fixed) and output price levels (as each different technique produces one homogeneous good), the diversity of production techniques reflected in the diversity of labour productivity would lead to uneven profit rates.

The selection process follows a replicator mechanism, where the profitability of each production technique is confronted to the average profit rate. The techniques whose profitability is above the average profit rate will survive and those below would tend to disappear. These selection dynamics would lead to convergence among profitability of techniques toward ‘best practice’ techniques. This selection process implies that, at a given moment in time, only a finite number of techniques are still used, representing the most advanced techniques ever discovered within this economy.

These evolutionary micro-mechanisms are then considered within a macro-economic framework directly inspired by Goodwin (1967) model of growth and cycles. Authors consider the co-evolution of employment and wages in explaining short-run cycles along long-run trends. More precisely, in Silverberg and Lehnert (1994), the wage dynamics are purely deterministic, following a linear Phillips curve depending on both the accumulated wage level and the rate of employment. Employment at the micro level follows the dynamics of capital accumulation, which depend on profits. Capital accumulation influencing labour productivity due to the embodied nature of technical progress, the latter will itself influence the dynamics of employment, wages and gross products.

Silverberg and Lehnert use this framework to model both economic growth process and technological long waves. They conclude that innovation clus-

ters are not necessary to lead to the existence of long waves in Schumpeter's analysis. Generating stochastic innovation in this framework might be sufficient to explain existing long waves. However, the model seems to rather concentrate on the diffusion of technical change, and its effect on economic growth, leaving apart any economic analysis of the generation of technical progress itself, replaced by a stochastic process.

Silverberg and Verspagen (1994) completes Silverberg Lehnert (1994) model introducing changes in strategic mechanisms through 'behavioural learning', and considering micro-founded mechanisms for the generation of technical change. Heterogeneity is considered at firm level. It concerns the technologies adopted, and firm R&D strategies.

Capital vintages are developed within firms. The discovery of new techniques is random. The innovation potential (influencing the probability at which new vintage to be discovered) depends on a firm's R&D efforts and on its ability to benefit from spillovers from other firms' R&D efforts. These spillovers might be defined as follows: first firms can catch spillovers from economy-wide R&D spending (weighted by the market share sum of firms individual R&D levels), and second depending on both economy-wide and firm-specific spillovers. This would also imply that, once an innovation is discovered and introduced into the production process, this would gradually ease other firms imitation or adoption of this innovation.

Firms are characterised by experiencing learning processes in choosing between innovation and imitation. Firms will choose imitation when their profitability is 'unsatisfactory' with respect to leading firms (in terms of profits). In this sense, imitation behaviour is thereby endogenously determined and directly depending on its relative technological gap. As a result, leading firms would less frequently adopt imitative behaviour than laggards.

This model exhibits the following results. First firms' micro-behaviour converge over time to a "stable evolutionary equilibrium" characterised by a positive rate of technical change and R&D investment. Second, within this framework, initial conditions have a great influence on this steady state, and a low or non-existent rate of R&D would lead to stagnation in a "low growth trap".

Silverberg and Verspagen (1995, 1998) introduce behavioural learning on R&D investment choices. Firms are still assumed to be bounded rational, following rules of decisions for their investment choices. They, however, are able to learn to invest and renew these decision rules according to their own experience or the others experience. The renewing of decision rules

can occur in two ways : Through experimentation (i.e. random renewing of their decision rules) or through imitation (i.e. adopting others' R&D strategies). The updates in the decision rules are subject to an 'internal selection process'. Hence the firms will stick to their decision rules as long as they remain profitable decisions.

These two last variations of the Silverberg and Lehnert (1994) model then stress the importance of firms behaviour in the dynamics of growth, technical change and market structures.

