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Structural transformations and cumulative causation towards an evolutionary micro-foundation of the Kaldorian growth model

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Maastricht Economic and social Research institute on Innovation and Technology (UNU-MERIT)
email: info@merit.unu.edu | website: http://www.merit.unu.edu

Boschstraat 24, 6211 AX Maastricht, The Netherlands
Tel: (31) (43) 388 44 00

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Structural Transformations and Cumulative Causation Towards an Evolutionary Micro-foundation of the Kaldorian Growth Model

André Lorentz[1] Tommaso Ciarli[2] Maria Savona[3] Marco Valente[4]

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Abstract
We derive the Kaldorian cumulative causation mechanism as an emergent property of the dynamics generated by a micro-founded model. We build on an evolutionary growth model which formalises the endogenous relations between structural changes in the production, organisation and functional composition of employment and of consumption patterns (originally proposed by Ciarli et al, 2010). We discuss the main transition dynamics to a self-sustained growth regime in a two-stage growth pattern generated through the numerical simulations of the model. We then show that these mechanisms lead to the emergence of a Kaldor-Verdoorn law. Finally we show that the structure of demand shapes the type of growth regime emerging from the endogenous structural changes, fostering or hampering the emergence of the Kaldor Verdoorn law. This depends on the endogenous income distribution and heterogeneity in consumption behaviour.

Keywords: Structural change; economic growth; final consumption; technological change; cumulative causation; evolutionary economics; Kaldor-Verdoorn Law
JEL: O41, L16, C63, E11, O14

[1] Université de Strasbourg, Université de Lorraine, CNRS, BETA, Strasbourg, France, alorentz@unistra.fr
[2] UNU-MERIT, Maastricht and SPRU, University of Sussex ciarli@merit.unu.edu
[3] SPRU, University of Sussex, UK; M.Savona@sussex.ac.uk
[4] University of L'Aquila, Italy; marco.valente@univaq.it

0. Introduction

One of the age-old questions in economics is how economies start to grow and develop. A consensus has built around the idea that innovation creates wealth and growth. On the one hand, this is due to a, perhaps too literal, reading of Schumpeter's writings on innovation and economic cycles (Schumpeter, 1934; Schumpeter, 1939; Schumpeter, 1942). Schumpeter places innovation at the heart of the creative-destruction process, responsible for the dynamics of capitalist systems. On the other hand, modern growth theories that date back to the 1950s, consider the long-run transformation of production technologies as the sole driver of long-term growth. These latter approaches build upon the distinction between growth dynamics based on the accumulation of production factors along a given production frontier (i.e. extensive growth) and on the general improvement of the technology moving up the production frontier (i.e. intensive growth). This leads to consider the general improvement of the technology as separate from the production activity. As a consequence, within Neoclassical growth theories, technological changes are triggered outside of the production activities (Solow, 1957) and/or through investments in specific innovative activities (Romer, 1990; Aghion and Howitt, 1992).

The relationship between technological change and economic growth is however much more complex. Economic historians argue that the first industrial revolution resulted from the complex interactions between increases of final demand, changes of intermediate demand and the productivity gains enabled by technological change (Mokyr, 1977; Bairoch, 1993; Mokyr, 1992).

Alternatives to endogenous growth theories provide conceptual and formal representations of growth dynamics that are more in line with historical analyses. For instance, evolutionary economics developed in line with Schumpeter's writings, and models economic dynamics as driven by technological changes, resulting from the complex interactions between *micro-level behaviors*, *knowledge diffusion* and *market selection* (Nelson and Winter, 1982; Dosi at al., 1988; Dosi at al., 1994; Saviotti, 1996; Metcalfe, 1998; Silverberg and Verspagen, 2005). These elements constitute the backbone of an out-of-equilibrium approach to economic dynamics as complex, uncertain, evolving systems, which offers alternative foundations to the endogenous growth theory.

Prior to evolutionary approaches, among alternative to Neoclassical growth theories, the seminal work of Nicholas Kaldor sparks the development of the Post-Keynesian approach. This offers analytical and empirical foundations to the analysis of long-run growth as a self-reinforcing process driven by the co-evolving macro-dynamics of effective demand and technological changes (Kaldor, 1957; Kaldor, 1961; Kaldor, 1966; Kaldor, 1972). Further developments of this stream of literature focus on the interactions between the dynamics of foreign demand (Thirlwall, 1979; McCombie and Thirlwall, 1994; Thirlwall, 2002), the structure of domestic demand (Boyer and Petit, 1981; Boyer, 1988; Petit, 1999) and intermediate demand (Pasinetti, 1981) with technical progress.

Both evolutionary economics and post-Keynesian theories share a common analytical framing of economic dynamics as a historical and out-of-equilibrium processes, while providing complementary views of long-run growth dynamics. A few scholars have tried to account for the Kaldorian-like dynamics within an evolutionary context (Verspagen, 1993; Llerena and Lorentz, 2004; Metcalfe at al., 2006; Los and Verspagen, 2006; Lorentz and Savona, 2008, Lorentz, 2015). Verspagen (1993), Metcalfe et al. (2006), Los and Verspagen (2006) and Lorentz and Savona (2008) focus on the selection and diffusion sides of evolutionary mechanisms in a Kaldorian framework, while Llerena and

Lorentz (2004) and Lorentz (2015) provide an evolutionary micro-foundation to the processes of emergence and diffusion of technologies.

Within this stream of literature, the aim of this chapter is to examine the evolutionary micro-foundations to Kaldor's principle of cumulative causation, and stress the interplay between structural change and economic growth. We build upon the evolutionary model developed in prior works (Ciarli at al., 2008; Ciarli at al., 2010b; Ciarli at al., 2010a, Ciarli and Lorentz, 2010; Ciarli at al., 2012; Ciarli and Valente, 2016; Lorentz at al., 2016; Ciarli at al., 2019), which formalizes the links between production, organization and functional composition of the employment on the supply side and the endogenous evolution of consumption patterns on the demand side.

In line with the evolutionary economics' tradition, our prior work considers aggregate transformations as resulting from the interactions of individual behaviors, on both the supply and the demand-side, and from the creation of product variety, as in Saviotti and Pyka, 2004; Saviotti and Pyka, 2008. Unlike these latter, we have explicitly linked product variety with individual behaviors.

A few scholars have explicitly accounted for firms' effort to invent, and interact with consumers in producing novelty (Malerba, Nelson, Orsenigo and Winter (2007); Dosi, Fagiolo and Roventini (2010). We build on these latter and look explicitly at the behavioral foundations of the structure of consumption and earnings in shaping the changing structure of demand.

The unified growth theory models also study the transformation from a stagnant agricultural economy to a rapidly growing industrial economy, typically referring to the industrial revolution in England (Desmet and Parente, 2012; Galor, 2010; Lagerlof, 2006; Stokey, 2001; Voigtländer and Voth, 2006). In these works, the sources of structural changes are however partially accounted for, as they either focus on the technological or supply-side changes while neglecting the demand side, or look at the changes of human capital formation, population growth and capital investment (Galor 2010, Voigtländer and Voth, 2006), or the joint changes in consumer goods and firm size (Desmet and Parente, 2012).

The main contribution resulting from the exercise proposed in this chapter is to derive the Kaldorian cumulative causation (Kaldor, 1966; Kaldor, 1972) mechanism as an emergent property of the dynamics generated by micro-behaviors. Here we define structural change in terms of changes in the organization and composition of production, income distribution and patterns of consumption. We investigate whether and how these aspects of structural change affect the long-term patterns of economic growth and technological progress, looking in particular at their inter-linkages and co-dynamics.

The remainder of the chapter is organized as follows. Section 2 reviews the main elements of the Kaldorian growth theories for which we aim to provide micro-foundations, based on the evolutionary model described in section 3. Section 4 discusses the emergent properties of the dynamics generated by our evolutionary model of structural change in line with the Kaldorian theories. More precisely section 4.1 presents the main dynamics of the self-sustained growth regime generated through the numerical simulation of the model. Section 4.2 discusses the mechanisms leading to the emergence of a Kaldor-Verdoorn law from the micro-dynamics of technological change. Section 4.3 discusses the conditions on the structure of demand allowing for (different) self-sustained growth regimes to emerge. Finally, Section 5 summarizes the main contribution to the literature that can be drawn from the model proposed here.

1. Elements of the Kaldorian Growth Theories

Kaldor's contribution to the theories of long-run growth revolves around three main pillars. First, economic growth is a historical process. Every theory of economic growth should account for historical regularities. Second, technical change and the transformation of the structure of production have to be considered as endogenous processes affecting economic growth. Third, aggregate demand and its transformation are central to ensure a self-sustainable growth process.

