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

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Abstract

We build upon the evolutionary model developed in prior works (Ciarli, Lorentz, Savona and Valente 2010b), which formalises the links between production, organisation and functional composition of the employment on the supply side and the endogenous evolution of consumption patterns on the demand side. The main contribution resulting from the exercise proposed here is to derive the Kaldorian cumulative causation mechanism as an emergent property of the dynamics generated by the micro-founded model. More precisely, we discuss the main transition dynamics to a self-sustained growth regime in a two-stage growth patterns generated through the numerical simulation 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 (among others the heterogeneity in consumption behaviour) itself shapes the type of growth regime emerging from the endogenous structural changes, fostering or hampering the emergence of the Kaldor Verdoorn law.

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

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1 Introduction

One of the age-old questions in economics is how economies develop, expand and keep growing. A consensus has built around the idea that innovation creates wealth and growth. On the one hand, this premise is due to perhaps 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, the mainstream growth theories that date back to the 1950s, consider the long-run transformation of production technologies as the sole driver of long-term growth. This approach builds upon the distinction between an expansion through the accumulation of production factors along a given production frontier (i.e. extensive growth) and the general improvement of the technology moving up the production frontier (i.e. intensive growth). This leads to detaching the general improvement of the technology from the production activity. As a consequence, technological changes are triggered outside of the economic sphere (Solow 1957) or through specific investments in ad-hoc innovative activities (Romer 1990, Aghion and Howitt 1992).

The relationship between technological change and economic growth is much more complex. Economic historians argue that the first industrial revolution resulted from the complex interactions between an expanding final demand, a transforming intermediate demand and the productivity gains enabled by technological change (Mokyr 1977, Bairoch 1993, Mokyr 1992). Beyond technological changes, it was the interactions and changes in both the production and consumption structures of economies that have induced or accompanied the process of economic growth.

Alternatives to the mainstream growth theories provide conceptual and formal representations more in line with historical analysis. The evolutionary theory, developed in line with the Schumpeter writings, models economic dynamics as driven by technological changes where the process of creative destruction results from the complex interactions between micro-level mechanisms of technical changes, knowledge diffusion and market selection (Nelson and Winter 1982, Dosi, Freeman, Nelson, Silverberg and Soete 1988, Dosi, Fabiani, Aversi and Meacci 1994, Saviotti 1996, Metcalfe 1998, Silverberg and Verspagen 2005). These elements constitute the foundation of an out-of-equilibrium approach to the dynamics of economic systems as complex, uncertain evolving systems, offering alternative foundations to the orthodox literature on growth.

Prior to the evolutionary approaches, though similarly as a direct response to the conceptual limitations of the mainstream growth theories, the seminal work of Nicholas Kaldor sparks the development of the Post-Keynesian growth literature. 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 dynamics (Kaldor 1957, Kaldor 1961, Kaldor 1966, Kaldor 1972). Further developments in this stream of literature focus on the interactions between the dynamics of foreign demand (Thirlwall 1979, Combie and Thirlwall 1994, Thirlwall 2002), the structure of domestic demand (Boyer and Petit 1981, Boyer 1988, Petit 1999) and intermediate demand (Pasinetti 1981) with the dynamics of technical progress.

Both evolutionary 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 the long-run growth dynamics. From the evolutionary economics perspective, a few scholars have tried to account for the Kaldorian principles in an evolutionary context (Verspagen 1993, Llerena and Lorentz 2004, Metcalfe, Foster and Ramlogan 2006, Los and Verspagen 2006, Lorentz and Savona 2008, Lorentz 2015). While Verspagen (1993), Metcalfe et al. (2006), Los and Verspagen (2006) and Lorentz and Savona (2008) focus on the selection and diffusion, side of evolutionary mechanisms in a Kaldorian framework, Llerena and Lorentz (2004) and Lorentz (2015) provide an evolutionary micro-foundation of the process of emergence and diffusion of technologies.

The aim of this chapter is to highlight the evolutionary micro-foundations to Kaldor's principle of cumulative causation, stressing the interplay between structural change and economic growth. We build upon the evolutionary model developed in prior works (Ciarli, Lorentz, Savona and Valente 2008, Ciarli et al. 2010b, Ciarli, Lorentz, Savona and Valente 2010a, Ciarli and Lorentz 2010, Ciarli, Lorentz, Savona and Valente 2012, Ciarli and Valente 2016, Lorentz, Ciarli, Savona and Valente 2016, Ciarli, Lorentz, Valente and Savona 2018), which formalises the links between production, organisation and functional composition of the employment on the supply side and the endogenous evolution of consumption patterns on the demand side.