The last family of models considered here is the so-called 'Technology-Gap' approach. In this framework, economic growth is directly driven by knowledge. A given economy is represented by its knowledge and technological dynamics. It means for a given economy the construction of its own knowledge stock and/or catching the others knowledge externalities. The economy dynamics are then directly linked to the interplay of two opposite processes. On the one hand, innovation will increase the innovator knowledge stock, but at the same time increase the technological and then economic gap with its followers. On the other hand, imitation or more broadly, technological diffusion processes tend to reduce the technological gap.

Technology-Gap approach then considers economic growth as a process that is based on the co-evolution of technological creation and diffusion. 'Technology-Gap' approach main concern is to explain inter-country growth rate differentials.

Fagerberg (1988) models aggregate output, or GDP as an increasing function of knowledge emanating from abroad, of knowledge domestically created, and the ability of the economy to exploit this knowledge in technological creation. This last component can be seen as the velocity of change in routines in adopting, adapting new technologies or knowledge in production process. The existence of this factor can also be seen as representing somehow the macro-competencies of the economy. These competencies allow the economy to combine different knowledge but also to exploit and gain from knowledge creation and diffusion. In this respect this approach can be seen as a macro-view of Nelson and Winter principles founding the evolutionary theory of firms. This macro-competencies cannot be only understood as the aggregation of firm level competencies, but as the whole spectrum of corporate and institutional competencies promoting knowledge diffusion, creation, and so one. In this respect this approach can be seen as a schematic view of what develops in details the systems of innovation literature.

The diffusion of foreign available knowledge is assumed to follow a logistic functional form. The diffusion of internationally available knowledge depends on the knowledge gap, such as the more the follower knowledge stock reaches the leader one, the longer and more difficult it would be to benefit from the others knowledge. The first technologies to be adopted are the less complex and easier to reproduce. The remaining ones require more R&D effort or competence increasing has to be done. Note that, as stressed by Fagerberg (1988), imitation might be used by followers to reach the leaders, but this would be insufficient without a gradual transition to innovation-driven technological progress within these countries. This will also mean that competencies to exploit knowledge should gradually be completed by competencies to create knowledge.

This quite simple and schematic modelling is rather developed in empirical analysis perspective, as most of ‘Technology-Gap’ approach. But it can also give us important hints in modelling knowledge and technology gap as factors of growth at an aggregate level.

Caniëls and Verspagen (1999) complete the ‘traditional’ Technology-Gap framework, reconsidering the mechanisms linked to the diffusion of knowledge and technologies among economies (regions). Authors consider a two-dimensional spillover mechanism, including at the same time technological and geographical distance. In this respect the absorption of foreign knowledge is localised and depend simultaneously from the technological gap and geographical neighbourhood. The geographical distance lowers the possibility to reduce the technological gap. The creation of domestic creation of knowledge follows a Kaldor-Verdoorn law.

Using this model to consider the evolution of patterns of technology gaps among regions, Caniëls and Verspagen (1999) found that for some high initial disparities, GDP growth rate differential tends to reduce, and not to increase. Geographical distance as technological distance might influence largely the catch-up process. It allows the authors to reproduce a ‘centre-periphery’ dynamic of the technology gaps well recognised in the development literature. The more the periphery region is far from leading centre, the harder the catching-up. This geographical specification aims as well to consider the tacit dimension of knowledge and of understanding, adopting or absorbing technologies.

## 4 Towards an Integrated Approach ?

The aim of this paper is to identify a formal framework to consider the co-evolution of macro-dynamics and technical change. We previously expose two approaches in modelling the economic growth process. These approaches constitute formal alternatives to the New Growth Theory. However these two approaches propose only partial analysis of the considered phenomenon. Our claim is then that combining elements of these two approaches one might find a satisfying formal framework to consider explicitly the interaction channels between macro-evolution and micro-dynamics of technological progress. The last part of this paper discusses the possibility of merging cumulative causation and evolutionary modelling of the economic growth process, and reviews the rare attempts to be found in the literature.

