# Product Variety and Changes in Consumption Patterns: The Effects of Structural Change on Growth*

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**Abstract**

The factors behind diverging long term growth experiences are diverse and difficult to disentangle, ranging from institutional and cultural aspects to economic conditions. This paper models the microeconomic relations between five dimensions of the long term process of structural change of an economy—organisation, technology, and sectoral composition of production on the supply side; distribution of earnings, and the related evolution of consumption patterns on the demand side—as the *explanans* of these different patterns of economic growth. We refer to a number of studies and empirical accounts of the history of the industrial revolution in the UK to set the model's foundations, and we analyse the model via numerical computation. Changes in the composition of workers-consumers related to the increase in firm size and organisational change induces product heterogeneity and firm selection, and the supply of new goods that satisfy less basic needs. Both selection and the emergence of markets increase market concentration, inducing capital investment accompanied by increasing labour productivity. Reduced cost then increases the demand of all consumer classes. Changes in firm size and organisation, investment, product innovation, and in expenditure shares of emerging classes, reach a critical point in which the economy transitions from slow to modern growth.

**Keywords**: Structural Change; Unified Growth Theory; Product Innovation; Consumption; Earnings Distribution
**JEL**: O12, O33, O41, L16, J31, D11, N33

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# 1 Introduction

In historical perspective the cross–country divergence in the growth rates of per capita income has been a solid empirical stylised facts for decades (Denison, 1967; Maddison, 1987; Barro, 1991; Durlauf and Quah, 1998). The factors behind these different experiences are diverse and often difficult to disentangle, ranging from institutional and cultural aspects to economic aspects such as allocation of resources, specialisation and trade, population dynamics, organisation of economic activities.

This paper aims to model the relations between five dimensions of the long term process of structural change of an economy. Namely, the organisation, the technology, and the sectoral composition of production on the supply side, the distribution of earnings, and the related evolution of consumption patterns on the demand side as the *explanans* of these different patterns of economic growth (*explanandum*).

A number of contributions in the economic literature have investigated those dimensions of (structural) change separately, but to our knowledge there is no growth model that attempts to study them jointly, not to speak of the study of their microeconomic interactions. Historians of economics and of technology help filling some of these *lacunae* delving into the causes of the industrial revolution looking at different aspects of culture, technology, and institutions in their manifold aspects (to name just a few, Allen, 2009; Berg, 2002; McCloskey, forthcominga; McCloskey, forthcomingb; Mokyr, 1992; Mokyr, 2010; Rosenberg, 1982; von Tunzelmann, 1978; Voth, 2003). They look at both micro, regulatory, and macro conditions and changes and propose plausible explanations for the occurrence of the industrial revolution in Britain rather than anywhere else, and for being the first country experiencing the "take-off", i.e. when changes in technology allowed for gains in value added well above the expansion of population (irrespective of their distribution).

## 1.1 The facts: features of the transition

In this work we need to abstract from the institutional and cultural aspects—incidentally the most relevant ones to explain the deep causes of modern growth—[1] holding them in the background while reviewing their direct or indirect effect on the main economic and technological dynamics. The recent evidence on these dynamics show very interesting features of the take-off. Voth (2003) summarise some of the evidence contending that (i) increase in productivity and well being has been initially slow, accompanied by (ii) a slow increase in wages; (iii) increase in population due to fertility (not linked to wages) with (iv) an increase in working hours (mass of unskilled labour) and of the household purchasing power increased market size; (vi) increase in market size is also due to sectoral diversification and the initial demand for goods with high income elasticity, accompanied by (vii) slow structural change in the sectoral composition; (viii) human capital as formal education was not relevant (possibly its lack was, in the case of Britain (Mokyr, 1992)).

[1] See for example the discussion by McCloskey (forthcominga) or the distinction between "proximate sources" and "deepest causes" of growth made by Abramovitz (1986) in another context.

Voigtländer and Voth (2006) add that although wages were stagnant while population was growing, (ix) this minimum wage was higher than in other "advanced" "European" countries like France, allowing for higher levels of productivity and consumption;[2] with respect to technological innovation they report that (x) property rights were very loosely enforced, and (xi) monetary incentives played a minor role in innovation; moreover, (xii) small innovators introducing small change in the machineries where more crucial than big inventors,[3] which is consistent with the idea that it was mainly entrepreneurial efforts to develop new ideas and more efficient ways to produce (increasing profits and possibly labour control) that sustained the industrial revolution (McCloskey, forthcomingb).

Some of the evidence summarised above is closely related to two more empirical regularities that have accompanied the industrial revolution (evidence is summarised in Desmet and Parente, 2009): (xiii) the organisational change from small artisanal producers to organised labour in centralised workplace (see also the lengthy discussion by Marx on the early capitalistic mode of production) and the related (xiv) secular increase in firm size.

Finally, the great majority of the evidence on the technical change associated with the industrial revolution concentrate on the case of process technologies, and on the institutional factors that induced the spur of innovations (Dudley, 2008; Lazonick, 1979) causing the jumps in productivity and profits (McCloskey, forthcomingb). Although these innovations were a crucial aspect of the changes in the organisation of production, product specialisation, and more in general in the organisation of society—for example in terms of class relations, control of labour, distribution of value, wages, and the rise of the "bourgeois dignity"— (xv) "[t]he expansion of eighteenth-century manufacture relied not just on process invention, but on product innovation" (Berg, 2002, p. 2); and product innovation was related with changes in the demand not (only) via prices, but via the changes in the types and quality of goods, tastes, and the opportunity to satiate unsatiated needs (Berg, 2002).[4].

Nonetheless, when taking seriously these facts, three considerations are extremely relevant. First, one has to keep in mind that these facts refer to one specific economy, that of the UK which was the first to experience the industrial revolution, but not the unique model of development or growth. Second, many of these historical facts are interdependent,[5] meaning that differences in one condition percolate in the whole economic system in

[2]Broadberry (2007) reports that within Europe the wage divergence starts after the Black Death in the fourteen century, and that consumption wages in the competing regions such as India and China started to fall with respect to Britain in the eighteen century. This is also said to have induced labour saving technologies in Britain, using the less expensive energy (coal) (Allen, 2009).

[3]See also Dudley (2008) on this discussion.

[4]See also the theoretical discussions by Pasinetti (1981) and Witt (2010), and the evidence observed by Engel and the more long term statistical account by Maddison (2001).

[5]For example von Tunzelmann (1995) convincingly shows how the industrial revolution and the coincident economic transformation occurred through changes in the organisation of production, labour conditions, demand, and product and process innovation. He partly builds on contributions that have analysed the different phases of economic development from within, and that are now relegated in the dusty shelves of growth and development theory, such as the Marxian work on the interactions between technological advance applied to production, changes in the modes of production and the underlying class

a way which is not easy to predict. Third, they are observations rather than explanations of modern economic growth, which needs to be informed by institutions and culture.

It is with this complex relation in mind between supply and demand side transformation mediated by the societal transformation that we develop the growth model in this paper. We propose a model which articulates the links between innovation and production on the supply side and the endogenous evolution of income distribution and consumption 'needs' on the demand side. Building on the model analysed in Ciarli, Lorentz, Savona, and Valente (2010a), we focus on the dynamics of product innovation—changes in the sectoral composition of production—and of consumption shares—as an outcome of the changing organisation of labour. The model is essentially micro funded and aggregate dynamics are the result of microeconomic behaviour and interactions. We analyse its properties via numerical simulation, studying both the aggregate dynamics, and some of the sectoral changes.

Although we are in the company of those "endogenous theories in which growth leads to growth" (McCloskey, forthcomingb, p. 7) in this work we attempt to show the complex microeconomic relations that are behind structural change and the growth leading to growth, leaving to other work the task to assess these microeconomic relations and how their (structural) changes are affected by culture and history

## 1.2 The model: an interpretation of the transition mechanisms

In the Schumpeterian tradition we model a manufacturing and an intermediate sector (see, among many other contributions, Aghion and Howitt, 1992; Aghion and Howitt, 1998; Aghion, 2002; Acemoglu and Guerrieri, 2008). The intermediate firms supply capital goods to the manufacturing sectors and are the source of changes in productivity as the result of embodied process innovation (Chiaromonte and Dosi, 1993; Silverberg and Verspagen, 2005). As firms grow they need to hire managers and modify their organisation from flat to pyramidal. This has an effect on firm's size, which increases more than proportionally with respect to the number of workers necessary for production, on the wage distribution, which becomes more skewed at any addition of a tier of managers (Simon, 1957; Lydall, 1959; Waldman, 1984; Abowd, Kramarz, and Margolis, 1999; Prescott, 2003), and on the average cost of production that increases with firm size, *ceteris paribus* (Idson and Oi, 1999).

The different tiers of workers also form different consumption classes, such that changes in the organisation of production correspond to changes in aggregate consumption behaviour, as the expenditure shares change across classes by effect of Engel curves. The different expenditure shares correspond to different needs that the consumers can satisfy by purchasing from firms in the different manufacturing sectors. The emergence of different sectors depends on the product innovation of manufacturing firms. Firms constantly

differences, changes in the ownership of capital and surplus appropriation, and changes in the product relations. Or the contribution of Rostow (1960) on the interplay between sectoral changes and consumer behaviour.

search for new prototypes attempting to address the needs for which there is higher potential demand, which is a result of the changing tastes of the different consumer classes as they evolve. As new, wealthier, classes are formed—as a consequence of changes in the organisation of production—expenditure shares shift toward more luxury goods. Expenditure shares evolve toward an asymptotic distribution that corresponds to the present share of the top percentile of consumers in the UK.

The model is essentially demand driven. In the beginning almost all the population is employed at the shop-floor as firms are small and managed by the owner. Firms produce only in a couple of sectors supplying the goods mostly consumed by the first class of workers. The initial low level of demand do not require capital investment and is accompanied by a stagnant productivity with low population growth and no changes in average wages. In the medium term though, small increases in the size of the firms with the largest market shares require a change in their organisation, accompanied by an increase in average cost. Provided that consumers of the first tier class—which represent most of the population at this stage—have a strong preference for the goods with lower price, demand converges on the firms that have remained smaller. As these firms also grow, increasing the average cost of production as a result of the changing organisation, demand becomes more and more concentrated on few firms. For a critical level of demand concentration manufacturing firms need to invest in new capital to satisfy it. This spurs investment in process innovation by capital suppliers and thus an initial increase in productivity. This reduces the average cost, increasing the demand of all classes of consumers, which is likely to accelerate more concentration of firms, capital investment, and process innovation.

As firms change their organisation they also cause the emergence of new consumer classes, with a different distribution of consumption shares that progressively shifts towards less basic goods. This has two effects. On the supply side firms produce prototypes that can satisfy this demand, and some of them innovate and move to the new sectors, increasing even more the concentration (the first firm moving to a new sector is in a monopolistic market), which reinforces to the dynamics described above. On the consumer side the preferences change, and consumers select goods more on the basis of their quality then price.

Under certain (very wide) conditions on technological change, organisational structure, and wage structure, the expansion of the market (both in terms of sectors and in terms of population) gives way to a take-off of the economy with an exponential growth of output nurtured by continuous investment and increase in aggregate productivity, product innovation, growth of income per capita, market concentration, increasing firm size and wage inequality.