From 1956 to 1961, Kaldor published a series of papers building and developing his first model of economic growth, as an alternative approach to both the contemporary Keynesians growth theory (Harrod, 1939; Harrod, 1948) and the Neo-classical theory (Solow, 1956; Solow, 1957). In his 1957 growth model, Kaldor states the importance of modelling and understanding the process of economic growth as an historical process. He identifies a set of historical regularities, or stylized facts, that characterize the process of economic growth:

SF1 Industrialized economies experience continuous growth in GDP and labor productivity.

SF2 Industrialized economies are characterized by a continuous increase in the ratio of capital per worker.

SF3 The profits rates on capital are constant.

SF4 The ratio of capital over GDP is unchanged over long periods.

SF5 Income distribution is constant over time. The share of labor income over GDP is constant over time: this implies that the rate of wage growth is, on average, proportional to productivity increases.

According to Kaldor, these regularities are not only incompatible with the Neoclassical growth theories, but also show that distinguishing between the intensive and extensive growth mechanisms makes little sense from a theoretical perspective. Building upon these regularities, he develops an extremely synthetic model that endogenies, first, the link between income distribution and the accumulation of capital and its future growth (Kaldor, 1956). Second, he relates the productivity dynamics to the accumulation of capital introducing a 'technical progress function' that marks the first model with endogenous technical change (Kaldor, 1957) (for a recent review of this, see (McCombie and Spreafico, 2016)). The combination of these elements allows Kaldor to propose a representation of economic growth as a path-dependent and endogenous process.

This model allows him to distinguish two growth-regimes of the capitalist economies: the stagnant growth path typical of the early stages of capitalism and the self-sustained growth path of the mature stages of capitalism.

In the mid-sixties, Kaldor revised his conceptualization of the growth process to further fit historical evidences and his growing interest in economic development processes.

On the one hand, beyond the mechanization process, he links technical change to dynamic increasing returns that underpin the technical progress function. These result from the combination of two distinct but interconnected processes (Kaldor, 1966; Kaldor, 1972): first, efficiency gains derive from the resources generated in the past and invested in renewing the production capacities. Second, Kaldor refers directly to Young (1928), a macro-level division of labor allows for efficiency gain. The resources made available are used to develop the general technical knowledge and favor the

diversification of production activities. The combination of these mechanisms is formalized at the macro-level as a linear link between the productivity growth rate and the growth rate of output. This relation is known as the Kaldor-Verdoorn law.

On the other hand, he stresses the importance of the structure and transformation of aggregate demand in the circular relationship between the efficiency gains due to increasing returns and the increase of production as a response to income growth. This relationship induces a 'chain reaction' in the economy. Growing sectors generate income growth, resulting both from final consumption, and from intermediate demand that generates in turn investment. Growing sectors generate (intermediate) demand for other sectors of the economy in a 'chain reaction', the amplitude of which depends on the structure of final demand, intermediate demand and foreign demand and their interconnections. Let us look at each of these more in depth.

First, the structure of final demand, linked to income elasticity of each sector, directly affects aggregate income growth. Income elasticities in turn depend on the income and employment structures of household. Kaldor (1966) distinguishes three income classes affecting income elasticities: (i) low-income classes, which mainly consume food and primary goods; (ii) high-income classes whose consumption concentrates on luxury goods and services; (iii) middle-income classes whose consumption concentrates on manufactured goods. The higher the income elasticity, the more efficient the 'chain reaction' is, though the role of the middle-income class in the growth process is central.

Second, the structure of intermediate demand explains how growth diffuses across the economy, through intersectoral linkages.

Third, foreign demand sparks the initial growth process. Economies have to reach a 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 resulting from foreign demand with the self-reinforcing growth of domestic demand.

Taken together, these elements constitute 'the principles of cumulative causation', according to which economic growth is a self-reinforcing phenomenon, that is able to generate the necessary resources to self-sustain in the long run. The cumulative nature of growth relies on a circular co-evolution of increasing returns and aggregate demand. The dynamic increasing returns ensure the long run improvement in the efficiency of production capacity, and the competitiveness of the economy. The increase of aggregate demand drives production capacity and the competitiveness of the economy.

For Kaldor, the cumulative nature of the growth process can only lead to two possible growth patterns:

1. Growing through a 'virtuous circle': the multiplier effect ensured by productivity gains sustains the growth of competitiveness and aggregate demand;

2. Drowning in a 'vicious circle': dynamic increasing returns are not sufficient to sustain competitiveness and/or the multiplier effect does not allow the necessary chain reaction on the demand side.

The structural characteristics of economies (consumption structure and industrial specialization, among others) define their ability to start a virtuous circle. These, together with the cumulative nature of the growth process, explain the history on long-run growth analysis.

The principles of cumulative causation are empirically identified as the three Kaldor's growth law at the heart of the Post-Keynesian literature on growth and development (Thirlwall 1983):

1. The growth of GDP is positively correlated to the growth of the manufacturing sector. This captures the multiplier effect linked to the structure of the final demand.
2. The growth of productivity in the manufacturing sector is positively correlated to the growth of the manufacturing sector (the Kaldor-Verdoorn law).
3. The growth of productivity of non-manufacturing sectors is positively correlated to the growth of the manufacturing sector.

A number of contributions have empirically tested the Kaldor's laws, including the Kaldor-Verdoorn law (for recent reviews see McCombie and Spreafico (2016), Pacheco and Thirlwall (2014), Romero (2016)). This literature has however mainly focused on SFs 1-3, those related to the three Kaldor's laws, and mainly in the context of how structural changes of (developed and developing) economies has affected aggregate productivity trends and economic growth (Bah, 2011; Pacheco and Thirlwall, 2014); whether the manufacturing sector has effectively been an engine of productivity growth vis a vis services (Di Meglio at al., 2018; Felipe and Mehta, 2016; Tregenna, 2011); and whether the Kaldor's laws could be detected in countries at different stages of development, such as South-East Asia (Dasgupta and Singh, 2005; Felipe at al., 2009) and the African countries (McMillan at al., 2014; Page, 2012; Wells and Thirlwall, 2003).

The evidence has not unanimously supported SFs 4-5 on the constant rate of profits and wages, whereby the financialization of economies that Kaldor could not predict at his time have led to increasing wage inequality. However, the above literature has in general found support to the fundamental role of the manufacturing sector as an engine of productivity growth and cumulative causation linked to domestic and foreign demand. This empirical support has in fact nurtured the sort of concerns around 'premature de-industrialization' put forward by Rodrik (2016). In a recent and comprehensive analysis, Di Meglio et al. (2018) show that, over several decades and across developed and developing countries, the Kaldor's laws are proven to be still valid for the manufacturing and business service sectors, and across Asian countries alongside mature industrialized countries, realizing the 'virtuous circle' mentioned above. However, still in line with empirical grounding to the Kaldorian SFs, the lack of a substantial industrial core as well as sectoral shifts to personal and low-tech services have had detrimental effects on the aggregate productivity growth, rather leading to the 'vicious circle' kind of patterns in many Latin American (Romero, 2016) and African Countries (McMillan et al., 2014; Rodrik, 2016; Wells and Thirlwall, 2003).

2. An Evolutionary Micro-Founded model of Structural Change and Economic Growth

Throughout a series of papers (Ciarli at al., 2008; Ciarli at al., 2010b; Ciarli at al., 2010a, Ciarli and Lorentz, 2010; Ciarli at al., 2012; Ciarli and Valente, 2016; Lorentz at al., 2016; Ciarli at al., 2019, we have developed a class of evolutionary micro-founded models of structural change. We model

economic growth as a result from the transformations in the economic structure rooted in microeconomic dynamics. We define here structural change in a broad sense. Beyond the change in the sectoral composition of the economy, we account for the inter-linkages and co-dynamics between the organization of production and the production technologies on the supply-side, and income distribution and consumption patterns on the demand side.

In the baseline model, the economy is composed by two production sectors (capital goods and final good producers) responding to the corresponding components of aggregate demand (investments and consumption). These sectors are composed by a fixed number of firms producing heterogeneous goods. Final demand is represented by a population of households earning their income by working in firms from both sectors, earning a share of profits generated by firms in both sectors and consume goods produced by firms in the final good sector. The firms in the final good sector invest in capital goods produced by firms in the capital good sector. Figure 1 summarizes the structure of the interaction between sectors.