Our prior work builds upon the recent contributions to the evolutionary growth literature as they consider the aggregate transformations as resulting from individual interacting behaviours, on both the supply and the demand-side. Also, they complement both literatures by adding to the works that have looked at economic growth as a result of structural change rooted in the creation of product variety (Saviotti and Pyka 2004, Saviotti and Pyka 2008).

These shall be acknowledged as the very first few attempts to focus on this issue, although they are limited in their representation of structural change as mainly an increased product variety, with no explicit reference to whether and to what extent these relate to individual behaviours. In this respect, an explicit account of firms' effort to invent, and interacting with consumers' behaviour in producing novelty is found for instance, in Malerba, Nelson, Orsenigo and Winter (2007), Dosi, Fagiolo and Roventini (2010) and following papers based on this framework. These contributions, however, overlook either the behavioural foundations of the changes in the structure of consumption or the structure of earnings in shaping the structure of demand, that we explicitly address in our models.

We shall highlight that the unified growth theory models propose to 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 2009, Galor 2010, Lagerlöf 2006, Stokey 2001, Voigtländer and Voth 2006). In these works, the sources of the structural changes at the heart of growth process, are however incomplete, as they tend to focus on the technological or supply-side changes while neglecting both the transformations on the demand side, and privileging a focus either on human capital formation changes in population growth and capital investment (Galor 2010, Voigtländer and Voth 2006), or the joint changes in consumer goods and firm size (Desmet and Parente 2009).

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 the micro-founded model. Here we define structural change in terms of changes in the organisation and composition of production, income distribution and patterns of consumption. We investigate whether and how these aspects of structural change affect 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 organised as follows. The next section recalls the main elements of the Kaldorian growth theories for which we aim to provide micro-foundation using the evolutionary model described in section 3. Section 4 discusses the emergent properties of the dynamics generated with 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 endogenous 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 summarises the rationale behind the model and the main contribution to the literature that can be drawn from its exploitation.

2 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 an historical process. Every theory of economic growth should account for historical regularities. Second, the undeniable influence of technical change and the transformation of the structure of production on growth have to be considered as endogenous processes. Third, Kaldor stresses the central role played by aggregate demand and its transformation 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 a direct answer to both the contemporary Keynesians growth theory (Harrod 1939, Harrod 1948) and the Neo-classical theory (Solow 1956, Solow 1957). By introducing his 1957 growth model, Kaldor states the importance of modelling and understanding the process of economic growth as an historical process.He underlines the set of historical regularities, or stylised facts, that characterise the process of economic growth:

- SF1 Industrialised economies face continuous growth in GDP and continuous increase in labour productivity.
- SF2 Industrialised economies face continuous increase in the ratio of capital per worker.
- SF3 Profits rates on capital are regular.
- SF4 Ratio of capital over GDP is constant and regular over periods.
- SF5 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.

For Kaldor, these regularities are not only incompatible with the neo-classical growth theories, but also show the non-sense of distinguishing between the intensive and extensive growth mechanisms. 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 path (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 of the early stages of capitalism and the self-sustained growth path of a mature stage of capitalism.

In the mid-sixties, Kaldor revised his conceptualisation of the growth process to further fit historical evidences and his growing interest in practical economic development issues. On the one hand, beyond the mechanisation process underlying the technical progress function, he links technical change to the existence of dynamic increasing returns. 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 invested in renewing the production capacities. Second, in this Kaldor refers directly to Young (1928), a macro-level division of labour allows for a macro-level efficiency gains. The resources made available are used to develop the general level of technical knowledge and the diversification of the productive activities. The combination of these mechanisms is formalised 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 of aggregate demand and its transformations as it closes a circular relationship between the productive efficiency gains due to increasing returns and the actual increase of production as a response to income growth and at the same time induce 'chain reaction' in the economy. The expanding sectors generate both a growth in income, resulting in an expansion of consumption, and in investment resulting in an expansion of intermediate demand, both resulting in the expansion of demand for the other sectors of the economy. The amplitude of this 'chain reaction' depends on the structure of final demand, intermediate demand and foreign demand and their interconnections.

First, the structure of final demand is linked to the income elasticities of each sector's demand and directly influences the diffusion of income growth through the economy. Income elasticities are directly connected to the social structure of household. Kaldor (1966) distinguishes three income classes affecting the nature of income elasticities: (i) low-income classes, which mainly consume food and primary goods; (ii) high-income classes whose consumption rather concentrates on services; (iii) middle-income classes whose consumption concentrates on manufactured goods. The higher the income elasticity, the more efficient the 'chain reaction' is, stressing the role of the middle income class in the growth process.