### 1.3 The literature

Our paper builds on a large number of existing theoretical and empirical contributions. In the following we briefly cite the relation with existing work not already mentioned above.

Our broad aim is similar to that of the recent unified growth theory which attempts to explain the transition from pre-Malthusian growth (population growth is negatively related to real wages growth) to modern growth (population and wages move in the same direction). 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 (see Galor (2010) for a recent review). Although the ability of providing an explanation for the transition is appealing, the model is at odds with the evidence that many economies had larger population than the Britain, where education levels were not particularly good. A part from the trade-off between more or better educated children which is modelled as a rational choice, we do find a lack of micro explanation in these models, which we think is required for a better understanding of the growth dynamics (see for example the recent work by Akerlof and Shiller (2009) and Frydman and Goldberg (2007)).

In our model the growth of population is an essential covariate of sustained economic growth, but it is not at all a sufficient determinant of the ignition of rapid growth—as we show for a previous version of the model with a single good, sold in one market, to satisfy one sole consumer's need (Ciarli, Lorentz, Savona, and Valente, 2010b). In fact, although there is no doubt that population sustains the demand, and thus the production of more goods, this comes at an increasing average cost that can be at best matched by the higher wages of he better paied executives. It is in fact the different changes in the structure of the economy that allows for a transition from low to high growth rates.

Within the unified growth theory a very recent model by Desmet and Parente (2009) is particularly close to our conjectures. The authors model both process and product innovation, where the latter is related to the changing population between rural and urban areas (who prefer larger variety of industrial goods). Increase in product variety is also linked to increasing firm size and diminishing mark-up. The transition occurs when population grows, industrial firms start process innovation, migration towards urban areas occurs, with a change in the consumer preferences. In our model product variety is also linked to new sectors that satisfy different expenditure share, which also change endogenously as a function of production organisation (with no distinction between urban and rural areas).

Particularly close to our work are the different articles on the effect of variety on economic growth in the tradition of Saviotti and Pyka (2008) and Metcalfe, Ramlogan, and Foster (2006), as well as the new models that bring closer evolutionary approaches and Keynesian ideas, such asDosi, Fagiolo, and Roventini (2010). Saviotti and Pyka develop several models in which they show that the creation of product variety, modelled as an exogenous emergence of new sectors, sustains economic growth even when the single sector's labour decline. Dosi, Fagiolo, and Roventini (2010) show how demand side Keynesian factors (and fiscal policies) interact with Schumpeterian supply side factors that affect the aggregate productivity and market dynamics. Patriarca and Vona (2009) also choose a post-Keynesian framework to show how the emergence of new sectors allow transition from stagnation to growth, when consumers (workers and entrepreneurs) change their preferences.

Finally, our work owes a lot to the traditional literature on growth and structural change (e.g. Pasinetti, 1981; Sirquin, 1988; Cornwall and Cornwall, 1994; Kaldor, 1966), and is related to the unbalanced growth models (e.g Murphy, Shleifer, and Vishny, 1989; Bonatti and Felice, 2008). In particular, more recently few models that include in the analysis a strong attention to the demand side have been published (Aoki and Yoshikawa, 2002; Bertola, Foellmi, and Zweimüller, 2006; Falkinger and Zweimüller, 1997; Matsuyama, 2002; Murata, 2009). Matsuyama (2002) builds his model to analyse the relation between inequality and growth allowing for using non-homothetic preferences of consumers, and increasing returns on the production side. New good exists if there is demand, then increase in productivity reduces the price of consumers goods, becoming affordable to more consumers classes, increasing the market, and productivity further more. The author also assumes that the range of consumed goods change across classes, this change when goods' price change, and needs and wants are relative to each class. In a similar vein Aoki and Yoshikawa (2002) make the income growth rate dependent on the pace of diffusion of new goods: the shape of the diffusion curve and the rate at which new goods are introduced. The model is quite standard on the supply side, depicting a final and an intermediate sector, and provide a probabilistic dynamics for the emergence of new goods. Also in this case the authors show the relevant relation between growth and distribution. The relation between product variety, income distribution, and growth is also at the core of Falkinger and Zweimüller (1997) and Zweimüller and Brunner (2005). In the first article the authors distinguish two channels through which variety can affect consumer utility: preference for variety and the hierarchical structure of consumer demand as in the previous models (assuming that different income classes have different levels of satiation for the different goods and can consume only a bundle of goods). They find that an increase in per capita income has a strong positive impact on the diversification of consumption, and a negative impact on the concentration of expenditure across categories, while income inequality has an effect on he number of consumed good, supporting the hypothesis of the hierarchical structure of consumption. This positive relation between income and product variety is found also in Jackson (1984). In the second paper (a model) the distribution of income is given, consumer are allocated to a rich and a poor class, where the first create an incentive for new products paying higher prices, and the latter generates the mass consumption. The authors analyse the effect of different market regimes and income distributions via the demand side, but the model is based on quite strong assumptions. More recently Föllmi and Zweimüller (2008) also use hierarchical preferences of consumers to show the relation between changes in the demand stricture, structural change on the supply side, and growth. In their model the most interesting part, the emergence of new goods is exogenous, and the satiation dynamics is modelled as a property of the goods that depends on their position on the hierarchies of needs (luxuries when they are introduced, their demand stagnate when fall far from the top of the hierarchy). With a different model Murata (2009) introduces as well the technological feasibility, analysing the final level of variety in an economy as a result of both demand and supply factors. Consumers have non-homotetic preference and different levels of desirability for different goods (reservation price), but not all goods are equally feasible in the sense that they are produced with different productivities, hence different consumer prices.

The interactions between organisation of labour, structural change and income inequality (a part from the already mentioned studies on the firm size-wage relation) refer to a number of existing contributions that can be summarised in the papers by Atkinson (1997), Aghion, Caroli, and García-Peñalosa (1999), Galbraith (1999).

Tangentially, we also refer to the model that make use of simulation to analyse the effect of different (aggregate) parameters on the dynamics of growth, such as (a part from the mentioned Desmet and Parente (2009)) Voigtländer and Voth (2006), Stokey (2001) and Lagerlöf (2006)). Provided that we also make use of simulation techniques and numerical solutions, the challenge to calibrate the model is for us more difficult, as we rely on much more micro dynamics, for which it is not possible to find relevant evidence. We do so when possible, otherwise we choose plausible values to analyse the benchmark model.[6]

In fact, from a methodological point of view we proposes a model that advances in the direction appealed by, among others, Akerlof and Shiller (2009) and Frydman and Goldberg (2007). We design a computational model with large space for microeconomic heterogeneity in the behaviour of agents, in line with Arifovic, Bullard, and Duffy (1997), Colander, Howitt, Kirman, Leijonhufvud, and Mehrling (2008), Deissenberg, Van Der Hoog, and Dawid (2008), Howitt (2006), Farmer and Foley (2009).

In the reminder of the paper we present the model in a detailed form in the following section (2), and provide a numerical description of its macro and meso economic properties, and discuss them, in Section 3.

## 2 The Model

We model a closed economy with three types of agents: *suppliers* that produce intermediate capital goods (hereinafter *capital (vintages)*), *firms* that produce consumer goods (hereinafter *commodities*), and consumers of commodities. Commodity producers use labour and capital. Labour has an infinite supply although wages are determined on a competitive market. Capital instead is constrained by the output of capital suppliers, which produce using only labour. We model a direct market interaction between commodity firms and capital suppliers and the productivity of capital vintages results from

[6] For space limitation we can not undergo the analysis of the crucial parameters in the same paper. Some results on a previous model without product innovation and hierarchical consumption can be found in Ciarli, Lorentz, Savona, and Valente (2010b). Similarly, we will devote another paper to report the effect of the parameters involved in product innovation.

these transactions. Both firms and suppliers have a typical pyramidal organisation, with shop floor employees working at the basis of the pyramid, and different tiers of employees organising the work of their subordinates (one tier below).

Commodities are classified into a finite number of sectors, each of which is defined on the demand side as satisfying a specific consumer need. Consumers thus have a finite number of innate needs according to which they allocate the purchasing choice. Here needs should not be seen strictly as necessities for physical survival, but as innate physiological and psychological stimuli (e.g. various aspects of conspicuous consumption in this respect are seen as needs). Although the simplifying assumption on a fixed number of needs may appear to be strong, it avoids much stronger and *ad hoc* assumptions on the way in which needs and wants evolve, which is matter for another research project. The consumption share allocated to each commodity (sector/need) depends on the income level of a consumer, in line with the evidence on Engel curves. The income of a given consumer class is affected by a macro dynamics that defines the minimum wage, and on the basis of the employment structure reflected in the pyramidal structure of all firms.

We model changes in the composition of the economy as the emergence of new goods on the supply side and the changes in consumption patterns on the demand side. The novelty created on the supply side as a result of product innovation may be *radical*, when the firm produces a commodity that serves a different sector/need, or *incremental*, when the firm improves the quality of the commodity, within the same sector.[7] Translated into innovation dynamics, firms constantly attempt to improve their output, either within the same sector or moving into neighbouring ones. In the first case firms simply increment the quality of the produced good, while in the second case they exit the current sector and enter a different one. The firm introduces a radical innovation when it moves to a sector which is not yet supplied. Radical innovations are then the sources of structural transformation on the supply side.

Changes in consumption shares occur as a new consumption class emerges, which is the result of the growing size of firms requiring an additional tier of employees to manage the growing pyramid, given that each employee can monitor only a relatively small number of subordinates. Each new labour/consumer class enjoys an exponentially higher income, resulting in a change in the consumption patterns from basic to luxury commodities. Shifts in the income structure then represent the source of structural transformation on the demand side.

We now turn to explaining how those dynamics are modelled in detail, discussing the formal implementation and assumptions of the behaviour of commodity firms 2.1, capital suppliers 2.2 and consumers 2.3

[7]In the literature there are different ways to define the innovation on the incremental–radical spectrum. Here we are not very much interested in this debate, although we want to differentiate innovations that induce structural change (radical) from hose that do not (incremental).

### 2.1 Commodity Firms

We model a population of $f \in \{1, 2, ..., F\}$ firms producing commodities for the consumer market. Each commodity satisfies one consumer need $n \in \{1, 2, ..., N\}$. Or, equivalently, each firm produces in one of the $n \in \{1, 2, ..., N\}$ sectors. Hereinafter we will refer to needs and sectors interchangeably.[8] The output of a firm $f$ addressing consumer need $n$ with price $p_{f,t}$ and quality $q_{f,t}$ can be described by the following vector:

$$\begin{pmatrix} n \\ q_{f,t} \\ p_{f,t} \end{pmatrix} \tag{1}$$

#### 2.1.1 Product innovation

Changes in the quality and in the sector of the supplied good result from the firm product innovation. The emergence of new commodities occurs in two stages: research and development (R&D) activity to develop new products, and their subsequent introduction in the market. In each period firms use a portion $R_{f,t}$ of their profits — when available — to develop new prototypes and store them in a set $\Phi$. The R&D process consists of (i) a searching phase in which firms choose the consumer need $n'$ in which they undertake innovation, and (ii) a development phase in which a prototype with quality $q'_{f,t}$ is produced.