[Figure 1 about here]

Within firms in both sectors, labor is hierarchically organized. At the base of the pyramid firms employ shop-floor workers, responsible for the production process. To define the other, endogenous, hierarchical levels of the organization we follow the evidence that that any given number of employees at a certain level has a coordinating manager. In this respect, the organization of labor implies static diseconomies of scale. Any expansion of production requires to increase both the number of shop floor workers, for a given labor productivity level, as well as the several layers of mangers. This leads to an increase in the unitary labor costs.

Each firm in the capital good sector produces a single capital good with a specific embodied level of productivity. Firms in the capital good sector improv the embodied level of productivity through innovation. This is the only source of productivity gains in the final good sector and in the economy as a whole.

The population of household composed by the workers/consumers in each sector is subdivided in different income classes characterized by different income levels and preferences. The different income classes, are assumed to correspond to the various hierarchical positions within the firms.

In total, the model includes three non-Walrasian markets (Colander at al., 2008; Dosi et al., 2010): final good, capital good, labor. On the final good market, households spend their income to buy products from final good firms whose supply is constrained by their production capacity (including stocks buffering short term differences). On the capital good market, producers use labor to produce the capital goods ordered by the firms in the final good sector. The demand for capital depends on the obsolescence of existing capital goods and on the investment decisions responding to increases in sales. New capital goods, produced on order, embody the most recent innovations offering increasing levels of labor productivity. The labor market is implicitly represented in the model. We assume a perfect coordination of the supply and the demand of labor in the long term, with short-term inertia allowing for transitory periods of disequilibrium. The minimum wage, used to set the wage of shopfloor

workers, reflects these transitory disequilibria as it increases with excess demand for workers, and in the long run follows productivity gains and inflation.

The baseline model makes a number of simplifying assumptions, such as, for example, lacking international trade and a financial sector. It, however, contains a fairly detailed account of the mechanisms aggregating individual decisions both on the demand and on the supply side so as to provide rather sophisticated macro-level properties. The implementation details of this baseline model have been described in several previous works (Ciarli et al., 2008; Ciarli et al., 2010b; Ciarli et al., 2010a; Ciarli et al., 2012; Lorentz et al., 2016). Further extensions of the model include: industrial dynamics and consumer imitation leading to the concentration on the supply and demand side (Ciarli and Valente, 2016); a multi-industry final good sector, firms liquidity constraints and labor market institutional settings to account for various growth regimes (Ciarli et al., 2018); product innovation, sectoral diversification and the emergence of new sectors as a source for long run development (Ciarli and Lorentz, 2010).

In the following we provide a brief description of the individual elements of the model, focusing in particular on the modules at the core of the structural changes. In particular we shed some light on the behavioral link between income and consumption, the preference structure and the role of expectations in firms' operative production decisions.

2.1 Final Good Sector

The final good sector is composed by a fixed number of firms offering a product whose quality is differentiated across firms and exogenously fixed. Firms produce using labor and capital, set the price of their product, invest in capital goods, and distribute wages and bonuses.

Production

Firms use heuristics to form expectations about their demand in each period, aiming to minimize the gap between realised production and sales – i.e. inventories. The level of output results from the combination of firms' planned production and their production capacity.

Firms first estimate the demand that they expect to receive during the current time step. The demand is subject to both random short-term volatility and long-term trend changes of the purchasing power, population and composition of demand across classes. We assume that firms adopt an adaptive rule based on the gap between past estimations and current demand. Formally, a firm's estimation of its own demand for the current period, $Y_f^e(t)$ is computed as:

$$Y_f^e(t) = a^s Y_f^e(t-1) + (1-a^s) Y_f(t-1) \tag{1}$$

where $Y_f(t-1)$ is the lagged value of the actual demand. The behavioral parameter a^s, defined in the [0,1] range, weights the importance the two elements, signaling a more conservative or a more forward looking strategy in forming expectations. A comparatively higher value implies a strategy more strongly anchored to past expectations making little importance to the realized level of demand. These firms tend to interpret observed deviations from expected values as due to randomness. On the contrary, a low level of the parameter signals a firm willing to adapt quickly to observed variations.

These firms are ready to promptly change their strategy in the belief that observed variations are likely to be permanent.

Second, firms define the desired production level ($Q_f^d(t)$) once after subtracting the stock of unsold past production ($S_f(t\ -\ 1)$), if positive, from the expected demand:

$$Q_f^d(t) = max\{(1+\bar{s})Y_f^e(t) - S_f(t\ -\ 1); 0\} \tag{2}$$

Finally, firms compute the actual production $Q_f(t)$ considering the amount of production factors available: labor $L_f^1(t-1)$ and capital $K_f(t\ -1)$, discounted by their respective productivities ($A_f(t\ -1)$ is the labor productivity embodied in the capital vintages and D_f is a fixed capital intensity ratio:[1]

$$Q_f(t) = min\{Q_f^d(t); A_f(t\ -1)L_f^1(t-1); D_f K_f(t\ -1)\} \tag{3}$$

<u>The Structure of the Workforce</u>

Following an established literature (Simon, 1957; Lydall, 1959; Waldman, 1984; Abowd at al., 1999; Prescott, 2003), we represent firms as hierarchical organizations. Under this assumption, only shop floor workers contribute to production, but the labor costs of a firm include also managers to coordinate workers and middle level managers. We assume that each manager is able to coordinate a given number of employees *v*, so that larger firms of require a larger number of layers of managers. For a given number of shopfloor workers $L_f^1(t)$, the total number of workers in each layer l is given by:

$$L_f^l(t) = v^{1-l}L_f^1(t) \tag{4}$$

The number of shopfloor workers is determined on the basis of the desired production and the current level of productivity embodied in the capital accumulated by the firm ($A_f(t\ -1)$), subject to two distinct adjustments. First, firms maintain a share of excess labor, indicated by u^l, as an insurance against unexpected failures of some workers. Second, changes to labor force are subject to procedural frictions during the processes of hiring and firing workers, so that only a portion ε of any desired change to the labor force can actually be carried out within a single time step. The formal representation of the number of shop floor workers (layer 1) in firm *f* at time *t* is then:

$$L_f^1(t) = \varepsilon L_f^1(t-1) + (1-\varepsilon)\left[\left(1+u^l\right)\frac{Q_f^d(t)}{A_f(t\ -1)}\right] \tag{5}$$

<u>Capital and Investments</u>

The level of productivity embodied in the capital stock is computed as the average productivity across all vintages available, discounted by their depreciation:

$$A_f(t) = \sum_{h=1}^{V_f(t)} \frac{k_{h,f}(1-\delta)^{t-\tau_h}}{K_f(t)} a_{g,\tau_h} \tag{6}$$

Where a_{g,τ_h} is the productivity embodied in the h vintage put in production at time τ_h. The variable $k_{h,f}$ is the amount of capital (measured in terms of units of output) whose contribution is discounted at the depreciation rate δ. The stock of capital $K_f(t) = \sum_{h=1}^{V_f(t)} k_{h,f}(1-\delta)^{t-\tau_h}$ is made of the sum of vintages of the units of capital purchased in the past and still in production, considering an exogenous rate of depreciation.

Final good firms order new capital when the expected demand cannot be satisfied with the capacity available with the current capital. They choose the capital supplier based on three features: price, productivity embedded in the capital vintage and delivery time. This last criterion reflects the fact that capital good producers work on order generating delays in the availability of capital goods. The cost of new capital is paid at delivery by final good firms using the funds accumulated through time as fixed share of revenues. Such funds pose an upper constraint on the amount of capital units a firm is able to order.

Wages, prices and profits

The model assumes a single, economy wide minimum wage, which is the only income received by shop floor workers. Employees in the remaining organisational layers (managers) receive two distinct sources of income: wages and bonuses (a variable income derived from non-spent profits), when available. The managers' wage is a multiple of that paid to shop floor workers, with the multiple proportional to the hierarchical level occupied (Simon, 1957; Rosen, 1982):

$$w_f^l(t) = b^{l-1} w_f^1(t) \tag{7}$$

The bonuses represent implicitly the remuneration of financial investments by households. The amount distributed as bonuses (also proportional to the hierarchical position) is the residual obtained by subtracting from revenues total wage costs and the cost of capital, if any.

The price of the final good products is determined as a mark-up on unit variable cost. Note that because of the larger management structure of larger firms, this cost structure implies short-term dis-economies of scale (Idson and Oi, 1999; Criscuolo, 2000; Bottazzi and Grazzi, 2010). Economies of scale are obtained dynamically by acquiring more productive capital goods compensating the organizational costs.