Second, the structure of intermediate demand explains how the growth impulses diffuse across the economy, through the cross sectoral linkages between industries. The rate of growth of final domestic and foreign demand defines the one of investments constituting an outlet for the various industrial sectors.

Third, external demand generates the initial growth impulses. 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 from foreign demand with the self-reinforcing growth of domestic demand.

Together, these elements constitute 'the principles of cumulative causation', according to which economic growth is a self-reinforcing phenomenon generating the necessary resources to self-sustain in the long run. The cumulative nature of the growth process relies on a circular co-evolution of increasing returns and expanding aggregate demand. The dynamic increasing returns ensure the long run improvement in the efficiency of production capacities, and the competitiveness of the economy. The expansion of aggregate demand drives the increases in production capacities and relies on the competitiveness of the economy. For Kaldor, the cumulative nature of the growth process can only lead to two possible growth patterns:

- Growing through a 'virtuous circle' when the multiplier effect ensuring that productivity gains sustain competitiveness and the expansion of aggregate demand coincides with dynamic increasing returns ensuring sustained productivity gains through the expansion of aggregate demand ;
- Drowning in a 'vicious circle' when 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 the economies (consumption structure and industrial specialisation, among others) define their ability to enter in a virtuous circle. These together with the cumulative nature of the growth process stress the grip of 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):

- 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.
- The growth of productivity in the manufacturing sector is positively correlated to the growth of the manufacturing sector (i.e. the Kaldor-Verdoorn law).
- The growth of productivity of the non-manufacturing sectors is positively correlated to the growth of the manufacturing sector.

A number of contributions have empirically tested the Kaldor 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, Gallego, Maroto and Savona 2018, Felipe and Mehta 2016, Tregenna 2011); and whether the Kaldorĺaws could be detected in countries with different stages of development, such as South-East Asia (Dasgupta and Singh 2005, Felipe, León-Ledesma, Lanzafame and Estrada 2009) and the African countries (McMillan, Rodrik and Verduzco-Gallo 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 financialisation 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 roles of the manufacturing sector as an engine of productivity growth and of cumulative causation linked to domestic and foreign demand. This empirical support has in fact nurtured the sort of concerns around 'premature de-industrialisation' 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 Kaldorĺaws are proven to be still valid for the manufacturing and business service sectors, and across Asian countries alongside mature industrialised countries, realising 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).

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

Throughout a series of papers, we have developed an evolutionary micro-founded model of structural change in which economic growth is seen as a qualitative process where the macroeconomic dynamics results 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 in the organisation of production and the production technologies, on the supply-side, as well as those of 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 need capital goods purchased from firms in the capital good sectors. Figure 1 summarises the structure of the interaction between sectors and agents.

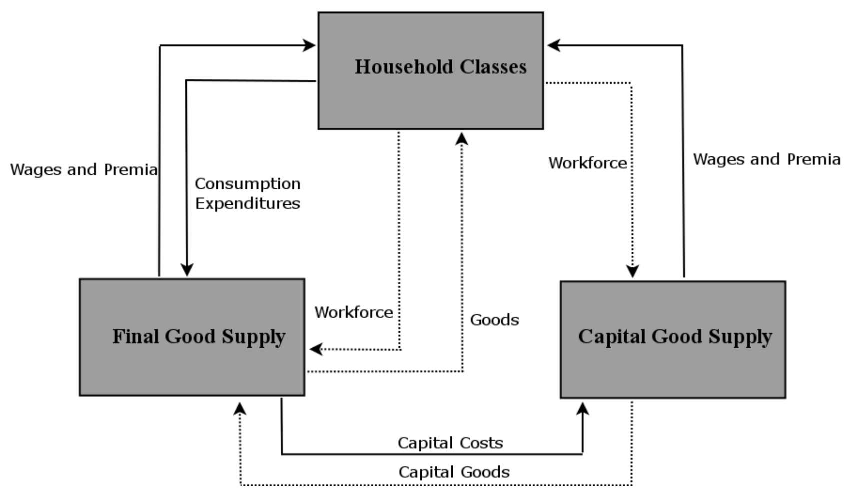


Figure 1: ***Flow diagram of the baseline model***

Within firms in both sectors, labour is hierarchically organised. At the base of the pyramid there are shop-floor workers carrying on the actual production process. The remaining of the organisation is based on the principle that any given number of employees at a certain level requires a coordinating manager. In this respect, the organisation of labour implies static diseconomies of scale. Any expansion of production requires to increase both the number of shop floor workers, for a given labour productivity level, as well as the corresponding number of organisational layers. This leads to an increase in the unitary costs.