The range of sectors $\left\{n^{min}_{f,t}; ...; n^{max}_{f,t}\right\}$ that a firm can explore is centred on the knowledge base of the currently produced sector $n$ (Nelson and Winter, 1982) and can be increased with R&D expenditure ($R_{f,t}$):

$$\begin{aligned} n^{min}_{f,t} &= max\left\{1; n - round\left(\tfrac{N}{2}\left(1 - e^{-\iota R_{f,t}}\right)\right)\right\} \\ n^{max}_{f,t} &= min\left\{N; n + round\left(\tfrac{N}{2}\left(1 - e^{-\iota R_{f,t}}\right)\right)\right\} \end{aligned} \tag{2}$$

where $\iota$ is a parameter that allows to study the effect of the speed at which new sectors are explored, leading to radical innovation and structural transformation. Within the set $\left\{n^{min}_{f,t}; ...; n^{max}_{f,t}\right\}$ the firm selects the sector $n'$ with the largest excess demand $Y^x_{n,t}$.[9] Formally:

$$n' = n \in \{n^{min}_{f,t}; ...; n^{max}_{f,t}\} | Y^x_{n,t} \geq Y^x_{m,t}, \forall m \in \{n^{min}_{f,t}; ...; n^{max}_{f,t}\} \tag{3}$$

In the development phase the firm produces a new prototype in sector $n'$, with a given quality negatively related to the distance between the old and the new sector. The result

[8] Although this is far from any approximation of the reality, it is more clear to talk about firms innovation in terms of sectors and of consumption patterns in terms of needs, when we refer to the same commodity. Whether there exists an actual mapping between the two, is definitely not an aim of this paper, and ultimately depends on the definition we want to give to *sectors*.

[9] Note that as long as some firms are active on a market, and their product reach the minimum level of quality demanded, excess demand equals zero. We assume that firms give priority to unexplored markets.

of R&D is stochastic:

$$q_{n',f,t} = \max\left\{0; q_{n',f,t} \sim N\left(q_{f,t}; \frac{\vartheta}{1-|n-n'|}\right)\right\} \tag{4}$$

where $\vartheta$ is a parameter that allows to study the effect of incremental innovations (variety in commodities quality). When the sector selected for innovation is the same one in which the firm currently produces the new prototype is retained only if it is of higher quality than the produced good, and if its introduction in the market represent an incremental innovation. Otherwise the innovation result is dismissed. If the set $\Phi$ of prototypes $q'_{\phi,f,t-1}$ contains less than three elements, the new prototype is added to the set. If, on the contrary, $\Phi = \{0; ...; 3\}$ the new prototype replaces the element with the lowest quality, if its own quality is higher. Otherwise the innovation result is dismissed. Formally, given an existing prototypes set $\Phi_{t-1} = \left\{q'_{1,n,f,t-1}, q'_{2,n,f,t-1}, 0\right\}$, the new set becomes $\Phi = \left\{q'_{1,n,f,t-1}, q'_{2,n,f,t-1}, q_{n',f,t}\right\}$. Given an existing prototype set $\Phi_{t-1} = \left\{q'_{1,n,f,t-1}, q'_{2,n,f,t-1}, q'_{3,n,f,t-1}\right\}$ such that, for example, $q'_{1,n,f,t-1} < q'_{2,n,f,t-1} < q'_{3,n,f,t-1}$ and $q'_{1,n,f,t-1} < q_{n',f,t}$, the new set becomes $\Phi = \left\{q_{n',f,t}, q'_{2,n,f,t-1}, q'_{3,n,f,t-1}\right\}$

The second stage of product innovation, i.e. the introduction of a new commodity in the market replacing the firm's current production, follows the well know Schumpeterian argument that firms innovate to seek for new sources of revenues. When the growth of sales is negative a firm has a positive probability to introduce one of the stored prototypes. The probability increases inversely with the negative growth of sales ($\Delta Y_{f,t} < 0$): the larger the losses the larger the probability to introduce an innovation. The probabilistic behaviour captures the limited forecasting capacity of firms, and allows to distinguish temporary pitfalls in sales from long term structural downturns that are more likely to require an innovation. We assume that the firm innovates introducing in the market its prototype with the highest quality $\left(max_{\phi}\{q'_{\phi,f,t}\}\right)$.

A new product is introduced subject to four conditions: first, the firm's set of prototypes is not empty; second, the firm has experienced negative sales for at least two consecutive periods; third, at least $T'$ periods have elapsed from the firm's previous innovation; finally, if, as a consequence of the innovation, the firm moves to a new sector, the number of firms in the new sector is lower than in the current sector $\left(F_{n' \neq n} + 1 < F_n\right)$. With the last condition we take into account the assumption that firms enter new sectors to escape competitive pressure. If, conversely, the new commodity is in the same sector of the current production, the prototype that is introduced must be of better quality than the currently marketed commodity. Formally, the probability of introducing a prototype and finalise the innovation stages is defined as follows:

$$\begin{aligned} &P\left[q_{n,f,t+1} = max_{\phi}\{q'_{\phi,f,t}\} | \Phi \neq \emptyset, \Delta Y_{f,t-1} < 0, F_{n' \neq n} + 1 < F_n\right] = 1 - e^{\min\{0; \frac{\theta}{\Delta Y_{f,t}}\}} \\ &P\left[q_{n,f,t+1} = q'_{n,f,t} | \Phi \neq \emptyset, \Delta Y_{f,t-1} < 0, q'_{n,f,t} = max_{\phi}\{q'_{\phi,f,t}\}\right] = 1 - e^{\min\{0; \frac{\theta}{\Delta Y_{f,t}}\}} \end{aligned} \tag{5}$$

where $\theta$ is a parameter that allows to study the effect of the speed at which radical and incremental innovations are introduced in the market.

### 2.1.2 Firm output and production factors

We assume that the level of demand faced by a firm is met with current production ($Q_{f,t}$) and inventories ($S_{f,t-1} \geq 0$) or delayed ($S_{f,t-1} < 0$) at no cost.[10] Firms form their sales expectations ($Y^e_{f,t}$) in an adaptive way to smooth short term volatility

$$Y^e_{f,t} = a^s Y^e_{f,t-1} + (1 - a^s) Y_{f,t-1} \tag{6}$$

where ($a^s$) defines the speed of adaptation. In order to cover unexpected changes in demand, firms maintain a level of inventories $\bar{s}Y^e_{f,t}$—where $\bar{s}$ is a fixed ratio.[11] The desired output $Q^d_{f,t}$ covers the expected demand $Y^e_{f,t}$, past inventories $S_{f,t-1}$, and the new inventories $\bar{s}Y^e_{f,t}$:

$$Q^d_{f,t} = (1 + \bar{s})\, Y^e_t - S_{t-1} \tag{7}$$

Firms produce using a fix coefficients technology

$$Q_{f,t} = \min \left\{ Q^d_{f,t}; A_{f,t-1} L^1_{f,t-1}; BK_{f,t-1} \right\} \tag{8}$$

where $A_{f,t-1}$ is the level of productivity of labour $L^1_{f,t-1}$ embodied in the firms' capital stock $K_{f,t-1}$. The capital intensity $\frac{1}{B}$ is constant[12]. The difference between $Q^d_{f,t}$ and $Q_{f,t}$ determines the level of inventories and backlogs.

Given $Q^d_{f,t}$ firms hire production workers $L^1_{f,t}$ according to the labour productivity $A_{f,t-1}$ and a reserve labour capacity ($u^l$) to face unexpected increases in final demand:

$$L^1_{f,t} = \epsilon L^1_{f,t-1} + (1 - \epsilon) \left[ \left( 1 + u^l \right) \frac{1}{A_{f,t-1}} min\{Q^d_{f,t}; BK_{f,t-1}\} \right] \tag{9}$$

where $\epsilon_L$ mimics labour market rigidities. Following Simon (1957) firms also hire 'executives': every batch of $\nu$ production workers requires one executive. Each batch of $\nu$ second tier executive requires a third level executives, and so on. The number of workers in each tier, given $L^1_{f,t}$ is thus

$$\begin{aligned} L^2_{f,t} &= L^1_{f,t} \nu^{-1} \\ &\vdots \\ L^z_{f,t} &= L^1_{f,t} \nu^{(1-z)} \\ &\vdots \\ L^{\Lambda_f}_{f,t} &= L^1_{f,t} \nu^{\left(1-\Lambda_f\right)} \end{aligned} \tag{10}$$

[10] The sector/need index $n$ is omitted for sake of readability.

[11] We assume an inventory/sales ratio that corresponds to the lower empirically observed values (see, e.g. McCarthy and Zakrajšek, 2000; U.S. Census Bureau, 2008), to avoid level effects that may be linked to the accumulation of inventories, and to reduce the propagation of production fluctuations.

[12] This assumption is sustained by evidence from numerous empirical studies, starting with Kaldor (1957). The capital investment decision ensures that the actual capital intensity remains fixed over time.

where $\Lambda_f$ is the total number of tiers required to manage the firm $f$. Consequently, the total number of workers is

$$L_{f,t} = \sum_{z=1}^{\Lambda_f} L_{f,t}^z = L_{f,t}^1 \sum_{z=1}^{\Lambda_f} \nu^{1-z} \tag{11}$$

Following Amendola and Gaffard (1998) and Llerena and Lorentz (2004) capital goods constitute the basis of firms' production capacity and define the efficiency of the labour force. Indicating with $V_f$ the number of capital vintages acquired, $k_{h,f}$ and $\tau_h$ the amount of capital and date of purchase of vintage $h$ respectively, the capital stock is computed as

$$K_{f,t} = \sum_{h=1}^{V_f} k_{h,f}(1-\delta)^{t-\tau_h} \tag{12}$$

where $\delta$ is the depreciation rate. The level of productivity embodied in the capital stock is computed as the average productivity across all the vintages available:

$$A_{f,t} = \sum_{h=1}^{V_f} \frac{k_{h,f}(1-\delta)^{t-\tau_h}}{K_{f,t}} a_{g,\tau_h} \tag{13}$$

where $a_{g,\tau_h}$ is the productivity embodied in the $h$ vintage.

Capital investment is then written as

$$k_{f,t}^e = (1+u)\frac{Y_{f,t}^e}{B} - K_{f,t-1} \tag{14}$$

where $u$ is a percentage of unused stock. The firm selects on of the capital producers $g \in \{1;...;G\}$ and place an order for the desired stock:

$$k_{g,f,t}^d = k_{f,t}^e \tag{15}$$

The probability to pick a producer $g$ increases with the embodied productivity of its output ($a_{g,t-1}$), and decreases with its price ($p_{g,t-1}$) and the cumulated demand still to satisfy. The actual delivery may take place after one or more periods

### 2.1.3 Wage setting, pricing and the use of profits

We define a minimum wage ($w_{min}$) at the macroeconomic level computed as an outwards shifting wage curve (Blanchflower and Oswald, 2006; Nijkamp and Poot, 2005) and using a Beveridge curve to compute unemployment given the vacancy rate generated by the model (Wall and Zoega, 2002; Nickell, Nunziata, Ochel, and Quintini, 2002; Teo, Thangavelu, and Quah, 2004). The outward shifts adjust the minimum wage with respect to changes in labour productivity and the average price of commodities. A detailed description of the computation of the minimum wage can be found in Ciarli, Lorentz, Savona, and Valente (2010a).