### 4.1 Complementarity, Convergences and Divergences

Trying to integrate these two approaches in a unified framework in modelling the co-evolution of macro-dynamics and the one of technical change starts from the strong complementarity between the two approaches. Hence, the one is responding to the weakness of the other. To stress this fact, let us recall briefly the main features of each of these analytical frames.

On the one hand cumulative causation presents a circular and self-sustained vision of the growth process. The latter is directly linked to the co-evolution of macro-dynamics and technical change. These two processes are interconnected. First macro-dynamics are linked to technical change via the existence of dynamic increasing returns. Second technical change is strongly related to macro-dynamics. Aggregate demand dynamics providing at the necessary resources to sustain technical change. However this macroscopic analysis of the growth phenomenon relies on a schematic representation of the mechanisms driving technical change. This representation brings with questionable quasi-automatic and constant improvements in technologies, leaving aside the analysis of the technological processes themselves.

Evolutionary modelling of economic growth, on the other hand, considers technical change as the core process driving macro-dynamics. This stream of literature concentrates on the emergence and diffusion of technologies and technical change within the economic systems. In line with Schumpeter it considers that the whole economic dynamics are responding to the micro-generated technological dynamics. The emphasis is then put on the analysis

of micro determinants and behaviours. The macro-dynamics are the resulting processes of the aggregation of micro-dynamics. The status given to macro-dynamics excludes any explicit consideration about the influence of the latter on the technological dynamics.

Hence where the Kaldorian approach lacks of micro-foundations of the processes driving technological change, evolutionary theories provide an entire battery of micro-based dynamics. This emphasis on representing micro-dynamics at the heart of the emergence and diffusion of technical change however suffer from the lack of macro-foundations. In the sense that it lacks of macro-frame allowing feedbacks from the macro-dynamics on the micro-level ones. In other words there is no explicit macro-constraint on the micro-dynamics. This is exactly where the Kaldorian approach completes the evolutionary modelling of the growth process. It emphasises the importance of the macro-structure in absorbing and amplifying the growth impulses emanating from technological dynamics. These growth impulses generate income providing through demand dynamics the resources to sustain technological dynamics.

In addition being complementary views, these two approaches also share some common conceptions of the representation of the growth process. That might sustain our willingness to integrate these two approaches in a common analytical frame.

First, these two streams of literature recognise the historical nature of the growth process. This historical nature is to be found first in the willingness to root theory into facts. Modelling of the growth process is based on a set of statistical regularities (i.e. Kaldor's stylised facts among others). Models aim first at reproducing observed growth path rather than generating eventually empirically testable balanced growth path as the NGT tends to. In this respect this willingness to stick to facts and history might be seen as a direct response to the NGT quasi-autism towards the empirical reliability of theories.

Second, Kaldorians as well as evolutionary theories on growth recognise the cumulative nature of the growth process. The latter can be linked to the cumulative and irreversible nature of technical change, and/or of knowledge accumulation, as in evolutionary approaches. It can also result from the complex interactions between macro-dynamics and technical change as for the cumulative causation approach. In any case the cumulative nature of the growth process, principally relies on the existence of dynamic increasing re-

turns. The presence of the latter generates irreversibility in the technological evolution. This reveals the path dependant nature of the growth path.

These two first points of convergence naturally lead the two approaches to share a common rejection of the equilibrium concept. This leads them to consider ‘out of equilibrium’ approaches to growth rather than the analysis of dynamic equilibria or balanced growth.

When turning to the modelling side of the theories, one can not help to stress some similarities. Hence the way cumulative causation links exports dynamics to competitiveness seems to be an implicit selection process, close moreover to the replicator mechanism to be found in many evolutionary models ; exports growing when competitiveness is higher then the average. It is, nevertheless, clear that this selection process remains partially implicit. But nevertheless in this respect cumulative causation already integrates evolutionary principles.