Each firm of the capital good sector produces a single capital good with a specific embodied level of productivity. The improvement of the embodied level of productivity though innovations occurring in the capital good sector are 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 characterised by different income levels and preferences. The different income classes, and the related preferences, are assumed to correspond to the various hierarchical positions within the firms.

In total the model includes three *non-Walrasian* markets (Colander, Howitt, Kirman, Leijonhufvud and Mehrling 2008, Dosi et al. 2010): final good, capital good, labour. 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 labour 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 increase production levels. New capital goods, produced on order, embody the most recent innovations offering increasing levels of labour productivity.

The labour market is implicitly represented in the model. We assume a perfect coordination of the supply and the demand of labour in long term with short-term inertia allowing for transitory periods of disequilibrium. The minimum wage, used to set the wages for all hierarchical levels, reflects these transitory disequilibria as it increases with inflation and excess demand for workers, and in the long-run follows productivity gains.

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 have been published, including: industrial dynamics and consumer imitation leading to concentration on the supply and demand side (Ciarli and Valente 2016); a multi-sectoral final good sector, firms liquidity constraints and labour 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 survey 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 behavioural link between income and consumption, the preference structure and the role of expectations in firms' operative production decisions at the heart of the baseline model.

3.1 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. They carry on production using labour and capital, determine the price of their product, buy capital goods, and distribute wage and bonuses.

3.1.1 Production

Individual firms are not able to predict exactly the demand for their good at each time period. Therefore, they need to adopt heuristics meant to minimise the gap between actual production and sales – i.e. inventories. The level of actual production is the result of the firms' planned production and technically constrained by its production capacities.

The first step for the firms consists in estimating the demand that they expect to receive during the current time unit. The quantity demanded is subject to both random volatility and long-term trend changes due to different composition of demand. We assume that firms adopt an adaptive rule based on the gap between past estimations and actual demand. Formally, a firm's estimation of its own demand for the current period, $Y^e_f(t)$ is computed as:

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

where $Y_f(t-1)$ is the lagged value of actual demand. The behavioural parameter a^s, defined in the [0,1] range, weights the importance the two elements, signalling a more conservative or a more aggressive strategy in forming expectations. A comparatively higher value implies a strategy more strongly anchored to past expectations making little importance to the realised 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.

The second step consists in defining the desired production level ($Q^d_f(t)$) once subtracted the stock of unsold past production ($S_f(t-1)$), if existing, from the expected demand :

$$Q^d_f(t) = \max\left\{(1+\bar{s})Y^e_f(t) - S_f(t-1); 0\right\} \tag{2}$$

Finally, the actual production $Q_f(t)$ is determined considering two distinct constraints reflecting the amount of production factors available for production, i.e.

workers $L_f^1(t-1)$ and capital $K_f(t-1)$, discounted by their respective productivities, where $A_f(t-1)$ is the labour productivity embodied in the capital vintages and D_f is derived from a fixed capital intensity ratio:[1]

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

3.1.2 The Structure of the Workforce

Following an established literature (Simon 1957, Lydall 1959, Waldman 1984, Abowd, Kramarz and Margolis 1999, Prescott 2003), we represent firms as composed by hierarchical organisations. Under this assumption only shop floor workers are able to contribute to production, but the labour costs of a firm include also managers to coordinate both workers and lower level managers. We assume here that each manager is only able to coordinate a given number of employees ν so that, firms of increasing size require an increasing number of layers of managers. For a given number of lower level employees used in production $L_f^1(t)$, the total number of workers in each layer l is given by:

$$L_f^l(t) = \nu^{1-l} L_f^1(t) \quad (4)$$

The number of shop floor workers determines the total dimension of the organisation and 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 labour, indicated by u^l, as an insurance against unexpected failures of some workers. Second, changes to labour 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 labour force can actually be carried out within a single time unit. The formal representation of the number of shop floor workers (layer 1) in firm f at time t is then:

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

3.1.3 Capital and Investments

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

[1] In line with large empirical evidence, starting from the seminal work by Kaldor (1957).

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

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.

A final good firm orders new capital when the expected demand cannot be satisfied with the capacity available with the current capital. The choice of the capital supplier depends on three factors: price, productivity and delivery lag. 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.

3.1.4 Wages, prices and profits

The model assumes a single, economy wide minimum wage forming the only income received by shop floor workers. Conversely, other employees (managers) receive two distinct sources of income: a fixed wage and, variable income derived from non-spent extra-profits (bonuses) 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 (again, 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 on the basis of a mark-up on top of unit variable cost. Note that because of the larger management structure of larger firms, this cost structure implies short-term dis-economies of scale, evidence confirmed in the literature (Idson and Oi 1999, Criscuolo 2000, Bottazzi and Grazzi 2010). Economies of scale are obtained only dynamically by acquiring large quantities of more productive capital goods compensating their organisational 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.