Profits are obtained multiplying the price by actual sales and subtracting total payroll costs. Profits are accumulated over time to be used, primarily, for capital purchase and, if not used for this purpose, distributed as bonuses to the managers.

2.2 Capital sector

The capital good sector is composed by firms producing units of capital goods whose embodied level productivity is variable, differentiated across different suppliers, and determined by their R&D. Capital producers start building an ordered capital good using their production capacity, determined by their labor force. Since typically production capacity is smaller than capital orders, capital producers need several time periods to complete an order. Capital producers maintain a backlog of orders that they use to estimate the time of delivery for prospective buyers.

Production and organization

Capital good firms fulfil orders on a 'first in first out' basis, always working on the oldest order in their book. As for the final good firms, only shop floor workers contribute to production, but their organization requires a hierarchy of managers and no other (explicit) input.

Technology, R&D and innovation in capital vintages

The technological level of a capital producer is expressed by the labor productivity embedded in the capital goods they sell. This level changes as a result of investments in R&D financed by past profits and spent in wages to pay a class of engineers, so that larger firms are able to maintain larger research labs (Llerena and Lorentz, 2004). Innovation is modelled following a standard random process (Nelson and Winter, 1982), where the size of R&D spending affects the likelihood to innovate.

A successful innovation offers the opportunity to improve the technological level of the firm, assuming gradual technological improvements. The new technological level provided by an innovation, when this is successful, is a random increasing in the current level:

$$a_{g,\tau} = a_{g,\tau-1}\left(1 + \max\{\varepsilon_g(t); 0\}\right) \qquad (8)$$

where $\varepsilon_g(t) \sim N(0, \sigma^a)$ is the random size of productivity increment provided by the innovation. The advances in the vintages' embodied productivity are higher, the larger the variance of the stochastic process of innovation σ^a.

When a firm innovates successfully, the new level of productivity is embodied in all capital goods delivered from the moment of its discovery onwards.

Wages, prices and profits

The determination of wages, prices and profits is similar to that used for final good producers. Firms pay wages to managers proportional to their position in the hierarchy as multiples of the shop floor workers (who receive the minimum wage). Prices are given by a mark-up on unit variable costs. Profits are accumulated over time and used to distribute bonuses to managers or to hire new R&D engineers.

2.3 Households

As in any macro-economic model there exist a connection between production costs and demand. However, in our model, the connection is at the level of the single employee who spends his/her income according to an individual demand function modelled after evidence collected from behavioral psychologists.

Income distribution

The two main features of consumers in our model are their income and preferences. We assume that preferences depend on the 'social' status determined by a consumer class. The class of each worker is determined by the hierarchical position occupied within the firm in which she works. We aggregate

consumers in classes whose members share the same preferences and average income, obtained by dividing the sum of income of all members of a class (wages plus bonuses) by its members.

Consumption

A crucial assumption in our model is that consumption expenditures in a given period of time do not necessarily equal total income accrued at the same time. The literature has long accepted that consumer spending is driven by long-term consumption smoothing (Krueger and Perri, 2005), less volatile than income. The model assumes that total consumption in a given period for each class is determined according to the following equation:

$$C_z(t) = \gamma C_z(t\ -1) + (1-\gamma)W_z(t) \tag{9}$$

Where $C_z(t)$ is the total consumption expenditure for class z and $W_z(t)$ its income. Notice that we assume here that savings are collected from excessive income when this is higher than consumption and these savings are used when consumption exceeds the income level. This implicit financial sector is neutral in redistributive terms across savers and, over the long term, matching in- and out-flows of savings. The parameter γ controls the speed at which consumers adjust their consumption expenditure when their income changes. When $\gamma > 0$ households are assumed to change the past level of expenditures only partially. The speed of adjustment of consumption to income γ can be thought as a sort of proxy for the propensity to consume, allowing to study how this aspect affects, beyond other factors, overall conditions of economic systems. The behavioral interpretations of this parameters are discussed and analyzed in Lorentz et al. (2016).

Purchase decisions and sales

The model computes separately the consumption decisions for each consumer class, so that the total sales by each firm are obtained aggregating the sales in each class. Formally, the model generates the distribution of market shares for the class across all products available, implementing the equivalent of a market research collecting the choice of a sample of consumers and then expanding the market share distribution of the sample to match the total consumption expenditure for the class, obtaining the absolute level of sales from that class for each producer.

At the core of the procedure to compute the sales is the representation of the choice by the individual consumer. The routine representing the consumer's choice is based on the literature on cognitive psychology and bounded rationality (Simon, 1982), as discussed in Valente (2012).

The routine consists in ranking alternative products (from different final good firms) according to one of the available product features (price or quality, in our case), and removing all dominated choices. The other dimension is used to further filter the remaining products. Instead of assuming that consumers choose the best product, we assume that they set a minimum threshold for each feature, and purchase from all final good firms above the threshold. The threshold is computed as a difference with respect to the best product (lowest price or highest quality). The routine therefore provides an intuitive and clear definition for preferences, which consists in the tolerance to accept deviation from the best option. Different tolerance levels (preferences) differentiate consumer class: higher income classes are more tolerant with respect to high prices, but less tolerant with respect to quality.

Conversely, low-income classes primarily look at the price of products, and among the lower price products are very tolerant with respect to quality.

Formally, classes are endowed with different values for the tolerance parameter, decreasing with income for quality and increasing for price. The parameters controlling the level and distribution of preferences across classes are assigned according to the following equations:

$$\upsilon_{p,z+1} = (1 - \delta_{\varsigma})\upsilon_{p,z} + \delta_{\varsigma}\upsilon^{min} \quad (10)$$

$$\upsilon_{q,z+1} = (1 - \delta_{\varsigma})\upsilon_{q,z} + \delta_{\varsigma}\upsilon^{max} \quad (11)$$

where $\upsilon_{p,z}$ is the tolerance in respect of price, measured here in terms of tolerance for cheapness, $\upsilon_{q,z}$ the tolerance in respect of quality, and z is the index for the class; assuming z to increase for higher income classes. The values υ^{min} and υ^{max} are the asymptotic values for the tolerance levels. Their effect on the economy does not depend on their absolute value but on their difference. When they are very close, income classes have similar preferences; as they increase the differences in the preferences of classes also increases. The parameter δ_{ς} controls the concentration of preferences distribution around their extreme values in the lowest and highest income classes. A high value differentiates strongly the lowest income classes from the others, while a low value produces a more even distribution.

3. Towards the Evolutionary Micro-foundations of the Kaldorian Growth Theories: Evidences from Numerical Simulations

Reverting to such an agent-based model usually aims at analyzing whether and how the interactions among micro-behaviors such as the ones presented above generate sensible aggregate dynamics. Our ambition here is to provide evidence that the evolutionary micro-dynamics at work in our model provide micro-foundations to Kaldor's growth theories. In order to do so, we first discuss the connection between the main outcome of the numerical simulations conducted with this baseline model in the light of Kaldor's growth theories, discussing the endogenous taking-off mechanisms allowing economies to transition from stagnant to growing economies (Section 4.1). Second, we show that some correlation between the aggregate outcome emerging from the evolutionary micro-dynamics allow the model to generate the endogenous technological dynamics necessary to support the cumulative causation mechanisms described by Kaldor (Section 4.2). Third, in the spirit of the co-evolving demand and technological dynamics sustaining cumulative causation, we are interested in disentangling the effect of changes in patterns of consumption on the functioning of the Kaldor-Verdoorn law.

3.1 An Emerging Two-Stage Growth Pattern.

The simulation results presented and discussed in the series of papers making use of this baseline model aimed more specifically at understanding how the micro-level source of structural changes affect the patterns of long-run growth and income distribution. The numerical simulations discussed in these papers were obtained using the model initialized on the basis of the benchmark configuration of the parameters as reprised in Table 6 in Appendix.

The main, and very robust, feature found in these numerical simulations is the emergence of a two-stage growth pattern (Ciarli et al., 2008, Ciarli et al., 2010b):

1. A pre-take-off phase in which the growth patterns are characterized by a low GDP growth and a stagnant labor productivity coinciding with a low degree concentration on the final good market and in terms of income distribution, stagnating wages and low income disparities.

2. A post-take-off phase in which the growth patterns are characterized by a high GDP growth and a steadily growing labor productivity together with increasing employment. This coincides with increasing concentration of the markets and in terms of income distribution, increasing wages, increasing profits and increasing, but limited, income inequality.