On the evolutionary side, one can build an evident bridge with Kaldor’s ‘technical progress function’ when considering the modelling of the R&D process. Hence, from Nelson and Winter (1982) to more recent models, technical change as resulting from the R&D process is strongly depending on investments. These investments influence directly the probability of success of the R&D activity. In short, technical change in evolutionary modelling could seem to rely on a stochastic version of the ‘technical progress function’ as developed by Kaldor (1957).

Hence, we do not have only complementary but also convergent approaches. This convergence occurs at two levels. First on the formal ground, they share common mechanisms linked to the growth process, such as the existence of dynamic increasing returns, explicit or implicit selection processes and the dependance of technical change to investments. Second, on the methodological ground, they commonly reject the equilibrium vision, considering the growth process as an historical, irreversible and cumulative process.

However, this apparent convergence hides an important implicit divergence. When Kaldorians consider the growth process as resulting from interactions between demand and supply, aggregate demand dynamics and technical change. It implies that the macro-dynamics influences directly the hidden micro-dynamics underlying the Kaldor-Verdoorn law. In other words a top-down process. While the evolutionary approach clearly considers economic dynamics as a bottom-up process. The dynamics of the economies are the direct consequence of micro-dynamics, and/or micro-behaviours. From



an evolutionary perspective it is then unconceivable that the macro-dynamics influencing or affecting micro-dynamics are not emergent properties of other micro-dynamics. Here one might particularly think about the balance of payment constraint that allows Kaldorians to deduce from it aggregate demand as a function of external demand. If one can easily overpass this conceptual divergence it however reveals the necessity, as modeller to carefully insure the existence and/or functioning of the interaction channels between macro and micro dynamics.

## 4.2 Formal Attempts of Integration:

The frontiers between cumulative causation and evolutionary conceptions of the growth process are not, as argued previously, hermetically sealed. Recently both cumulative causation and evolutionary literature seemed to increasingly try to overpass these frontiers.

The recent developments in cumulative causation approach include some explicit references to the ‘Technology Gap’ ideas.<sup>9</sup> Hence, Amable (1993), Cimoli (1994), Leòn Ledesma (2000), Castellacci (2001) and ourselves in Lorentz (2001), reconsider the formal representation of technical change from the original cumulative causation modelling. They complete the traditional Kaldor-Verdoorn law in order to capture some features characterising the technology gap approach. These modifications aim at including the effect of technological diffusion on labour productivity dynamics. The latter reduces divergence in growth and productivity, but stresses the importance of adoption/adaptations capacities for the economies to gain from the external flows of technology. It somehow creates an intermediate path to the dichotomy vicious/virtuous circle : the catching-up path, that can be complete, partial or fail.

On the evolutionary theory side, only few formal works explicitly introduce cumulative causation modelling in the evolutionary framework. These mainly are the works by Verspagen (1993, 1999, 2002).

Verspagen (1993, chap. 7) proposes, what can be understood as an evolutionary re-reading of cumulative causation approach to economic growth modelling. He represents growth within a multi-sectorial balance of payment

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<sup>9</sup>See Castellacci (2001) for a survey.

constraint framework. The sectorial level is the smallest unit analysed here. Sectors of a given country differ in terms of goods produced. This would imply that the different sectors might experience different income elasticities inside and among countries.

A selection mechanism is explicitly introduced through a replicator equation, reflecting competition between foreign and domestic producers of a given sector. This reflects the idea that consumers, in the absence of quality differences (reflected in income elasticities), would prefer low-priced products. Production costs are endogenously determined as a function of both technological and macro-economic factors, i.e. production costs depend negatively on the technological level of the sector and exchange rates, and positively on wage rates. Wages are determined through productivity growth and the unemployment growth rate, including some persistence, reflecting wage fixation as a path-dependent process. Exchange rates are quite rigid. They adjust slowly to ensure purchasing power parity in the long term. Thus, the selection process is a traditional evolutionary market selection process.