3.2 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 labour 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 used to estimate the time of delivery for prospective buyers.

3.2.1 Production and organisation

Capital good firms fulfill orders on a "first in first out" basis, always working on the oldest order in their book. As for the final good peers, only shop floor workers can be counted on for actual production, but their organisation requires a hierarchy of managers and requires no other (explicit) input.

3.2.2 Technology, R&D and innovation in capital vintages

The technological level of a capital producer is expressed by the labour productivity embedded in its machines. This level changes as a result of investments in R&D financed by the past profits of the capital producer and spent in wages to a class of workers/researchers ("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 dimension of the 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 occurs, is a random step increasing the current level:

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

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 an improved is obtained it is embodied in all capital goods delivered from the moment of its discovery.

3.2.3 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. Prices are decided by marking-up unit variable costs. Profits are accumulated over time and used to distribute bonuses to managers or to hire new engineers.

3.3 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 behavioural psychologists.

3.3.1 Income distribution

The relevant aspects of a consumer in our model are her income and preferences, where the latter is represented by relative weights of price and quality in making consumption choices. We assume that preferences depend on the "social" status determined by a consumer class. The class of each household/worker is determined by the hierarchical position occupied within in the firm employing the household. Hence, we aggregate consumers in classes whose members share the same preferences and consider the average income, obtained by dividing the sum of income of all members of a class (wages plus bonuses) by number of its members.

3.3.2 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), because the former, determined by social habits as well as financial rational decisions, is far less volatile than income. To replicate this evidence 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 $W_z(t)$ is the income for the same period and the same class. Notice that we assume here that the savings are collected from excessive income when this is higher than consumption and these savings 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.

Parameter γ controls the speed by 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 of consumption, allowing to study how this aspect affects, beyond other factors, overall conditions of economic systems. This parameter has a clear behavioural interpretation further discussed and analysed in Lorentz et al. (2016).

3.3.3 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 therefore the representation of the choice by the individual consumer. The routine representing the consumer's choice is based on the literature on cognitive psychology, is robustly supported by evidence on the actual behaviour of people, and respects the principle of bounded rationality (Simon 1982). As discussed in (Valente 2012), for this reasons and for its ability to deal with heterogeneous multi-characteristic choices, it can be successfully adopted to represent consumers' behaviour .

The routine consists in ranking available alternatives according one of the available dimensions (price or quality, in our case), and removing all dominated choices. The other dimension is used to further filter the remaining options until only one remains. Crucially, the available products are evaluated according to their passing a threshold of tolerance, in terms of difference with the best option (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, permitting to differentiate for consumer class: the higher income classes, the more tolerant to high prices, but the less compromising with quality. Conversely, low-income classes primarily look at the price of products, and only among the lower price options seek the best quality. The tolerance of consumers is represented by the percentage of difference from the best value considered as equivalent to the best.

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

$$\upsilon_{p,z+1} = (1-\delta_{\varsigma})\upsilon_{p,z} + \delta_{\varsigma}\upsilon^{min} \tag{10}$$
$$\upsilon_{q,z+1} = (1-\delta_{\varsigma})\upsilon_{q,z} + \delta_{\varsigma}\upsilon^{max} \tag{11}$$

where $\upsilon_{p,z}$ is the tolerance in respect of price, measured here in terms of tolerance for cheapness, $\upsilon_{q,z}$ 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 extreme values for the tolerance levels. Their effect on the system does not depend on their absolute value but only in respect of their difference. When they are very close, the classes differentiate very little in respect of one another, while increasing differences between the two values produce large differences in the preferences of the extreme classes.

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.

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

Reverting to such an agent-based model usually aims at analysing whether and how the interactions among micro-behaviours such as the ones presented above generate sensible aggregate dynamics. Our ambition here is to provide evidences that the evolutionary micro-dynamics at work in our model provide micro-foundation 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.