This two-fold growth pattern can be illustrated by Figure 2 presenting the time series for selected aggregate outcome generated using the benchmark setting of the model.

[Figure 2 about here]

Similar patterns are shown within the unified growth theory models, which also attempts to explain the transition from pre-Malthusian growth to modern growth (see Galor, 2010, for a recent review). However, in these models the economy is usually characterized by an agricultural sector for subsistence and a manufacturing sector. Households maximize their utility by deciding between the quantity and quality of their children, where quality is education. Returns to education increase with technological change, while high education increases technological progress, allowing to escape from the Malthusian trap as population grows. Although these models provide an appealing explanation for the transition, the models seem at odds with the evidence that many economies had larger population than Britain before the industrial revolution, where education levels were not particularly high. Moreover, apart from the trade-off between more or better educated children, modelled as a rational choice, these models lack connection with other micro parts of the economy on the supply and demand side which we think is required for a better understanding of the transition.

Instead, the two-fold pattern generated with our model resonates with Kaldor's early works on growth. Rejecting the Neo-classical approach to economic growth, and the use of a traditional production function, he stresses the need to consider technical change as driven by investments, and to the construction and expansion of production capabilities. These investments on the other hands are a direct response to the distribution of income as they can be triggered by both profit-seeking behaviors or an expanding effective demand (Kaldor, 1957; Kaldor, 1961). With this alternative approach to modelling economic growth, Kaldor claims to be able to account for the two phases of capitalism that the British economy experienced prior and following the first industrial revolution:

1. An early stage of capitalism characterized by a low productivity growth and wages remaining close to the subsistence. Investments are constrained by profits margin and remain too low to ensure a sufficient accumulation of capital to sustain productivity growth.

2. A mature stage of capitalism where investments are independent from the profits rate and driven by the actual level of demand, insuring a sufficient growth of productivity. This high productivity growth allows wages to surpass the subsistence level and sustain the expansion of demand.

In the simplistic formal model developed by Kaldor, the key mechanism allowing the transition from the early to the mature stage is played by investments. For Kaldor, switching from profit seeking to expected demand as the behavioral driving force to investment allows the economy to mature and sustain long run growth and productivity gains.

The transition between the two stages in our simulation model also relies on the investment mechanisms. Though, the rules defining the investment behavior remain fixed in our model. As discussed by and large in Ciarli et al. (2010b), the transition is triggered by the accumulation of resources to sustain an R&D activity in the capital good sector due to the accumulation of investment by the final good firms. The cumulativeness of investment requires the combination of two key mechanisms: an expanding final demand triggering the expansion the production capacities at the macro-level and a selection mechanism directing demand toward the firms already benefiting from productivity gains due to prior expansion of their production capacities.

We analyzed, in previous papers, the conditions on the parameters controlling the micro-dynamics at the heart of the structural change processes allowing for the take-off to take place. We showed that both the parameters defining consumption behaviors and income distribution on the demand-side as well as the ones controlling the changes in the production structure both in terms of labor and capital have a significant effect either on the occurrence or the amplitude or the timing of the transition from a stagnant to a growing economy (Ciarli et al., 2012; Lorentz et al., 2016).

First, a subtle balance in the selection dynamics is required to allow for the transition between the two growth phases to occur since the nature of the consumers' preferences can hamper or favor the transition from one phase to the other. Hence, contrary to what is usually found in the evolutionary literature, an initial big push toward industrial diversification is not conducive to high growth. High product variety plays a relevant role in the economic growth only when it is accompanied by a broad heterogeneity in consumer preferences (Ciarli et al., 2012). Otherwise, when product heterogeneity is broad during the initial stages of stagnant growth, the strong firm selection induced by homogenous consumers before the expansion of demand level hinders the cumulative feedbacks. Though, as discussed in Lorentz et al. (2016), the higher the consumer selectivity the faster and the more ample the transition mechanisms leading to the higher output and labor productivity growth.

Second, the structure of consumption, affecting the selection mechanisms, also evolves with the structure of income. Hence, the firms' organizational and earning structures affect economic growth both via the level of aggregate demand and income disparities through selection. More complex hierarchical structures sustain aggregate demand in the long run, with a larger amount consumed despite increasing average wages and prices, and inducing the transition to demand-led cumulative causation growth allowing for the necessary heterogeneity in consumption behavior increasing the number of intermediate consumer classes at the cost of increased income inequality (Ciarli et al., 2012).

Third, more complex hierarchical structures, coupled with large productivity gains embodied in capital goods, accelerate the transition and lead to higher output levels. On the one hand, in the

long run, larger productivity gains increase wages and reduce the amount of labor per unit of production containing prices, both sustaining the expansion of final demand. On the other hand, in the short run, the larger the productivity gains the higher the profits, which are then more evenly distributed with more complex hierarchical structures. These increase the available income and final demand fostering the transition mechanisms (Ciarli et al., 2012).

It takes time to build the mechanisms allowing the investments to generate productivity gains, and the economy to take-off. The simulation results discussed in Ciarli et al. (2012) and Lorentz et al. (2016) show that the take-off requires a subtle balance between the expansion of income and final demand and the selection mechanisms distributing these resources to the firms.

3.2 Emerging Dynamic Increasing Returns

The historical regularities listed by Kaldor and discussed in more details in section 2 stress the continuous expansion of production, productivity and mechanization of developed economies on the supply-side, and regularity of income distributions as well as their connection to supply dynamics on the demand-side. At the time, these were meant to validate the relevance of a model of economic growth. We focus, in this section, on the mechanisms connecting SF1 and SF2 in the simulations results produced by the model starting from the description of the pattern systematically emerging in the simulations initialized on the basis of the benchmark configuration. We show in this section that the mechanisms allowing the model to generate dynamics in line with these facts are responsible for the emergence of dynamic increasing returns.

[Figure 3 about here]
[Figure 4 about here]

Figure 3 displays the two-fold output growth patterns endogenously emerging from the model, for which the turning point is around step 1100. During the first stage the GDP is characterized by a stable pattern of growth: growth in income, through wages and/or population increments, feeds increasing spending for final consumption and firms' expansions, inducing a cumulative pattern. In this state, however, investment grows at the rate broadly similar to the rate of capital depreciation and the increase in employment. Hence, this level of demand for capital goods is not sufficient to finance a sufficient level of R&D, therefore capital producers are not able to introduce innovations. In the second stage, increase in the final demand percolate to large capital investment in new technology with increased productivity. There are enough workers employed to sustain a growing final demand, requiring a larger expansion of the production capacities. These investments create an additional source of income for capital producers to invest in R&D sustaining further innovations. The results show that productivity starts to increase (see Figure 4), though with volatility across firms.

At a first look the two phases of growth patterns differ in terms of the R&D expenditure in the capital sector driving technological innovation and the labor productivity of the economy. The combined growth of GDP and productivity (SF1) only emerges in this second phase the simulation. This relationship between the growth of GDP and that of labor productivity, initially identified by Verdoorn (1949) and restated by Kaldor (1966), is since known as the Kaldor-Verdoorn law. This empirical

relationship is, for Kaldor (1966), evidence of the existence of the dynamic increasing returns necessary for a self-sustained growth regime to emerge.

Table 1: Kaldor-Verdoorn Law OLS and LAD cross-section estimates over 100 replications of the benchmark setting for the average growth rates (over 2000 simulation steps)

		$\Delta Y/Y$	Const.	R^2	R^2_{corr}	Obs.
(OLS)	$\Delta A/A$	0.1004***	0.0004***	0.46	0.45	100
		(0.100)	(7.23e-05)			
(LAD)	$\Delta A/A$	0.1091***	0.0004***			100
		(0.019)	(0.0001)			

*** p<0.01, ** p<0.05, * p<0.1
Least Absolute Deviation (LAD) estimates computed using the Barrodale-Roberts simplex algorithm.
LAD standard error derived using the bootstrap procedure with 500 drawings

In Table 1, we estimate the Kaldor-Verdoorn law for the whole period and find significant evidence of the positive relation between productivity growth and output growth. Our evolutionary micro-founded model of structural change therefore generates an endogenous Kaldor-Verdoorn law.