The wage paied to the first tier workers is linearly related to the minimum wage, $w_{f,t}^1 = \omega w_{min,t-1}$, and it increases exponentially along the firm hierarchies by a factor

$b$ that determines the skewness in the wage distribution in line with Simon (1957) and Lydall (1959):

$$\begin{aligned} w^2_{f,t} &= b\omega w^1_t = b\omega w_{min,t-1} \\ &\vdots \\ w^z_t &= b^{(z-1)}\omega w_{min,t-1} \\ &\vdots \\ w^{\Lambda_f}_t &= b^{(\Lambda_f-1)}\omega w_{min,t-1} \end{aligned} \tag{16}$$

The price is set by firms applying a mark-up on unitary production costs (Hall and Hitch, 1939; Blinder, 1991; Hall, Walsh, and Yates, 1997), i.e. the total wage bill divided by labour capacity:

$$p_{f,t} = (1+\mu)\frac{\sum_{z=1}^{\Lambda_f} w^z_{f,t} L^z_{f,t}}{A_{f,t-1} L^1_{f,t}} = (1+\mu)\frac{\omega w_{min,t-1}}{A_{f,t-1}} \sum_{z=1}^{\Lambda_f} b^{(z-1)} \nu^{(1-z)} \tag{17}$$

This is line with the evidence that firms mainly use a mark-up as a pricing mechanism, the price is revised only once an year, and the main reasons for price adjustemnts are inputs and wage costs (Langbraaten, Nordbø, and Wulfsberg, 2008). The tier-wage structure also implies diseconomies of scale in the short-run, affecting costs and prices, in line with the literature on the relation between firm size and cost (e.g. Idson and Oi, 1999; Criscuolo, 2000; Bottazzi and Grazzi, 2007).

The profits that result from the difference between the value of sales and the cost of production

$$\pi_{f,t} = p_{f,t-1} Y_{f,t} - \omega w_{min,t-1} L^1_{z,t} \sum_{z=1}^{\Lambda_f} b^{(z-1)} \nu^{(1-z)} \tag{18}$$

are used for (i) investment in new capital $\left(k^e_{f,t}\right)$, (ii) R&D for product innovation ($R_{f,t}$), and (iii) wage premia to executives ($D_{f,t}$). We assume that when firms face capital constraints and are in need to increase the level of output they always priorities capital investment, while a parameter $\rho$ determines the allocation of the remaining profits between R & D and wage premia:[13]

$$R_{f,t} = max\left\{0; \rho\left(\sum_{\tau=1}^{t} \pi_\tau - \sum_{h=1}^{V_f} k_{h,f} p^K_{g,h} - \sum_{\tau=1}^{t-1} (R_{f,\tau} - D_{f,\tau})\right)\right\} \tag{19}$$

[13] We are well aware of the recent empirical evidence that suggest that there is no positive causal relation between profit growth and R&D growth, while the causal factor affecting R&D seems to be sales (see for example Coad and Rao (2010) and Moneta, Entner, Hoyer, and Coad (2010), or Dosi, Marengo, and Pasquali (2006) for a review). Indeed, by assuming a fixed mark-up, in our model profits are a constant share of sales. In other words, we can easily maintain that R&D is related to the previous period sales figures but that having no credit market in the model we need to constraint the R&D investment with the available resources, i.e. profits. Moreover, the reader will notice that by including bonuses to executives the model can easily account for situations in which profits are not at all employed for R&D and redistributed to shareholders/managers (as suggested by some of the cited literature).

$$D_{f,t} = max\left\{0; (1-\rho)\left(\sum_{\tau=1}^{t}\pi_\tau - \sum_{h=1}^{V_f} k_{h,f}p^K_{g,h} - \sum_{\tau=1}^{t-1}(R_{f,\tau} - D_{f,\tau})\right)\right\} \quad (20)$$

Wage premia are assumed to be distributed proportianally to the regular wage only to executives tiers ($z \in \{2; ..; G\}$). The share $\psi^z_t$ of redistributed profits to the executives of each tier $z$ is computed as

$$\psi^z_{f,t} = \begin{cases} \frac{w^z_t}{\sum_{z=2}^{\Lambda_f} w^z_t} D_{f,t} = \frac{b^{z-1}}{\sum_{z=2}^{\Lambda_f} b^{z-1}} D_{f,t} \ ; \forall z \in \{2; \Lambda_f\} \\ \\ 0 \ ; \text{for } z = 1 \end{cases} \quad (21)$$

and the overall earnings for an employee of tier $z$ is $w^z_{f,t} + \psi^z_{f,t}$.[14]

## 2.2 Capital suppliers

### 2.2.1 Output and production factors

The capital good sector is formed of a population of $g \in \{1, 2, \ldots, G\}$ capital suppliers that produce one type of capital good characterised by the vintage $\tau_h$ and the embodied productivity $a_{\tau_h}$. In line with the empirical evidence (see e.g. Doms and Dunne, 1998; Cooper and Haltiwanger, 2006), we assume that the production of capital is just–in–time, with no expectation formation or accumulation of inventories. Capital suppliers receive purchase orders $k^d_{g,f,\tau_f}$ from firms in the commodities sectors (when they invest)—where the $\tau_f$ refers to the date of the order placement by manufacturing firm $f$—and fulfill them by sequence of arrival. The total demand $K^D_{g,t}$ for a capital supplier $g$ in period $t$ is the sum of current orders and of the orders from previous periods still unfulfilled $U^K_{g,t-1}$:

$$K^D_{g,t} = \sum_{f=1}^{F} k^d_{g,f,t} + U^K_{g,t-1} \quad (22)$$

For simplicity we assume that machinery firms employ labour as the sole input

$$Q_{g,t} = A_g L^1_{g,t-1} \quad (23)$$

where $L^1_{g,t-1}$ are the production workers and $A_g$ is their productivity, assumed to be constant in this sector. In each period firms sell the available manufactured orders and over time cumulate a number of uncovered orders:

$$Y_{g,t} = min\{Q_{g,t}; K^D_{g,t}\} \quad (24)$$

$$U^K_{g,t} = \sum_{\tau=1}^{t}\sum_{f=1}^{F} k^d_{g,f,\tau} - \sum_{j=1}^{t} Y_{g,j} \quad (25)$$

[14] Correcting for the evidence that the exponential wage structure of hierarchical organisation is not sufficient to explain earnings disparities (Atkinson, 2007).

Upon completion a capital good vintage $\tau_h$ is determined, and it is transferred to the purchasing firm.[15]

Such as for commodity firms, capital suppliers hire a number of workers necessary to fulfill the demand, given labour productivity and a reserve of labour capacity $u$:

$$L^1_{g,t} = \epsilon L^1_{g,t-1} + (1-\epsilon)\left[(1+u)\frac{K^D_{g,t}}{A_g}\right] \tag{26}$$

where $\epsilon_M$ are labour market rigidities in the capital sector. In order to organise the production capital suppliers hire an executive every batch of $\nu$ production workers $L^1_{g,t}$, one executive every batch of $\nu$ second-tier executives, and so on. The total number of workers in a firm is therefore

$$L_{g,t} = L^1_{g,t} + ... + L^z_{g,t} + ... + L^{\Lambda_g}_{g,t} = L^1_{g,t}\sum_{z=1}^{\Lambda_g}\nu^{1-z} \tag{27}$$

### 2.2.2 Process innovation

Capital suppliers increase the productivity $a_{\tau_h}$ of the produced capital by devoting a share of their resources to R&D, which occurs through hiring engineers.[16] In the tradition of Schumpeterian growth models (e.g. Aghion and Howitt, 1998; Silverberg and Verspagen, 2005) the outcome of R&D is stochastic and the probability of an increase in productivity $\left(P^{inn}_{g,t}\right)$ depends on the amount of financial resources invested (i.e. to the number of engineers employed $\left(L^E_{g,t-1}\right)$). Following Nelson and Winter (1982) and Llerena and Lorentz (2004):

$$P^{inn}_{g,t} = 1 - e^{-\zeta L^E_{g,t-1}} \tag{28}$$

where $\zeta$ determines the effectiveness of R&D investment. Firms set the number of engineers they wish to employ as a ratio $\nu^K$ of first tier workers constrained by the share $\rho_k$ of cumulated profits $\Pi_{g,t}$ allocated to R&D:[17]

$$L^E_{g,t} = min\left\{\nu^K L^1_{g,t}; \rho\frac{\Pi_{g,t}}{w^E_{g,t}}\right\} \tag{29}$$

The R&D routine is modelled as follows:

1. Firms draw a number from a Uniform distribution on [0 ; 1].
2. If this number is contained in the interval [0 ; $P^{inn}_{g,t}$] the R&D is successful and the productivity of the new capital vintage is randomly drawn:

$$a_{g,\tau_h} = a_{g,\tau_{h-1}}\left(1 + max\{\varepsilon^a_{g,t}; 0\}\right) \tag{30}$$

where $\varepsilon^a_{g,t} \sim N(0;\sigma^a)$ is a normally distributed random function.

[15] We recall that one of the three determinants of the probability of being selected by a firm in the commodities sector is the cumulated demand still to satisfy.

[16] We recall that one of the three determinants of the probability of being selected by a firm in the commodities sector is the productivity of the current capital vintage produced.

[17] See footnote 13 for a discussion on profits and R&D.

### 2.2.3 Wage setting, price and profits

Prices of capital goods $p_{g,t}$ are set according to a fixed mark-up rule ($\mu^K$) where variable costs include production workers, executives, and engineers, divided by the level of output ($Q_{g,t}$):

$$p_{g,t} = (1+\mu^K)\omega w_{min,t-1}\left(\sum_{z=1}^{\Lambda_g}\frac{b^{z-1}\nu^{1-z}}{A_g} + \frac{\omega^E L^E_{g,t-1}}{Q_{g,t}}\right)$$

where $w^E_{g,t}$ is the wage of engineers. As for the commodities firms the first tier wage is a linear function of the minimum wage $w_{min,t}$, as well as for engineers (with a multiple $\omega^E$ of the minimum wage), for which we assume they all work in the same tier.[18] Wages increase exponentially along the firm hierarchies by a factor $b$ which is identical to the one assumed for commodities firms.

Profits resulting from the difference between the value of sales and the costs for workers and engineers:

$$\pi_{g,t} = p_{g,t}Y_{g,t} - \omega w_{min,t-1}\left(L^1_{g,t-1}\sum_{z=1}^{\Lambda_g} b^{z-1}\nu^{1-z} + \omega^E L^E_{g,t-1}\right) \tag{31}$$

are cumulated ($\Pi_{g,t}$) and a share $\rho_k$ is used to finance R&D activity while the remaining share $1-\rho_k$ is distributed to executives as wage premia, proportionally to their wage.[19] The share of redistributed profits is computed as:

$$D_{g,t} = max\left\{0;(1-\rho)\Pi_{g,t}\right\} \tag{32}$$

with

$$\Pi_{g,t} = \sum_{\tau=1}^{t-1}\pi_{g,\tau} - \sum_{\tau=1}^{t-1} w^E_\tau L^E_\tau - \sum_{\tau=1}^{t-1} D_{g,\tau} \tag{33}$$

## 2.3 Demand

The demand side of the model co-evolves with the structure of production (change in product composition, firm organisation and production process) acting as the endogenous transmission mechanism through which structural changes on the supply side affect changes in income growth.