Another selection process applies at a more aggregate level, concerning this time the sectorial composition of aggregate demand. Hence, following Pasinetti (1981), Verspagen (1993) considers endogenous structural changes in the demand pattern. Demand elasticities (for each sector) with respect to income being function of the distance between the actual demand level and a predefined satiation level. In this respect the model can generate patterns of sectorial specialisation generating uneven GDP growth rates.<sup>10</sup>

Verspagen's specification of technological progress is directly rooted in the Kaldorian tradition as it is modelled using the Kaldor-Verdoorn law. This approach of technical progress is, in his own words, 'stylised' and "does not involve endogenous investment in R&D[...]" But technological change is all the same endogenously determined, through a process of learning-by-doing and dynamic scale economies, due to the Kaldor-Verdoorn law. Concerning his approach to technical change, Verspagen (1993) is then rather closer to the Kaldorian tradition than to the Nelson and Winter search process approach.

His framework is developed to analyse the influences of a country's integration into worldwide trade and of its technological level on the growth rates constrained by trade balances. More precisely, to analyse effects of differences in technological competence between countries, on the growth rate

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<sup>10</sup>A country leading in a given sector could grow slower than others if it is specialised in low growing sectors.

differential among nations. The multi-sectorial aspect of his analysis allows him to consider endogenous specialisation patterns. Cumulative characteristics of growth, technical change and wages tend then to bring about an explicit tendency towards industrial specialisation. This aspect was clearly assumed in the Kaldorian growth tradition, but is justified in this framework by an evolutionary selection process. This model tends to highlight clear relations between sectorial specialisation, technological change, and the growth process. These processes are both interdependent and self-reinforcing.

Verspagen (1999, 2002) propose a slightly different approach. The model uses a schematic multi-sectorial representation of the Dutch economy directly inspired by Keynesian macro-economics. The structure of the economy explicitly considers the interaction structure among sectors, with the use of an input/output matrix as an aggregate representation of the production capacities. Following the Kaldorian tradition, Verspagen considers that long run growth is linked to external demand. The computation of the aggregate demand dynamics is deduced from the balance of payment constraint. He obtains this way a reduced form for GDP growth rates including the sectorial interactions within what can be considered as a trade multiplier. The dynamics of external demand are modelled using a replicator equation. External demand is function of the competitiveness of the economy.

The framework presented aims at analysing the effect of different scenarios on the macro-dynamics, through their diffusion along the economy. The author concentrates on two types of scenarios: competitiveness shocks and technological shocks. The first scenarios induce some modifications in the growth impulse generated by external demand dynamics. The second affect the factors coefficient of the input/output matrix. These shocks will affect the structure of the economy. For a given growth impulse generated by external demand, it is then the propagation of these growth impulse that will be modified. Technical change is not endogenously considered in this model. Its interest for us is exactly that it demonstrate that the macro-economic framework itself strongly influence the macro-dynamics, by defining and constraining the diffusion channels of growth impulses.

More recently, in Llerena and Lorentz (2003), we introduce some evolutionary micro-founded mechanisms to generate technical change in a balance of payment constrained growth model. This way the model tend to provide some possible micro-foundations of the Kaldor-Verdoorn law, using a framework close to evolutionary models à la Nelson and Winter. At the same

time the use of the balance of payment constraint framework imposes some explicit macro-structure to the traditional evolutionary growth modelling.

More formally the model proposes a macro-economic framework directly in-line with Thirlwall' s model of balance-of-payment constrained growth, defining through international trade relationship the dynamic of aggregate demand and GDP. Aggregate demand dynamics is function of foreign aggregate demand growth through a trade multiplier, and of the economy's competitiveness of international markets (represented by its market share on international markets). The latter being related to firm's ability to increase their productivity and to the wage dynamics. Wages dynamics follow proportionally the economy' s labour productivity evolution, with some time lags. These two processes play then the role of macro-constraints on the micro-evolution of firms, being at the same time function of the latter. In this sense, we try to capture the co-evolution of the micro-evolution of technical change and the macro-dynamics.