Table 2: Kaldor-Verdoorn Law Sub-Period Estimations. LAD cross-section estimates over 100 replications of the benchmark setting for sub-period average growth rates

Time Period		$\Delta Y/Y$	Const.	Obs.
1-200	$\Delta A/A$	-0.250	0.011	100
		(0.857)	(0.007)	
		$\Delta Y/Y$	Const.	Obs.
200-400	$\Delta A/A$	-0.009	3.732e-05	100
		(0.062)	(0.0002)	
		$\Delta Y/Y$	Const.	Obs.
400-600	$\Delta A/A$	0.027	-8.065e-05	100
		(0.063)	(0.0002)	
		$\Delta Y/Y$	Const.	Obs.
600-800	$\Delta A/A$	0.130	-0.0005	100
		(0.102)	(0.0004)	
		$\Delta Y/Y$	Const.	Obs.
800-1000	$\Delta A/A$	-0.038	0.0001	100

		(0.049)	(0.0003)	
		$\Delta Y/Y$	Const.	Obs.
1000-1200	$\Delta A/A$	0.324***	-0.002***	100
		(0.062)	(0.0003)	
		$\Delta Y/Y$	Const.	Obs.
1200-1400	$\Delta A/A$	0.128***	-0.0004***	100
		(0.009)	(9.09e-05)	
		$\Delta Y/Y$	Const.	Obs.
1400-1600	$\Delta A/A$	0.127***	-0.0006***	100
		(0.020)	(0.0001)	
		$\Delta Y/Y$	Const.	Obs.
1600-1800	$\Delta A/A$	0.184***	-0.001***	100
		(0.0146)	(0.0001)	
		$\Delta Y/Y$	Const.	Obs.
1800-2000	$\Delta A/A$	0.141***	-0.0007***	100
		(0.011)	(8.05e-05)	

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Least Absolute Deviation (LAD) estimates computed using the Barrodale-Roberts simplex algorithm.
Standard errors derived using the bootstrap procedure with 500 drawings.

When we turn to the same relation for different sub-periods (Table 2), there is an even stronger evidence of the presence of a Kaldorian regime occurring after a structural change in firms-organization and production technology, preceding the take-off, and is based on dynamic increasing returns and sustained investment in technology.

[Figure 5 about here]

In the early stages of (stagnating) growth, the low pace of change in organization and technology does not increase the production capacity to a level sufficient to generate sustained productivity gains. As presented in Figure 5, the phase of sustained growth and productivity gains also corresponds to a deepening in the use of capital relative to labor in the production process. In this respect, the model reproduces the SF2 stressing the capital deepening, i.e. a constantly increasing ratio of capital per worker for a growing output.

In Table 3, we show estimates of the effects of an increase in the output growth rate on the capital / labor ratio ($\Delta K/L$) for the whole period. Capital deepening in our model is the mechanism

through which output growth affects labour productivity and explains the Kaldor-Verdoorn law. Indeed, growth is accelerated by increases in productivity, which is the result of investment in new capital goods with higher embodied labor productivity, leading to an increase of the K/L ratio.

Table 3: Capital deepening and growth (SF2). OLS and LAD cross-section estimates over 100 replications of the benchmark setting for the average growth rates (over 2000 simulation steps).

		$\Delta Y/Y$	Const.	R^2	R^2_{corr}	Obs.
(OLS)	$\Delta \frac{K}{L} / \frac{K}{L}$	0.140***	-0.0004***	0.650	0.646	100
		(0.010)				
(LAD)	$\Delta \frac{K}{L} / \frac{K}{L}$	0.142***	0.0004***			100
		(0.014)	(8.95e-05)			

*** p<0.01, ** p<0.05, * p<0.1

Least Absolute Deviation estimates computed using the Barrodale-Roberts simplex algorithm. LAD standard error derived using the bootstrap procedure with 500 drawings

These evidences on the key role played by capital deepening in explaining sustained productivity growth are reinforced when considering sub-period estimates, as reported in Table 4. As for the Kaldor-Verdoorn law, the positive correlation between GDP growth and capital deepening appears significant only during and after the take-off phase. The expending final demand triggers the expansion of production capacities by firms in the final good sector. These investments in capital goods embody productivity gains. The aggregate productivity increments, as well as capital deepening, are the direct results of the expansion of final demand in the take-off phase. Productivity gains and capital deepening are sustained in the post-take-off phase through a drop in production costs, as productivity gains at the firm level overcome the growing cost induced by larger hierarchical structures. The drop in costs and therefore prices fosters final demand, triggering further investments and the resulting capital deepening. Capital deepening on the other hands fosters intermediate demand providing resources for firms in the capital good sector to invest in R&D and sustain the productivity gains embodied in the capital goods they produce. This then sustains the macro-level productivity gains. The combination of these mechanisms therefore translates into the Kaldor-Verdoorn law.

Table 4: *Capital deepening and growth (SF2). LAD cross-section estimates over 100 replications of the benchmark setting for sub-period average growth rates*

Time Period		$\Delta Y/Y$	Const.	Obs.
1-200	$\Delta \frac{K}{L} / \frac{K}{L}$	-0.220	0.004***	100
		(0.138)	(0.001)	
200-400	$\Delta \frac{K}{L} / \frac{K}{L}$	-0.014	6.11e-05	100
		(0.026)	(5.42e-05)	
400-600	$\Delta \frac{K}{L} / \frac{K}{L}$	-0.036	0.0001	100
		(0.026)	(0.0001)	
600-800	$\Delta \frac{K}{L} / \frac{K}{L}$	-0.307***	0.001***	100
		(0.112)	(0.0004)	

800-1000	$\Delta \frac{K}{L} / \frac{K}{L}$	-0.048 (0.048)	0.0001 (0.0003)	100
1000-1200	$\Delta \frac{K}{L} / \frac{K}{L}$	0.233*** (0.097)	-0.001** (0.0005)	100
1200-1400	$\Delta \frac{K}{L} / \frac{K}{L}$	0.238*** (0.021)	-0.001*** (0.0002)	100
1400-1600	$\Delta \frac{K}{L} / \frac{K}{L}$	0.161*** (0.021)	-0.001*** (0.0002)	100
1600-1800	$\Delta \frac{K}{L} / \frac{K}{L}$	0.217*** (0.008)	-0.001*** (6.73e-05)	100
1800-2000	$\Delta \frac{K}{L} / \frac{K}{L}$	0.217*** (0.018)	-0.001*** (0.0001)	100

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Least Absolute Deviation estimates computed using the Barrodale-Roberts simplex algorithm.
Standard errors derived using the bootstrap procedure with 500 drawings.

Final demand, as seen above, plays a crucial role in sustaining these productivity gains, as a trigger for capital deepening, in the take-off phase, and in creating a feedback loop between productivity gains and capital deepening in the second growth phase. Note that we choose to focus here on SF1 and SF2, overlooking the SF3 to SF5. As discussed in section 2, recent empirical evidences tend to contradict these historical regularities stressed by Kaldor in the 1950s. A detailed account of the stylized facts the family of model we developed from this baseline model is further discussed in Ciarli et al. (2019)

3.3 Consumers behavior and the Kaldor-Verdoorn Law

Defining the principles of cumulative causation, Kaldor stresses that the technological factors alone are not sufficient to explain growth processes. Increasing returns on the supply side are also strongly influenced by the structure of demand. In this section we investigate the effects of the structure of final demand on the dynamics of productivity growth as measured by the Kaldor-Verdoorn law.

We focus here on the parameters controlling the degree of heterogeneity in preferences among consumer classes. The conjecture is that these parameters affect both the macro-level price and non-price elasticity, thus varying the resources of firms and, ultimately, their investment capacity and the resulting productivity gains. For each parameter setting, we run 40 replications each lasting for 2000 steps[1]. This allows to account for same-configuration volatility and consider two distinct sets of results, the first being the overall effects on levels of GDP and the second the strength of the Kaldor-Verdoorn law on aggregate productivity. To measure the size of the economy we use the final values for (log) GDP and aggregate productivity. As in the case of the benchmark simulations, we estimate the presence of the Kaldor-Verdoorn law by considering the cross-simulation correlation between average increase in GDP and labor productivity[2].

The parameters υ^{max} and υ^{min}define the limit tolerance levels and their difference controls, first, the class differences in preferences between the lowest consumer/income class and the

asymptotical preferences towards which the highest consumer/income class tend to. Second, in this specification of the model, the distribution of preferences corresponds to the differences in the relative weights assigned to the characteristics of the products, namely, price and quality levels. Increasing these differences therefore increases the heterogeneity in the relative weights of the characteristics of products in consumer's decision. Hence this parameter controls both inter-class heterogeneity and the preference space of the consumer/income of the single classes.