We assume that each tier of employees in the hierarchical organisation of firms defines one (income) class of consumers that share the same income, consumption shares, and preference structure. In our model there is a perfect mapping between classes of workers and classes of consumers. In other words, socio-economic differences can be traced back to the place of work. This is of course a restrictive assumption, but by far more helpful than assuming two fixed classes such as rural and urban workers, or homogeneous consumers.

Consumers with limited information on the characteristics of the goods choose among the goods produced by the different commodities firms in the different sectors.

[18]Given the very low numbers of engineers, this assumption does not affect the results.

[19]The scheme of distribution of premiums is the same as for final good firms.

### 2.3.1 Disposable income by consumer class

Each consumer class $z \in \{0, 1, \ldots, \Lambda_t\}$[20] has a disposable income $W_{z,t}$ composed of wages ($W^w_{z,t}$), distributed profits ($W^\psi_{z,t}$), and an exogenous income ($\bar{W}_{z,t}$). The total wage of a class $z$ is the sum of the wages paied by all firms, in the commodity and capital sectors, to the corresponding tier :

$$W^w_{z,t} = \sum_{f=1}^{F} w_{f,z,t} L_{f,z,t} + \sum_{g=1}^{G} w_{g,z,t} L_{g,z,t} \ , \ \forall z \in \{1; 2; ...; \Lambda_t\} \tag{34}$$

Assuming that all firms use the same wage multipliers ($\omega$, $b$) this can therefore be expressed as follows:

$$W^w_{z,t} = b^{z-1} w_{min,t-1} \left( \sum_{f=1}^{F} L_{f,z,t} + \sum_{g=1}^{G} L_{g,z,t} \right) \ , \ \forall z \in \{1; 2; ...; \Lambda_t\} \tag{35}$$

The total wage bonus of a class $z > 1$ is the sum of the share of profits redistributed by firms to the corresponding tier:

$$W^\psi_{z,t} = \sum_{f=1}^{F} \psi_{f,z,t} + \sum_{g=1}^{G} \psi_{g,z,t} \ , \ \forall z \in \{2; ...; \Lambda_t\} \tag{36}$$

The income available for households consumption is then directly affected both by firms' production structure and by their output level.

### 2.3.2 Evolution of household's expenditure

The total level of expenditure in a time period is a convex combination of the current level of income and the past level of expenditure ($X_{z,t-1}$):

$$X_{z,t} = \gamma X_{z,t-1} + (1 - \gamma) W_{z,t} \tag{37}$$

where $\gamma \in [0; 1]$ determines the level of consumption smoothing. As we have noted above consumers share their consumption across different needs $n \in \{1; ...; N\}$—each of which is satisfied by a sector—allocating to each need a share $c_{n,z}$ equal for all consumers in a class. The *desired* consumption level per need $C^d_{n,z,t}$ can be easily derived as

$$C^d_{n,z,t} = c_{n,z} X_{z,t} \text{ with } c_{n,z} \in [0; 1] \ ; \ \sum_{n=1}^{N} c_{n,z} = 1 \ \forall z \tag{38}$$

Following the literature on the distribution of expenditures shares and the evidence on Engel curves we assume that these expenditure shares vary across income classes. More precisely, as we move from first tier classes to classes of higher wages and bonuses the expenditure shares move from satiated primary goods to luxury goods. In our model the

[20] Where $\Lambda_t$ is the number of tiers of the larger firm in the market, and $z = 0$ is the class of engineers in capital sector firms.

number of classes is endogenous, and depends on the firm's size. In other words, we can not know in advance the number of classes that emerge through time, as this number depends on the structural conditions of the economy.[21] Therefore we need to assume an "initial" distribution of consumption shares that characterises the first tier class in the initial period of the model, and an "asymptotic" distribution of consumption shares $\bar{c}_n$ towards which the shares tend as new hierarchical tiers and classes emerge. Given that we are analysing long-term growth for the asymptotic (long-run) distribution we use the consumption share of the UK top income centile in 2005 across ten aggregate sectors (Office for National Statistics, 2006)—which we assume to satisfy ten different needs—ordered from the smaller to the larger (Figure 1).[22] Finally, we assume that the consumption shares of the first tier class a few centuries before—the initial period of the model—are distribute symmetrically.[23]

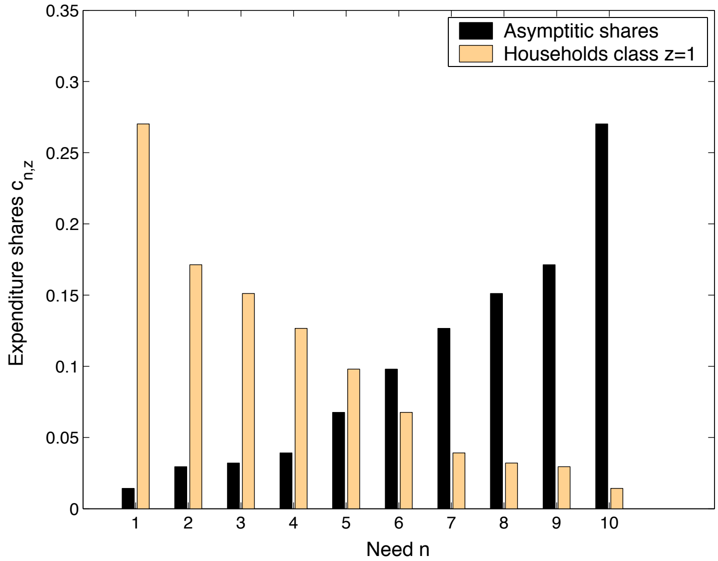



Figure 1: ***Expenditure shares: initial and asymptotic***. *The distribution of the asymptotic level of shares corresponds to the current shares of expenditures for the higher percentile of UK consumers. For the seek of simplicity, the initial shares are assumed to be distributed symmetrically.*

Each time a new income class $z$ emerges due to the expansion of firms' activity the corresponding expenditure shares $c_{n,z}$ evolve as follows:

$$c_{n,z} = c_{n,z-1} \left(1 - \eta \left(c_{n,z-1} - \bar{c}_n\right)\right) \tag{39}$$

where the parameter $\eta$ controls the speed of convergence to the asymptotic value of expenditure shares. Such dynamics is illustrated in Figure 2 for a typical case in which 10

[21] See for example the results on an older version of the model with no consumption shares and one homogeneous need in Ciarli, Lorentz, Savona, and Valente (2010b).

[22] We thank Alessio Moneta for sharing the data with us.

[23] Qualitative evidence to support this assumption on the changes in household expenditure shares can be found in Maddison (2001).

hierarchical tiers and classes emerge.[24]

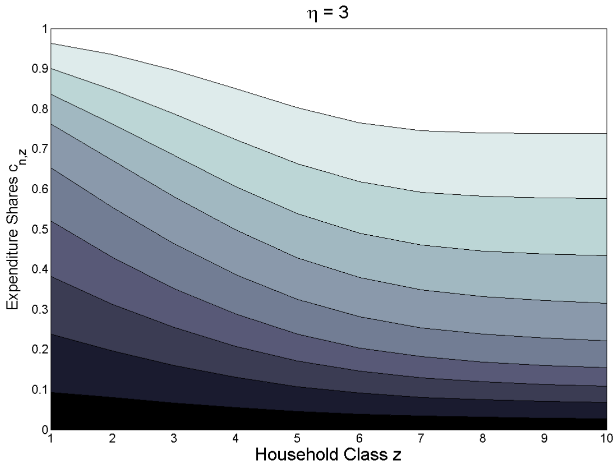



Figure 2: ***Expenditure shares dynamics according to the Engel curve****. We illustrate the share dynamics linked to the Engel curve for 10 income classes of households. The actual number of classes is endogenous in the model.*

When only a limited number of commodities are available (i.e. some needs can not be satisfied) consumers are forced to adapt consumption shares accordingly, redistributing consumption shares for non available needs to available products, proportionally to the consumption shares of existing commodities. We can now define excess demand, which guides the choice of the sector in which commodities firm innovate and produce the prototype, as:

$$Y^x_{n,t} = \sum_{f_n} Y_{f_n,t} p_{f_n,t} - \sum_z c_{n,z} X_{z,t} \tag{40}$$

### 2.3.3 Consumer Behaviour and Firm Sales

We model bounded rational consumption behaviour inspired by the literature on experimental psychology, which has the properties of empirically observed behaviour (Gigerenzer, 1997; Gigerenzer and Selten, 2001).We model the purchasing decisions of consumers in

[24]The speed and pace at which the share of a given need $n$ changes is function of its distance with the asymptotical share, and of the speed at which the share of the other needs change. Verspagen (1993) and Lorenttz (2005) discuss the dynamics of Engel curves that account for the interdependences between consumption shares for different consumption categories. In a general setting the changes in consumption shares across income classes can be formalised as follows:

$$c_{n,z} = c_{n,z-1}\left(1 + \frac{\partial c_{n,z}}{\partial z}\Delta z\right)$$

where

$$\frac{\partial c_{n,z}}{\partial z} = c_{n,z-1}\sum_{\bar{n}\neq n}^{N} \eta_{\bar{n}n}\left(c_{\bar{n},z-1} - \bar{c}_{\bar{n}}\right) - \left(c_{n,z-1} - \bar{c}_n\right)\sum_{\bar{n}\neq n}^{N} \eta_{n\bar{n}} c_{\bar{n},z-1}$$

and the parameters $\eta_{\bar{n}n}$ and $\eta_{n\bar{n}}$ account for the interdependence. To simplify here we assume $\eta_{\bar{n}n} = \eta_{n\bar{n}} = \eta$.

each class independently. Consumers in a given class $z$ are divided into $H \in N^+$ identical groups that spend an equal share of the class's income $\frac{X_{z,t}}{H}$.

For each need $n$ each consumer group $m$ in each class $z$ assigns to each firm that produces the good satisfying need $n$ ($f_n \in F_n$) a perceived value for both the price $p_{f_n,t}$ and the quality $q_{f_n,t}$ of its good:

$$i^*_{f_n,m,t} \sim N\left(i_{f_n,t}, \sigma^i i_{f_n,t}\right) \;\; ; \forall i = \{p; q\} \tag{41}$$

where $\sigma^i i_{f_n,t}$, the variance of the normal distribution, should be interpreted as the measure of the perception error of a purchasing decision.[25] Given $i^*_{f_n,m,t}$ consumers select only the products of firms $f^*_n$ whose perceived values score equivalent to the (perceived) best product ($i{*}_{B_n,m,t}$) for each of the characteristics (i.e. lowest price, highest quality):

$$f^*_n = f_n \in \{F_n\} | i^*_{f_n,m,t} \equiv i^*_{B_n,m,t} \tag{42}$$

The equivalence criterion is determined with a range $\upsilon^i_z \in [0, 1]$: the perceived value of a product characteristic $i^*_{f_n,m,t}$ is considered equivalent to $i^*_{B_n,m,t}$ if the difference between the two values is smaller than a given percentage $\upsilon^i_z$. Formally:

$$i^*_{f_n,m,t} \equiv i^*_{B_n,m,t} \Leftrightarrow |i^*_{f_n,m,t} - i^*_{B_n,m,t}| < (1 - \upsilon^i_z) i^*_{B_n,m,t} \;\; ; \forall i = \{p; q\} \tag{43}$$

The parameter $\upsilon^i_z$ should be interpreted as a tolerance level for products whose characteristics are of less–than–optimal quality. For example, when $\upsilon^i_z = 1.0$ the consumer group discards any product with a perceived value only marginally lower than optimal and chooses the best firm. For $\upsilon^i_z = 0.6$, on the other hand, the consumer group is indifferent over goods that are at least 60% as good as the optimal good.