4.1 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):

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

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

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

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 characterised by an agricultural sector for subsistence and a manufacturing sector. Households maximise 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

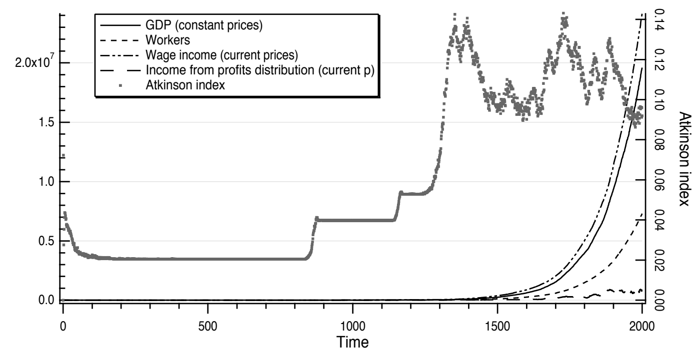


Figure 2: ***Main Aggregate Output (Constant Price GDP, Employment, Wage income, Profit income, and Atkinson Index****; for each time step the series reports the average value across 100 replications*

before the industrial revolution, where education levels were not particularly high. Moreover, a part 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 behaviours 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:

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

- 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 overreach 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 behavioural 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 behaviour 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 analysed, 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 structuring of consumption behaviours and income distribution on the demand-side as well as the ones controlling the changes in the production structure both in terms of labour 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 and the nature of the consumers' preferences can hamper or favour 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 together with variety 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 labour productivity growth.

Second, the structure of consumption, affecting the selection mechanisms, also evolves with the structure of income. Hence, the firms' organisational 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 behaviour 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 in the long run, but saving on labour reduce unit production costs, both sustaining the expansion of final demand. On the other hand, in the short-run, the larger the productivity gains, the higher the profits, these 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.

4.2 Emerging Dynamic Increasing Returns

The set of historical regularities listed by Kaldor and discussed in more details in section 2 stress the continuous expansion of production, productivity and mechanisation 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 initialised 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 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 characterised by a stable pattern of growth: growth in income, through wages and/or population increase, feeds increasing spending for final consumption and firms' expansions, inducing a cumulative pattern. In this state, however, investment grows at the rate of capital depreciation and the increase in employment. Though this level of demand for capital good 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

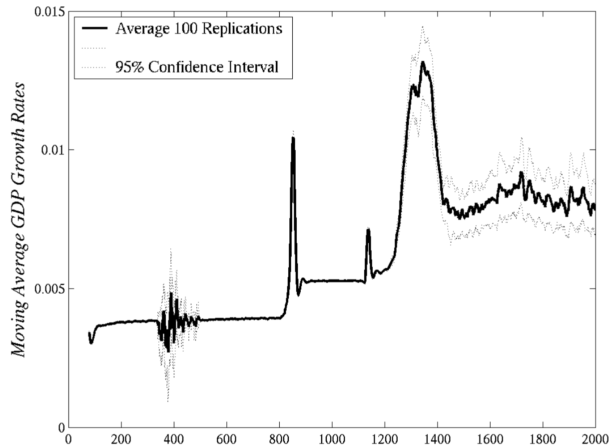


Figure 3: ***Growth rates for the economy output across time (SF1)****; data from 10 periods moving averages computed over punctual growth rates. For each time step the series reports the average value across 100 replications together with inter-replication 95% confidence intervals*

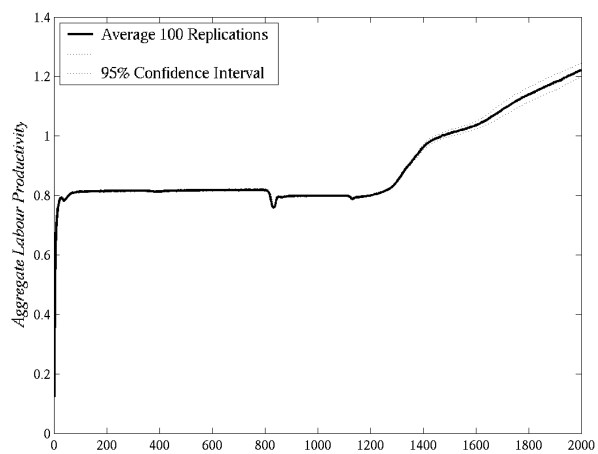


Figure 4: ***Aggregate Labour productivity across time steps (SF1)****. For each time step the series reports the average value across 100 replications together with inter-replication 95% confidence intervals*

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 labour productivity of the economy. The combined growth of GDP and of productivity (SF1) only emerges in this second phase the simulation. This relationship between the growth of GDP and that of labour 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), the evidence of the existence of the dynamic increasing returns necessary for a self-sustained growth regime to emerge.

		$\Delta Y/Y$	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 estimates computed using the Barrodale-Roberts simplex algorithm.

LAD standard error derived using the bootstrap procedure with 500 drawings

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)*

In Table 1, we estimate the Kaldor-Verdoorn (K-V) 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.