The parameter δ_ς controls the speed of convergence toward the asymptotical preferences as the number of income classes increases. The larger the value of the parameter, the smaller the intermediate distribution of preferences in the population between the initial and the asymptotic distributions. If $\delta_\varsigma = 1$, all consumer/income classes but the first tier adopt the asymptotic distribution. If $\delta_\varsigma = 0$, all consumer/income classes have the same preference pattern as the lowest income class, regardless their income.

[Figure 6 about here]

Figure 6 presents the average outcome (over the 40 replications) after 2000 simulation steps in terms of GDP and labor productivity levels, changing the values assigned to parameters, υ^{min}, υ^{max} and δ_ς. The results obtained through numerical simulations show that heterogeneity in preferences has a non-linear effect of growth. For lower differences in the distribution of preferences, the lower the difference, the higher the GDP at the end of the simulation runs. In these cases, the faster the distribution of preferences tends to the asymptotic differences, the higher the GDP levels. However, GDP levels reach the highest levels for higher differences in the preference parameters ($\upsilon^{max} - \upsilon^{min}$) together with a high number intermediate distribution among classes. These correspond to the demand regimes with the highest degree of heterogeneity among consumers. Interestingly, though, the heterogeneity in consumption seems to limit productivity gains, as high levels of heterogeneity lead to the lowest level of productivity. Conversely, the faster the distributions of preferences converge to the asymptotic distribution, the higher the productivity levels.

These results reflect two distinct growth regimes. On the one hand, GDP and productivity grow in parallel, and consumption is highly standardized. On the other, trends in GDP and productivity diverge and consumption is highly heterogeneous. These regimes reflect the long-known dichotomy between extensive and intensive growth. In our simulations, the extensive growth regimes correspond to the path in which the systems experience high consumer's heterogeneity and the engine of long run growth is to be found in the generation of variety on the production side. The diversity of consumption behaviors allows (or forces) the final good sector to diversify into niches. This allows a larger number of firms to survive producing heterogeneous products. Sales being spread across a larger number of firms, the macro-level production capacities are spread across a larger number of producers, requiring fewer investments. Fewer investments translate into lower productivity gains. The more spread the sales, the more labor force is required to produce, generating higher demand, through higher employment levels. The corresponding increase in the number of consumer/income layers reinforces this heterogeneity. Conversely, in the intensive growth regime characterized by highly standardized consumer's preferences, the engine of long run growth lays in productivity gains. The final good market is more concentrated, i.e. fewer firms serve the final demand. These firms have

to expend their production capacities, and therefore gain in productivity through the growing investments in increasingly more efficient machinery. The resulting drops in costs imply drops in prices leading to an expending final demand. The larger demand calls for more investments in production capacities and further productivity gains.

Table 5: ***Kaldor-Verdoorn Law LAD estimates with changes in δ_ς and $\upsilon^{max} - \upsilon^{min}$***

		δ_ς						
		0.0	0.1	0.2	0.4	0.6	0.8	1
	0.0	1.789***	1.094*	1.305***	1.403***	1.774***	0.094	0.929***
	0.2	1.300***	1.203***	1.441***	1.087**	1.576***	1.049***	0.882*
$\upsilon^{max} - \upsilon^{min}$	0.4	1.439***	1.672***	1.644***	1.535***	1.676***	0.564	0.175
	0.6	0.575	2.168***	1.333***	0.493	0.775**	0.877***	0.484**
	0.8	-0.093***	0.150***	0.173***	0.102***	0.134***	0.120***	-0.120***

Standard errors (computed with 400 bootstraps) in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Least Absolute Deviation: Estimates computed using the Barrodale-Roberts simplex algorithm.
Standard errors derived using the bootstrap procedure with 500 drawings.

Table 5 presents the results of the LAD estimates of the Kaldor-Verdoorn law for each parameter settings. In most of the cases, the law is verified, the estimates being positive and significant, and, in accordance with the results discussed above, the lower the heterogeneity in preferences, the higher the value of the Verdoorn coefficient. On the one hand, the more homogenous the preference patterns the higher is the amplitude of increasing returns. In these regimes, growth is mainly intensive. The emergence of these increasing returns is the necessary condition for the growth process to hold. First, productivity gains are required for demand to expend through drops in costs and prices. Second, these productivity gains draw on the expansion of productive capacities triggered by the expending demand. With estimated values above 1, however, as the economy grows the employment is reduced. The effective demand expands due to increases in wages resulting from these productivity gains, compensating for the loss in income due the reduction in employment at the macro level. On the other hand, in a regime with higher heterogeneity in consumption, growth is mainly extensive. Demand is spread in niches; the expansion of production capacity is less dramatic and so does capital deepening and productivity gains. The economic growth is driven by the expansion of demand linked to income gains, rather than the sole drop in prices. As the production capacities are spread across a larger number of firms and niches, the productivity gains are less concentrated, and an expanding demand requires more workers. With estimated values of the Verdoorn coefficient between 0 and 1, as the economy grows, employment expands, but less than proportionally in respect of the growth of production. This expansion of employment leads to an expansion of income and of effective demand, without the necessity for high productivity gains. This also explains why GDP is higher in this regime despite the lower productivity levels as depicted in Figure 6

4. Concluding remarks

This chapter has aimed to add to the large and diverse literature on structural change and economic growth by addressing the joint effects of different dimensions of structural transformations on economic growth and aggregate productivity.

We have argued in our previous work that structural change encompasses much more than a change in the sectoral composition of economies. The structure of production, and the way in which it is organized by firms, together with the structure of demand, are the main candidates to explain the growth differences that we observe across and within countries over time. The changes in production factors along a production function are not independent from the shifts of the function, usually referred to as the Solow residual, or technological change. We have modelled the complex set of mechanisms at work, providing solid micro-foundations to macro-evidences and stylized facts on long-term growth.

In this chapter we build upon this analytical effort and focus on the specific effects that these micro-founded structural changes have on the occurrence of the Kaldor-Verdoorn law and the emergence of different cumulative causation regimes. First, we show that the two-phases or two-regimes of endogenous growth in capitalist systems, discussed both in Kaldor (1957) and Kaldor (1966), are indeed related and that the transition from one to the other one results from a fine balance between technological change, selection mechanisms and the growth of demand. Second, we show that these mechanisms are also responsible for the emergence of dynamic increasing returns as measured by the Kaldor-Verdoorn law occurring in the post-take-off phase. Finally, we analyze the role of the heterogeneity in consumption patterns resulting from changing preferences and income classes' mobility on these dynamic increasing returns. In particular, different degrees of heterogeneity in consumption behaviors shape different growth regimes emerging from the endogenous structural changes. We find that the more homogenous the demand, the more dominant are intensive growth dynamics, allowing for larger productivity gains, and higher increasing returns. Conversely, the more heterogeneous is consumption, the more the extensive growth patterns dominate. The economy grows faster despite low productivity gains, through the growth of income and employment. The switch between one regime to the other can be directly triggered by changes in the market structure resulting from demand-driven structural changes.

Overall, our contribution allows to strengthen the stream of literature on growth dynamics as labeled by 'When Schumpeter meets Keynes '(Dosi et al., 2010), which in fact revisits earlier contributions that accounted for evolutionary dynamics and post-Keynesian elements, that we reviewed in Section 2. We consider this line of investigation to be of fruitful potential use, both for positive and normative purposes. While the present attempt can be ascribed to the positive/analytical contribution, our research agenda definitely includes the normative use of our proposed model and theoretical approach, most especially toward leading countries out of gloomy recessions.