The expenditures of the group $m$ for the need $n$ are equally shared among the selected firms $f^*_n$. Let $F{*}_{n,m,t} \subset F_n$ be the subset of firms satisfying the equivalence criterion. The share ($y_{f_n,z,m,t}$) of a group $m$ in class $z$ expenditures for the need $n$ spent on a firm $f_n$ product can then be written as:

$$y_{f_n,z,m,t} = \begin{cases} 0 \; ; \forall f_n \notin \{F^*_{n,m,t}\} \\ \\ \frac{1}{F^*_{n,m,t}} \; ; \forall f_n \in \{F^*_{n,m,t}\} \end{cases} \tag{44}$$

The total units sold ($Y_{f,t}$) by a firm is then the sum of sales over all groups and classes:

$$Y_{f,t} = \frac{1}{p_{f,t}} \sum_{z=1}^{\Lambda_t} \sum_{m=1}^{H_{n,z}} y_{f_n,z,m,t} \frac{X_{z,t}}{H} \tag{45}$$

On the supply side the desired consumption level per need defines the potential demand that commodities firms observe when they decide within which need they undergo R&D

[25] The reader may object that price, unlike quality, is generally easy to assess. However, it is frequently the case that consumers fail to assess the true costs of a purchasing option (e.g. maintenance and usage costs). Moreover, this method allows us to represent the heterogeneity within a class.

(see Equation 3). Hence, as firms increase their spending in R&D along time, they learn to produce goods that satisfy unsatisfied needs. Given the way in which we model the spur of income classes, as the total income grows, the share of non met needs also increases, inducing firms to move from basic to luxury goods

Finally, these sales ($Y_{f,t}$) are used by the final goods firms to set their expectations for the next period's demand ($Y^e_{f,t+1}$, see equation 6).

# 3 A numerical analisys

## 3.1 Simulation procedure and sensitivity analysis

Prior to discussing the growth patterns emerging from the numerical simulations this section presents and discusses the basic initial settings of the model and its sensitivity to random seeds. We do not aim with this model to reproduce actual historical dynamics. The numerical simulations are therefore not calibrated on a specific economy. The parameters of the model are nevertheless set to keep an empirical consistency. The full set of parameters values is reported in Table 2.

The commodity sector is composed of $f = \{1, 2, ..., 100\}$ firms evenly distributed across the two initial existing sectors among the $n \in \{1, 2, ..., 10\}$ ones that can emerge. The remaining 8 sectors emerge as a results of firm's product innovation. The initial quality of the product is drawn from a Uniform distribution: $i_2 \sim U[98, 102]$. Each product innovation results in an increase in quality of 1% ($\vartheta = 0.01$), on average, discounted if the product innovation implies entering a new sector.

Firms in the commodity sectors are, initially, identical in all other respects. The capital coefficient ($B = 0.4$) insures that the capital intensity of the economy is consistent with empirical evidence. The mark–up ($\mu = 5\%$) and the share of available resources devoted to R&D ($\rho = 50\%$) are set so that firms spending on R&D remains in the range of observable data (Marchetti, 2002).[26] The depreciation rate of capital goods ($\delta = 0.1\%$) departs from observed data in modern economies to insure that the growth pattern of the economy is not constrained by the fast decline of firms production capacity due to the depreciation of capital and that the capital stock of firms is fully renewed in the course of the simulation run, even if demand do not raise.

The parameters defining firm's organisational layers and wages ($\nu = 5$; $b = 2$; $\omega = 1.1$) are set at average levels found in Simon (1957), Lydall (1959), and Prescott (2003), while the relation between workers' and engineers' wages is in the range of current empirical observations.[27]

The capital sector is populated by $g = \{1, 2, ..., 10\}$ firms, which are initially homogeneous competitors. The structure of the labour force ($\nu = 5$), the layer multiplier

[26] Note that R&D expenditure is on average substantially reduced by the priority that firms give to capital investment over any other use of the resources, and amounts to 2.6% of revenues.

[27] Based on the Eurostat Structure of earnings survey 2006 (http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/en/earn_ses06_esms.htm)

($\nu^K = 5$), and the wage multipliers ($\omega^K = 1.1$ ; $\omega^E = 1.5$ ; $b = 2$) are set according to the empirical evidences mentioned above. We assume that capital suppliers face a less competitive market than commodity firms and charge a mark-up larger than average ($\mu = 50\%$) (Marchetti, 2002). Having found no evidence on the revenues/engineers ratio, we assume that firms spend 70% of profits in hiring engineers for R&D ($\rho = 70\%$).[28] . In the initial period all firms are identical.

All firms are initially small, requiring only one manager. Capital firms also hire an engineer. This labour structure defines three initial classes of consumers: engineers, first tier workers, and a tier of managers. The expenditure share of each class are based on the the 2004 UK expenditure survey, as described in section 2.3.2 and depicted in Figure 1. Different consumer classes are also assumed to have different preferences with respect to product's quality and price: the first tier workers have a high tolerance toward quality ($i_2\left(\upsilon_{1,2} = \upsilon^{min} = 0.1\right)$), but are highly sensitive to even small price differences ($i_1\left(\upsilon_{1,1} = \upsilon^{max} = 0.9\right)$). Each following class of managers ($z + 1$) reduces the tolerance toward shortfalls in quality and increases the tolerance toward price by a fixed multiplier ($\varsigma$): $\upsilon_{z+1,2} = (1-\varsigma)\upsilon_{z,2} + \varsigma\upsilon^{max}$ and $\upsilon_{z+1,1} = (1-\varsigma)\upsilon_{z,1} - \varsigma\upsilon^{min}$, where $\upsilon^{max}$ and $\upsilon^{min}$ are the boundaries of the possible tolerance level with respect to product quality levels. The preferences of the engineers are drawn randomly ($\upsilon_{0,m} \sim U\left(0, 1\right)$). Finally, each consumer class is divided in $h_z \in \{1, 2, ..., 100\}$ purchasing samples.

Each of the simulation run lasts for 2000 simulation steps, and the results presented and discussed in the next section are averages over 200 simulations to control for random effects.

### 3.2 Results

The model reproduces an endogenous growth dynamic of output that becomes exponential after round about one thousand time periods (Figure 3). When looking at different series of results generated with different initial random seeds we observe an increasing difference across simulations (we report results from 200 different simulations) through time, despite they all become exponential around the same period. Indeed, because of the exponential pattern the difference across series becomes larger, as a consequence of different stochastic processes summing up through time. The results thus show that a consistent pattern of the long process of growth that we observe is related to random events, which do not cancel out more often than they do (as for the series that are close to the 200 series average), in line with some of the literature on modern growth (e.g., Voigtländer and Voth, 2006). Incidentally, Figure 3 also shows that a large majority of the 10 series averages lay within the 10% confidence interval of the average over 200 series, and that there is a quite small variance between them. This is important as it allows to analyse the effect of the model's parameters using ten series rather than 200, with an exponential reduction in computation time.

[28] Which is about 52.5% of the firm revenues.

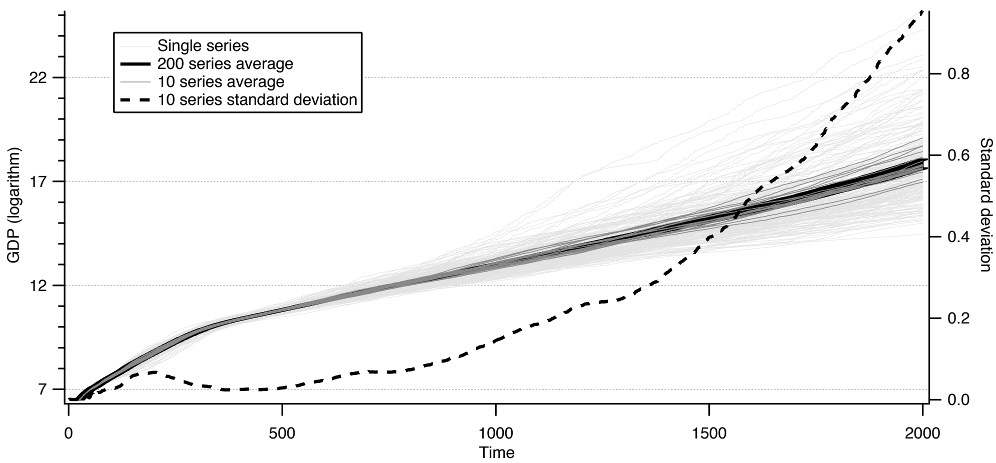



Figure 3: ***GDP over 2000 simulated periods***. *Light grey series reproduce single runs (with different stochastic behaviour), the darker grey series the average over ten random series, and the black series is the 200 series average with its 10% Confidence Interval. The dashed series is the standard deviation across the 20 different 10 series averages*

### 3.3 Some aggregate features of long run growth

The model represents too complex micro dynamics to be fully calibrated. We discuss in the model description (Section 2) and in the preceding section (3.1) the empirical justification for most of the microeconomic assumptions and parameters values that approximate available information (see Tables 1 and 2). Indeed, such information can not be available all for the same period (going back beyond the twentieth century it is difficult to find any microeconomic data at all). We are as well unable to define a precise enough measure of a time period which involves many micro dynamics, which would not sound completely *ad hoc* (with all related drawbacks). The following results should then be read within the context of an abstract model, and are thus abstract in nature, with no prediction power, but with the possibility to show properties of log run growth and structural changes.

As mentioned above the evolution of output (our proxy for GDP) shows a typical pattern of initial slow accumulation followed by a take-off and an unprecedented increase (Figure 4). Or, to use the unified growth theory language, a period of pre-malthusian growth followed by modern growth after a transition that occurs around period 1000.

It should be noted that in both periods the economy experiences growth, as shown when we rescale the picture for the two different time periods (Figure 3.3), but the level and growth of output in the pre take-off period are low and comparable—in relative terms—to those of the pre-industrial revolution.