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

In the early stages of (stagnating) growth, the low pace of change in organisation and technology does not increase the production capacity to a level sufficient

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 estimates computed using the Barrodale-Roberts simplex algorithm.
Standard errors derived using the bootstrap procedure with 500 drawings.

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*

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 labour, in the production process. In this respect, the model re-

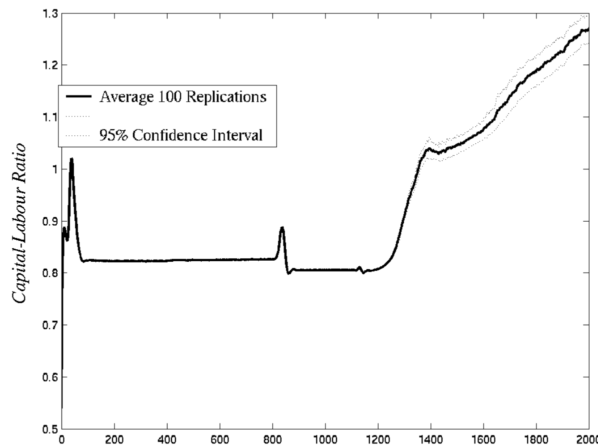


Figure 5: ***Capital-Labour ratio across time steps (SF2)****. For each time step the series reports the average value across 100 replications together with inter-replication 95% confidence intervals*

produces the SF2 stressing the capital deepening, i.e. a constantly increasing ratio of capital per worker for a growing output.

		$\Delta Y/Y$	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)	(6.43e-05)			
(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

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).*

In Table 3, we show estimates of the effect of an increase in the output growth rate of output on the capital labour 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 labour productivity, leading to an increase of the K/L ratio.

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 gains, as well as capital deepening are direct results for 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 of the hierarchical structure. 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 sectors 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.

Final demand, therefore, 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 evidence tend to contradict these historical regularities stressed by Kaldor in the 1950s. A detailed account of the stylised facts the family of model we developed from this baseline model is further discusses in Ciarli et al. (2018).

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)	
		$\Delta Y/Y$	Const.	Obs.
200-400	$\Delta\frac{K}{L}/\frac{K}{L}$	-0.014	6.11e-05	100
		(0.015)	(5.42e-05)	
		$\Delta Y/Y$	Const.	Obs.
400-600	$\Delta\frac{K}{L}/\frac{K}{L}$	-0.036	0.0001	100
		(0.026)	(0.0001)	
		$\Delta Y/Y$	Const.	Obs.
600-800	$\Delta\frac{K}{L}/\frac{K}{L}$	-0.307***	0.001***	100
		(0.112)	(0.0004)	
		$\Delta Y/Y$	Const.	Obs.
800-1000	$\Delta\frac{K}{L}/\frac{K}{L}$	-0.048	0.0001	100
		(0.048)	(0.0003)	
		$\Delta Y/Y$	Const.	Obs.
1000-1200	$\Delta\frac{K}{L}/\frac{K}{L}$	0.233**	-0.001**	100
		(0.097)	(0.0005)	
		$\Delta Y/Y$	Const.	Obs.
1200-1400	$\Delta\frac{K}{L}/\frac{K}{L}$	0.238***	-0.001***	100
		(0.025)	(0.0002)	
		$\Delta Y/Y$	Const.	Obs.
1400-1600	$\Delta\frac{K}{L}/\frac{K}{L}$	0.161***	-0.001***	100
		(0.021)	(0.0002)	
		$\Delta Y/Y$	Const.	Obs.
1600-1800	$\Delta\frac{K}{L}/\frac{K}{L}$	0.217***	-0.001***	100
		(0.008)	(6.73e-05)	
		$\Delta Y/Y$	Const.	Obs.
1800-2000	$\Delta\frac{K}{L}/\frac{K}{L}$	0.217***	-0.001***	100
		(0.018)	(0.0001)	

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.

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

4.3 Consumers behaviour 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.

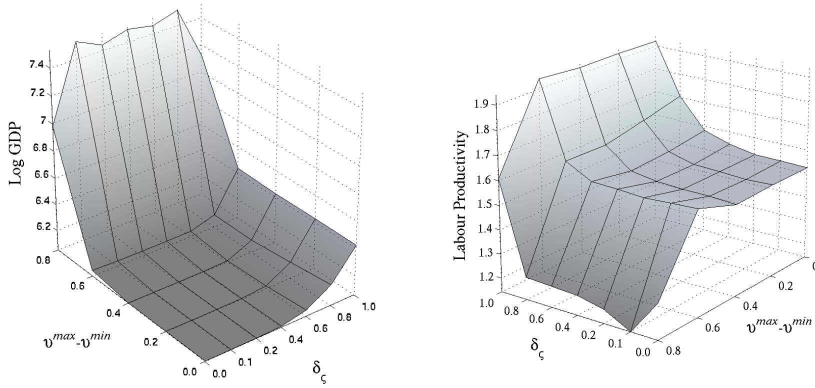
We focus, here, on the parameters controlling the degree of heterogeneity in preferences among consumer classes. The conjecture is that these parameters affect both the macro-level price and non-price elasticity, thus varying the resources of firms and, ultimately, their investment capacity and the resulting productivity gains. For each parameter setting, we run 40 replications each lasting for 2000 steps[2]. 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 labour productivity[3].