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Table 6: *Parameters setting. Parameter's (1) name, (2) description, (3) value, and (4) empirical data range*

Parameter	Description	Value	Data
$\underline{i}_2$	Minimum quality level	98	See Ciarli et al. (2012)
$\bar{i}_2$	Maximum quality level	102	See Ciarli et al. (2012)
a^s	Adaptation of sales expectations	0.9	-

$\overline{s}$	Desired ratio of inventories	0.1	[0.11 - 0.25]
u^l	Unused labor capacity	0.05	0.046
u	Unused capital capacity	0.05	0.046
$\overline{\mu}$	Mark-up	0.2	[0-0.28]; [0.1, 0.28]; [0.1, 0.39]
δ	Capital depreciation	0.001	[0.03, 0.14]; [0.016, 0.31]
$\frac{1}{D}$	Capital intensity	0.4	D = [1.36, 2.51]
ε	Labor market friction	0.9	0.6; [0.6, 1.5]; [0.7, 1.4]; [0.3, 1.4]
ω	Minimum wage multiplier	1.11	[1.6, 3.7]
b	Executives wage multiplier	2	See Ciarli et al. (2012)
ν	Tier multiplier	5	See Ciarli et al. (2012)
γ	Smoothing parameter	0.8	See Lorentz et al. (2016)
ς_j^i	Error in the consumer's evaluation of characteristics	j = 1: 0.05; j = 2: 0.1	-
δ_ς	τ inter-class multiplier	0.2	See Lorentz et al. (2016)
$\upsilon^{min} = \upsilon_{2,1}$	Highest = first tier quality tolerance	0.1	See Lorentz et al. (2016)

$\upsilon^{max} = \upsilon_{1,1}$	Lowest = first tier quality tolerance	0.9	See Lorentz et al. (2016)
z	Parameter innovation probability	10000	–
σ^{a}	Standard deviation productivity shock	0.01	See Ciarli et al. (2012)
ρ	R&D investment share	0.7	–
ω^{E}	Engineers' wage multiplier	1.5	[1.2, 1.4]
F	Final good firms	50	–
G	Capital good firms	15	–
H_z	Consumer samples	50	–

Note that the detailed references and data sources used to set the parameter values for the baseline model can be found in Ciarli et al. (2008), Ciarli et al. (2010b), Ciarli et al. (2010a) and Ciarli et al. (2012)

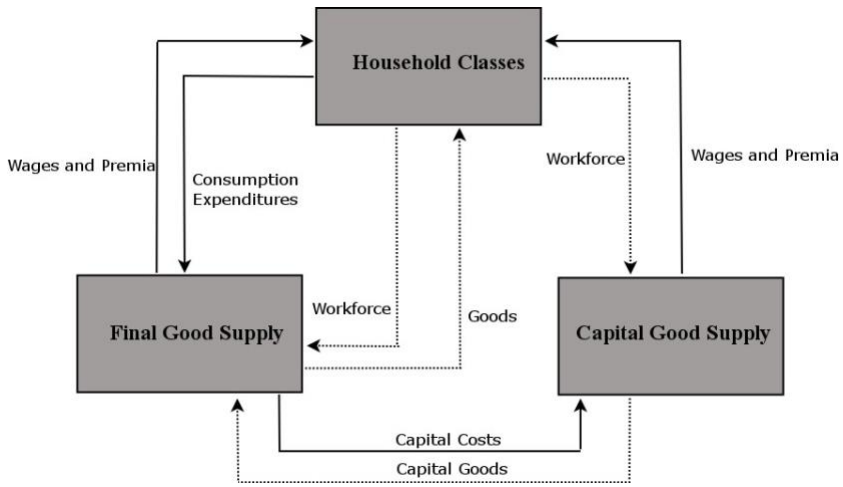


Figure 1: *Flow diagram of the baseline model*

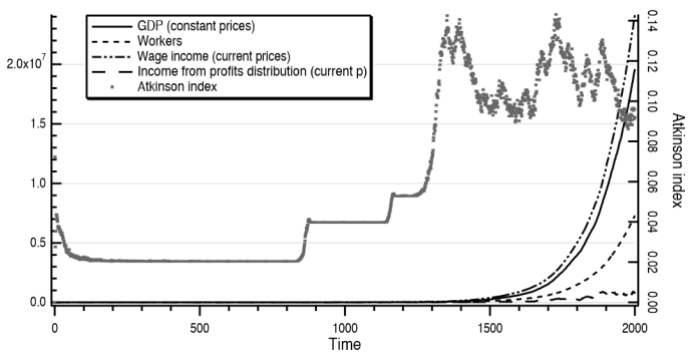


Figure 2: Main Aggregate Output (Constant Price GDP, Employment, Wage income, Profit income, and Atkinson Index of inequality; for each time step the series reports the average value across 100 replications

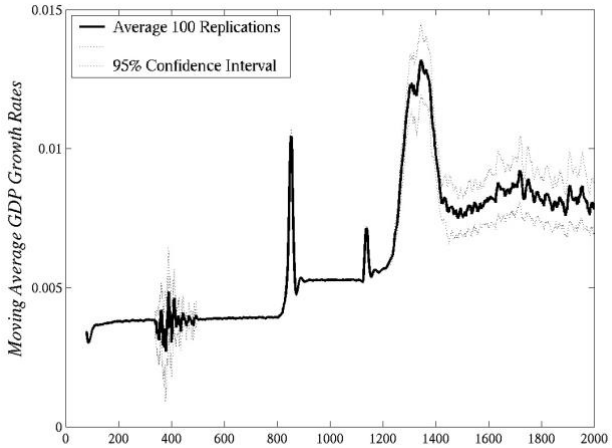


Figure 3: Growth rates for the economy output across time (SF1); data from 10 periods moving averages computed over punctual growth rates. For each time step the series reports the average value across 100 replications together with interreplication 95% confidence intervals

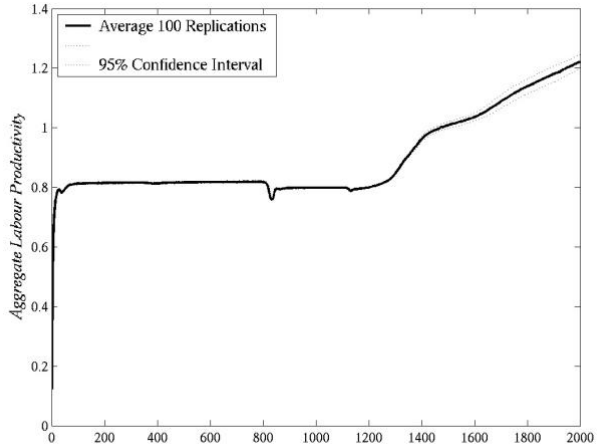


Figure 4: Aggregate Labor productivity across time steps (SF1). For each time step the series reports the average value across 100 replications together with inter-replication 95% confidence intervals

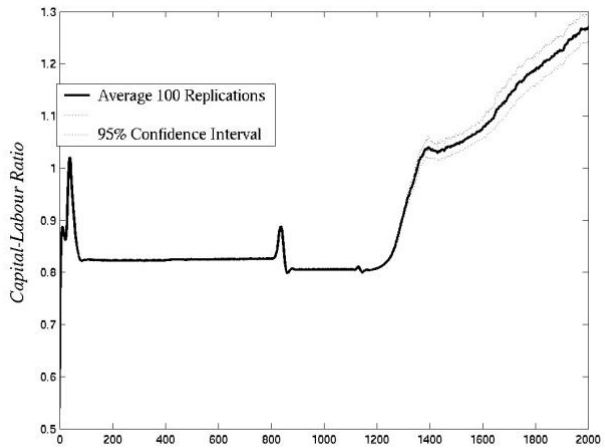
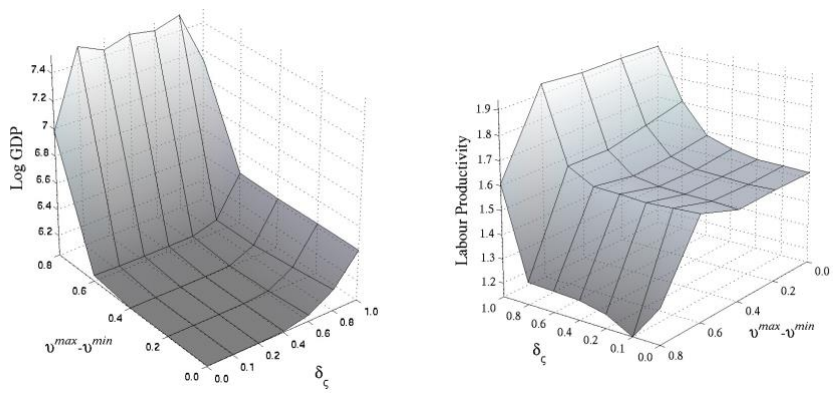


Figure 5: Capital-Labor ratio across time steps (SF2). For each time step the series reports the average value across 100 replications together with interreplication 95% confidence intervals



(a) Log GDP (b) Aggregate Productivity

Figure 6: Log GDP and Aggregate Labor Productivity levels at step 2000 for changing values of δ_ς and $\upsilon^{max} - \upsilon^{min}$

[1] The number of replications is large enough to ensure significant and robust results (see Ciarli et al., (2012)). The resulting sample of replications is sufficiently large to sustain the Least Absolute Deviations estimations. The duration of each simulation replication is arbitrarily set to ensure that every replication reaches a stabilized post-take-off stage.

[2] For each simulation we compute the average level of GDP growth and labor productivity growth. We then estimate the regression of average GDP growth onto average productivity growth across all the 40 simulations adopting the same parameters configuration; the reported values are the coefficients of the regressions.

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