The second relevant aggregate property of the model is the dynamics of the aggregate productivity, which is the result of the capital investment by manufacturing firms, and of the process innovation embedded in the new capital vintages. As already noted in the introduction the industrial revolution did not occur as a sudden increase in TFP, but as the result of market expansion via the expansion of sectors and the increase in the demand

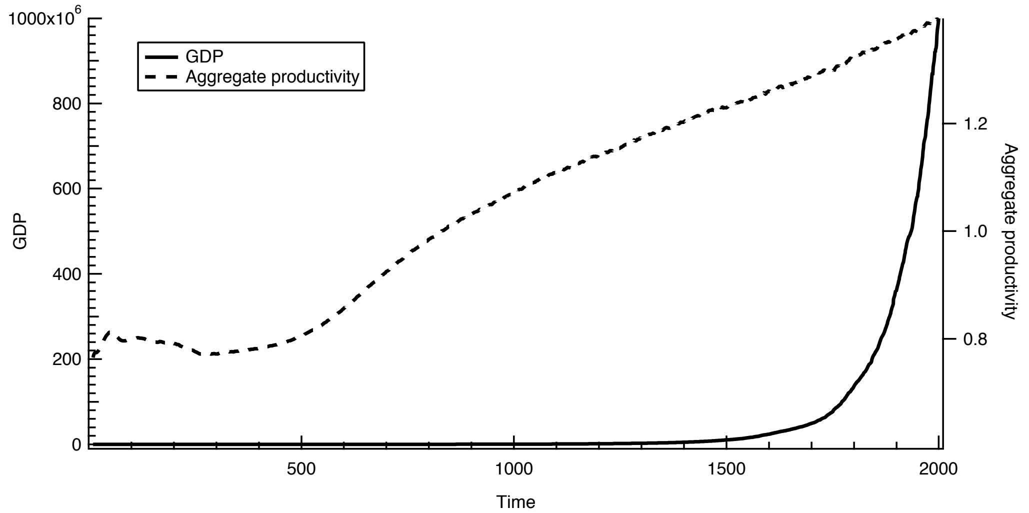
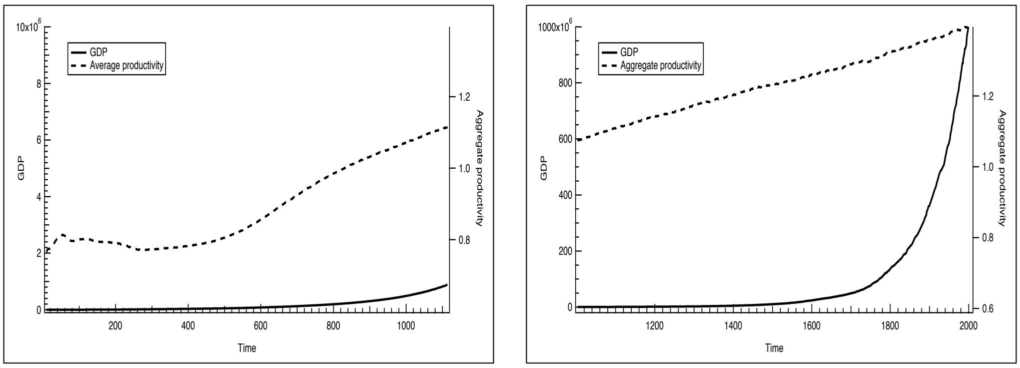



Figure 4: ***GDP and aggregate productivity over 2000 simulated periods.***




(**a**) Pre take-off (**b**) Post take-off

Figure 5: ***GDP and aggregate productivity rescaled before and after the take-off.***

for high income elasticity goods. In our model it is through market selection of firms, concentration of the demand on few firms, and large investment that these firms need to do to respond to the shift in demand, that process innovation takes place in the form of R&D of capital suppliers. Firms also introduce new products and move to other sectors to escape competition and reducing sales, facing monopolistic markets an increasing demand due to the evolution of consume classes that accompanies the growth of firms. We will come back to this issue in the next section, when we show some of the micro properties of the model.

Third, the change in aggregate productivity occurs together with a slowing down of population growth rate and a corresponding increase in the per capita GDP (Figure 6). In our model the initial GDP per capita, together with real wages, reduces due to the large increase in population, which in the first periods is not counterbalanced by the increase in aggregate productivity (comparing Figures 4 and 6). It is then the initial slow down of population growth followed by small increases in aggregate productivity that induces the continuous increase observed in GDP per capita. The two dynamics of population and aggregate productivity are clearly linked: although firms grow across all periods (reflected in the increasing population) more than proportionally with respect to workers employed in the production chain, the increase in productivity through time reduces the demand for labour per unit of output, without affecting aggregate demand that expands towards new classes and sectors.

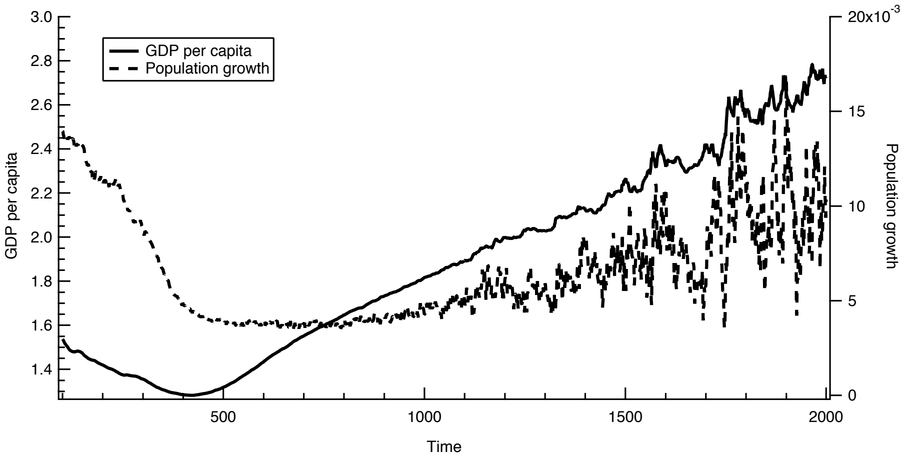



Figure 6: ***GDP per capital and population growth rate.***

We should also note that the GDP per capita dynamics is linked to the secular changes in prices, which after an initial period of growth due to the higher costs incurred by firms increasing in size (and hence in overall cost, as well described in much of the literature on the relation between firm size and costs), reduce throughout the whole period, as a result of the dynamics of aggregate productivity (Figure 7).

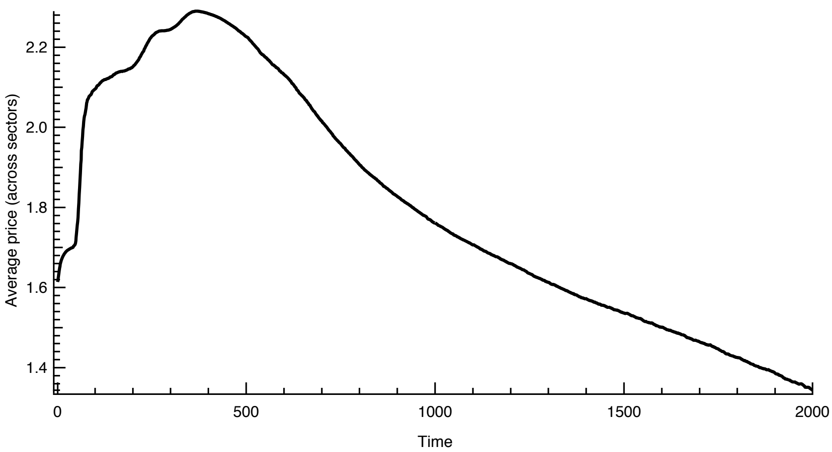
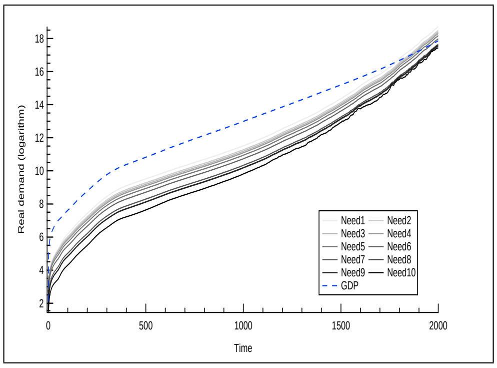


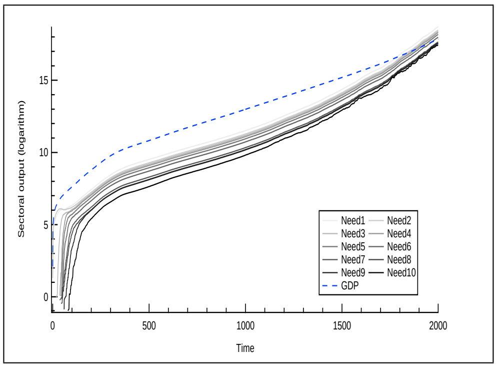

Figure 7: ***Average price across sectors.***

### 3.4 Micro and meso–dynamics

The next question is how these aggregate dynamics are accompanied by changes in the composition of the economy. And how the two levels are linked. We start by showing the way in which the potential demand and the actual supply in the different sectors change through time as a result of product innovation, and the creation of new sectors and classes of workers. In Figure 3.4 we compare potential demand (a) for the different goods to satisfy the different needs (one good, produced in one sector, satisfies a corresponding need) with the actual sectoral sales (b).




(**a**) Potential demand for different sectors




(**b**) Sales in the the different sectors

Figure 8: ***Potential demand and sales divided by sectors.***

Initially, while a small latent demand exists for all needs (see Figure 2 for the consumption share of the two classes present at the beginning of the dynamics), they are not yet supplied in the market. Indeed, as firm size increases, and the organisation of production changes involving different tiers of workers with a different compensation, the demand for non existing goods increases, increasing the incentives for firms to innovate in those non covered sectors. When the first firm enters the new market the increase in production is tremendous, and the initial diffusion of the new product quite fast, to slow down later on when demand reaches satiation and output converges to the average pace of growth. As we can note from both figures a and b the way in which the population changes through time does not allow for the substitution of one good/need with another, but the series do tend to converge as the number of workers in the higher tiers of the firms increase through time. Indeed, the demand for basic goods remain among the main determinants of the exponential growth due to the large of population in the first working tier and class.

The evolution of markets (which implicitly depicts an industrial dynamic that we are not discussing here) determines as well the concentration of the industry, which increases through time (Figure 9), showing the passage from a dispersed production of small firms, to a more concentrated industrial structure.

The pattern towards more concentrated market shares, though, is non linear and different in timing across sectors. This clearly depends on the innovation dynamics, and on the pace at which firms enter into new markets when they radically change their output by

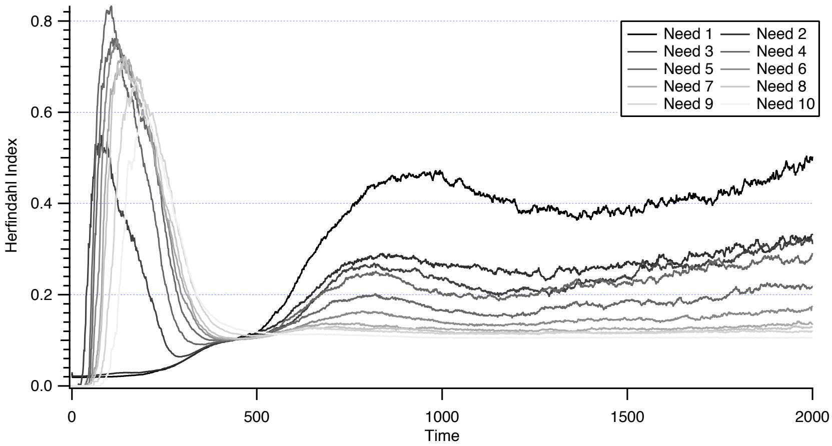



Figure 9: ***Concentration of market shares across sectors (Herfindahl Index)***.

introducing a new prototype. In particular, we note two main features of market dynamics, when referring to sectors non existing since the first period of the simulation (Need 3 and above). First, we can depict three phases: an initial phase in which the good is introduced by a firm and a few followers, characterised by a stark market concentration; a subsequent increase in competition due to the dynamics of firms changing market and introducing new prototypes in the industries with less competition; and a final increase in the concentration of all markets due to the different patterns of quality improvement, and price reduction of the firms. In other words, when the markets are stabilised, and they cover all consumer needs, and firms do not attempt to change and enter new markets, they focus on the improvement of the product's quality, and on the process innovation that allows to compete on prices—particulrly relevant for the basic goods that have the highest share of the largest income classes, which has a low tolerance towards relative higher prices. The effect of price competition is clearly seen when observing the larger concentration in the production of the more basic goods with respect to more luxury goods. Using the vocabulary of industry life cycle, firms turn toward incremental innovation and compete on the established product standards.