At the micro level, we consider firms represented by a Leontiev production function, with labour as unique production factor. Technical change affects labour productivity. We derive it from the accumulation of capital vintages. These generations of capital are developed within firms. They result from firms R&D activity. The modelling of the R&D process is directly inspired by evolutionary models à la Nelson and Winter. Investment behaviours by firms with respect to R&D expenditures and to the introduction of capital goods in the production process are subject to adaptive decision rules. The latter are respectively responding to the gaps with the average competitiveness (for capital investment), and to average productivity level (for R&D expenses). Firms resources (i.e. profits) will then constrain the investment realisation.

We use this framework to consider the effect of some key parameters settings in generating growth rate divergence. We concentrate on two sets of parameters ; first on the effect of income elasticities (to imports and to exports) heterogeneity, on the macro side, and second on heterogeneous technological opportunities and appropriability of technological externalities on the micro-side. The model exhibits some refined results both with respect to Kaldorian and Evolutionary literature. Hence, macro-heterogeneity does not necessary drive towards vicious or virtuous circles, even if generating significant differences in GDP growth rates. Second, technological micro-heterogeneity is not always generating persistent divergence, as the evolutionary literature would suggest. Their effect might be absorbed or faded by some macro-mechanisms (i.e. wage dynamics).

This model has to be understood as a first attempt to use evolutionary micro-dynamics in a cumulative causation framework.

## 5 Concluding remarks

We try along this paper to find an approach to endogenous growth processes analysing the co-evolution of macro-dynamics and technological changes. To achieve this goal we choose to go through two heterodox approaches to the economic growth analysis: the cumulative causation framework and the evolutionary theorising of economic growth.

Considering the possible interactions between macro and technological dynamics implies to consider not only the way technical change generates productivity increases and then GDP growth. It also includes the analysis of the possible influence of macro-dynamics on technological change itself. Such an analysis then requires a framework that considers at the same time a clear understanding of the emergence and diffusion of technologies and of the macro-economic framework and mechanisms underlying the growth process. The two considered approaches seem, as we argued in this paper, to complete each other in describing these mechanisms. Hence when cumulative causation approach provides a complete description of the macro-mechanisms underlying the growth process, its description of technological dynamics remains schematic. It however helps considering the channel through which technical change contributes to economic growth, generating income and then demand allowing GDP growth. But it also underlines the importance of macro-dynamics in generating the resources necessary for technical change to occur. This last point might be one of the weaknesses of evolutionary models. They on the other side provide a more complete analysis of the emergence and diffusion of technologies at a micro-level, stressing the importance of firms behaviours in terms of R&D activity and investment behaviours.

This apparent complementarity leads us to consider the possibility to integrate the two approaches within the same framework. This should provide us with a modelling of the growth process allowing for a more complete analysis of the interactions between macro-dynamics and technical change. Few formal attempts can be found in the literature trying to achieve this merging. One could note the work by Verspagen (1993), that rather reconsiders the cumulative causation framework introducing explicit selection processes but without going into the micro-foundations of technical change. The model

we proposed in Llerena and Lorentz (2003), considers the macro-framework deduced from the cumulative causation as a macro-constraint framing the micro-dynamics and so technical change.

This formal attempt is nevertheless to be considered as a first brick in the construction of an integrated framework. Considering the macro-economic framework as a constraint implies an assumed rigid structure of the economy. Hence future developments, we claim, should reconsider the macro-structure itself. This might go through endogenous structural change modelling, among others. To achieve this, one might have to consider the micro-foundations of the aggregate demand dynamics, the macro-structure being then the result of the evolution of micro-behaviours. In other words the macro-framework should itself be an emergent property of the micro-evolution.

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