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 class above the first tier adopt the asymptotic distribution. If $\delta_{\varsigma} = 0$, all consumer/income classes have the same preference pattern, regardless their income.

[2]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 stabilised post-take-off stage.

[3]For each simulation we compute the average level of GDP growth and labour 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.



(**a**) Log GDP (**b**) Aggregate Productivity

Figure 6: ***Log GDP and Aggregate Labour Productivity*** *Levels at step 2000 with changes* δ_ς *and* $\upsilon^{max} - \upsilon^{min}$

Figure 6 presents the average outcome (over the 40 replications) after 2000 simulation steps in terms of GDP and labour 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 standardised. 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 corresponds to the path in which the systems experiences 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 behaviours 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 labour 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 characterised by highly standardised consumer's preferences, the engine of long run growth lays in productivity gains. The final good market is more concentrated. Fewer firms actually 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 investments in production capacities and further productivity gains.

		δ_ς						
		0.0	0.1	0.2	0.4	0.6	0.8	1
$\upsilon^{max} - \upsilon^{min}$	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*
	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: ***Kaldor-Verdoorn Law*** *LAD estimates with changes in* δ_ς *and* $\upsilon^{max} - \upsilon^{min}$

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 to 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, themselves, draw on the expansion of productive capacities necessary to respond to the expending demand. With estimated values above 1, however, as the economy grows, employment reduces. The effective demand only expands through 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 around 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

5 Concluding remarks

This chapter aims to add to the large and diverse literature on structural change and economic growth, by addressing the mutual effects of different dimensions of structural transformations on GDP growth and aggregate productivity.

We have argued in previous work that the structure of production and the way in which it is organised by firms, together with the structure of demand, are the main candidates to explain the growth differences we observe across countries and within countries through time. The changes in production factors along a production function are not independent of the shifts of the function, usually referred to as the Solow residual, or technological change. Structural change encompasses much more than a change in sectoral composition. We have then modelled the complex set of mechanisms at work, providing therefore solid micro-foundation to macro-evidence and stylised facts on growth.

In this chapter we build upon this analytical effort and focus on the specific effects that these micro-founded structural changes on the occurrence of the Kaldor-Verdoorn Law and different cumulative causation regimes. More in particular, we show that the two-phases or two-regimes of endogenous growth in capitalist systems discussed in both Kaldor (1957) and Kaldor (1966) are indeed related and that the transition from one to the other results from a subtle balance between technological mutation mechanisms, selection mechanisms and the expansion of demand. We show that these mechanisms are also responsible for the emergence of dynamic increasing returns as measured by a Kaldor-Verdoorn law in the post-take-off phase. Finally we analyse the role of the heterogeneity in consumption patterns resulting from changing preferences and income classes' mobility on these dynamic increasing returns. More in particular, the degree of heterogeneity in consumption behaviour is sufficient to shape the growth regime emerging from the endogenous structural changes. The more homogenous the demand, the more the intensive growth dynamics dominate, 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 lower productivity gains, through the expansion of income, and employment. The switch between one regime and the other can be directly triggered by the market structure resulting from demand-driven structural changes.

Overall, our contribution allows to strengthen the stream of literature which is enlarging our deeper understanding of growth dynamics behind the motto of 'When Schumpeter meets Keynes' (Dosi et al. 2010), which we consider to be of extremely 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 normative use of our results, especially toward the aim of leading countries out of the consequences of recessions.

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Parameter	Description	Value	Data
$\underline{i_2}$	Minimum quality level	98	See Ciarli et al. (2012)
$\overline{i_2}$	Maximum quality level	102	See Ciarli et al. (2012)
a^s	Adaptation of sales expectations	0.9	
$\bar{s}$	Desired ratio of inventories	0.1	[0.11 - 0.25]
u^l	Unused labour capacity	0.05	0.046
u	Unused capital capacity	0.05	0.046
$\bar{\mu}$	Markup	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]
$\frac{1}{\bar{D}}$	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)
ςi_j	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)

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