Second, firms in the first two sectors (existing since the beginning of the simulation periods) are in a very competitive market until some of them start to address the needs of new emerging classes, innovate, and move to other sectors. This dynamics increases the concentration of the market also in the first two needs. As already mentioned, the larger concentration in which those two sectors end up is due to a competition which is based more on price than on quality.

The relation between price variation across firms and market concentration is quite robust in our results, as depicted in Figure 10. This property of the model is extremely important in our results, being the main trigger of the transition from the first to the second phase of growth.

This effect of price dispersion and firm concentration is of course related to a number of other micro dynamics, and is per se not a sufficient condition. In fact, the choice to

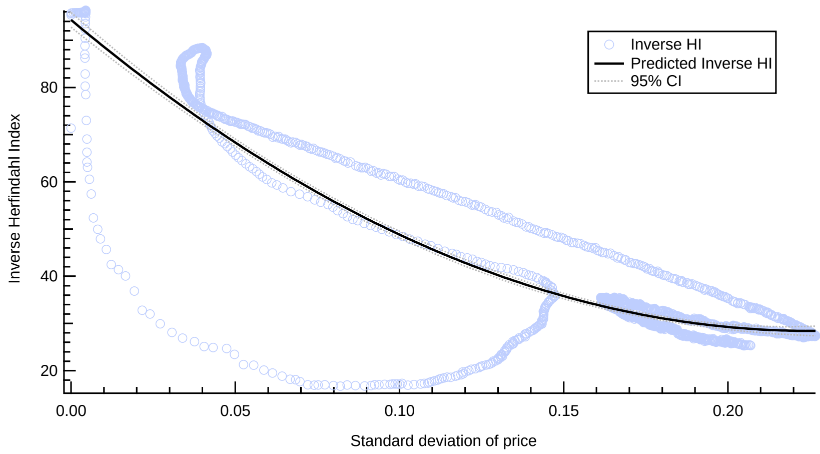



Figure 10: ***Relation between price variance and market concentration***.

purchase a good from a specific firm is initially mainly based on the price differences across the firms. This is based on the assumption that consumers in the first tier are very responsive to price and very little to quality. If this assumption holds, when the demand reaches a critical level consumer selection increases the concentration of production on a small number of more competitive firms. Price dispersion is due to two main reasons in the initial phases. First, firm organisation requires them to hire more executives as they increase their sales, up to a point in which they need to include one more tier of executives to which they pay a higher wage. All this increases the cost per unit of output. Second, the choice of consumers is veiled by a non-perfect information on the relative characteristic of the goods, which introduces a small degree of randomness in the consequent choice. Taken together these conditions cause a growth of firms that is not completely homogeneous. In other words, for the relation in Figure 10 to hold and to affect the transition it is required that firms have a tendency to change their organisation (toward vertical hierarchical forms), consumers with a low income are very reactive to price differences, and they make part of their choice randomly.[29] These are all conditions that can only be assessed studying the historical, institutional and cultural aspects of development and growth, which are not treated here.

Going back to the microeconomic dynamics, even a small market concentration in turn increases the size and average cost of selected firms even more, which has the double effect of increasing overall demand and its variety, assuming the above conditions hold—emrgence of new tiers of workers due organisational change. The firms that first increase their average cost loose most of their demand, and try to innovate and move to new sectors. This has again two main effects. First, the large demand for the first two needs concentrates on a reducing number of firms, while some of the other firms enter in markets that are monopolistic or oligopolistic: increase in market concentration. Second, the

[29]See (Ciarli, Lorentz, Savona, and Valente, 2010b) for a study of the effect of the parameter determining the pace of organisational change in a previous version of the model with a single good, no product innovation and no consumption shares.

market expands as some firms are entering new sectors, addressing demand that remained unmatched till then, and workers in the new tiers benefit from higher purchasing power.

Following, the large rise in market concentration implies that few firms have to respond to an increasing aggregate demand and see their own demand raising tremendously. This implies that firms have to increase their production capacity, raising investment, thus raising the resources for capital suppliers to undergo R&D and increase the productivity embedded into capital, thus reduce prices, and pave the way for more selection and the later large jumps in aggregate productivity.

Finally, when new classes emerge the selection process occurs at both the price and the quality level, adding to the the already sustained growth dynamics. Although not shown here,[30] these dynamics are accompanied as well by an increase in minimum wage that keep the pace of the initial price increases, and of productivity increases.

# 4 Summary of results and final remarks

We start with an economy with very low income, a small population, two sectors of consumables satisfying two consumer needs, consumer homogeneity, and a flat organisation of production populated by small firms. In the initial periods such an economy maintains an extremely low increase of output (stagnant or increasing very slowly), low and not increasing productivity, low concentration of production, increasing population (at a negative rate), and with a stagnant or reducing *real* wage.

The endogenous increase of population induces through time an increase in demand that is sufficient to increase firm size. Meanwhile, firms attempt product innovation to enter more profitable sectors, while consumer select out firms that are increasing price due to the increase in average cost linked to the increase in size. We thus have three dynamics that take place together: increased market concentration, increased product variety, and increased consumer heterogeneity (market size). All three dynamics contribute to an increase in firms' investment in new capital, giving way to process innovations that by increasing firm and aggregate productivity, reduce aggregate prices, increase real wages, and sustain the growth of the final demand.

The increases in demand, accompanied by an even stronger concentration of the economy due to changes in the expenditure shares, in the products offered by the firms, and in the price dispersion, sustains firms investment, process innovation and increase in productivity. While these dynamics occur in a cyclical way until the transition periods—i.e., some firms grow and invest, while others experience a reduction in sales, alternating leadership—they become regular after the take-off occurs, inducing a regular cumulative causation process.

These are the mechanisms that stand out as the main forces of growth in our model. The model is highly micro founded and is an attempt to analyse how the different structural transformation that occur in the process of long run growth interact together, as a result

[30] Results available from the authors.

of the behaviour of the agents that are active in this processes. Namely, the organisation, composition and technology of production on the supply side, and the changes in the distribution of income and in consumption behaviour on the demand side.

The results have shown that these aspects of structural change co-evolve, and they all play a role in the complex dynamics of long run growth. In particular, changes in the *organisation of production* and the increase in firms size required to satisfy the demand of an increasing population generate price dispersion and changes in income classes. Firms selected out also have an incentive to increase their sales and profits by inventing *new goods* that satisfy needs still uncovered, extending the size of the market by addressing existing unmatched demand. The demand for new goods increases with the emergence of the new consumer classes as a result of the *income structure*—defined by the organisational change—that also change the *consumption pattern* . The changing *composition of production* and price dispersion allow consumer to select and concentrate the demand on a small number of firms. This generates oligopolistic competition, high profits and investment in new capital goods and *production technology.*

The big advantage of our model is that we can clearly show the microeconomic mechanisms that stand behind some of the dynamics that scholars have observed, for example, during and after the industrial revolution, and the structural changes that have accompanied them. We endogenise the relations between these microeconomic behaviours in one model, which allows to analyse the relevance and complementarity of each of them. As expected, random events play a big role on the final outcome, but it is the relation of micro behaviours under different structural conditions that determine the pace of output growth.

These results can be nicely complemented, and substantially enriched, by an understanding of how these structural and institutional conditions have changed, and how and why they have done so in the way they did.

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Table 1: Parameters setting: initial values

| $Par/Var_{t-1}$ | Description | Value |
|---|---|---|
| $W_0^w$ | Wage Income | 50 |
| $W_0^\phi$ | Profit Income | 100 |
| $w_0^m$ | Minimum wage | 1.25152 |
| $\bar{A}_0$ | Aggregate productivity | 0.18 |
| $\bar{p}_0$ | Average price | 1 |
| $\bar{A}a_0$ | Moving average of aggregate productivity | 0.18 |
| $S_0$ | Firm stock | 0 |
| $Q_0$ | Firm production | 1 |
| $L_0$ | Work force | 5 |
| $p_0$ | Price | 0.2 |
| $Y_0^e$ | Expected sales | 1 |
| $c_0$ | Production cost | 125 |
| $A_0$ | Embodied labour productivity | 1 |
| $p_0^k$ | Capital firm price | 1 |
| $L_0^{k1}$ | Capital firm work force | 1 |
| $z_0$ | Market shares | 0.02 |
| $a_{\tau_0}$ | Embodied labour productivity in capital vintage $\tau_0$ | 1 |

# A Tables

Table 2: Parameters setting: parameter values

| $Par/Var_{t-1}$ | Description | Value |
|---|---|---|
| $a^s$ | Speed of adaptation of sales expectations | 0.9 |
| $\bar{s}$ | Desired ratio of inventories | 0.1 |
| $D$ | Capital coefficient | 0.4 |
| $\epsilon_L$ | Labour market friction (final good firms) | 0.9 |
| $u^l$ | Unused labour capacity | 0.05 |
| $\nu$ | Tier multiplier | 5 |
| $\omega$ | Minimum wage multiplier | 1.11141 |
| $b$ | Executives wage multiplier | 2 |
| $\mu$ | Markup | 0.05 |
| $\delta$ | Capital depreciation | 0.001 |
| $u$ | Unused capital capacity | 0.05 |
| $\theta^p_f, \theta^a_f, \theta^d_f$ | Preference weights in capital supplier choice | 1, 1, 1 |
| $\epsilon_M$ | Labour market friction (capital firms) | 0.9 |
| $u^K$ | Unused labour capacity in the capital sector | 0.2 |
| $\omega^K$ | Wage multiplier in the capital sector | 1 |
| $A^K$ | Labour productivity (capital firm) | 1 |
| $\omega^E$ | Engineer's wage multiplier | 1.5 |
| $\mu^K$ | Markup (capital firm) | 0.5 |
| $\zeta$ | Parameter innovation probability | 10000 |
| $\nu^K$ | targeted Worker-Engineer ratio (capital firm) | 5 |
| $\rho$ | R&D investment share | 0.7 |
| $\sigma^a$ | Standard deviation productivity shock | 0.01 |
| $\gamma$ | Smoothing parameter in consumers expenditures | 0.8 |
| $H$ | Number of consumer class sub-groups | 100 |
| $\sigma_i$ | Variance in the the evaluation of characteristics | 0.05; 0.1 |
| $\varsigma$ | Inter-class multiplier for tolerance levels | 0.2 |
| $\upsilon_{1,q}$ | First income class tolerance towards quality | 0.1 |
| $\upsilon_{1,p}$ | First income class tolerance towards price | 0.9 |
| $\upsilon_q^{max}$ | Maximum tolerance towards quality | 0.9 |
| $\upsilon_p^{min}$ | Minimum tolerance towards price | 0.1 |
| $\varrho$ | Households' inequality aversion (Atkinson Index) | 0.5 |