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Working Paper Series

Structural Change of Production and Consumption: A Micro to Macro Approach to Economic Growth and Income Distribution

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2008/08 April 2008

ISSN (online) 2284-0400

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First complete draft: March 10, 2008
This draft: May 16, 2008

Abstract

We propose a theoretical model/framework for the analysis of the concomitant effects of structural changes in both production and consumption, on long run economic growth and income distribution.

To accomplish with such a broad aim, we develop an evolutionary model with agent–based micro–foundations. At the core of the model we take into account: (*i*) firm–level organisational structure and technological changes; (*ii*) the impact of technology and organisation on the structure of earnings and income of workers/consumers; and (*iii*) the consequent changes in consumption patterns. The model thus articulates the links between production and organisation structures on the supply side, and the endogenous evolution of income distribution and consumption patterns on the demand side.

We first analyse the model's properties, via numerical simulations, for a given setting of the structural conditions; we graphically show that the main determinants of endogenous economic growth and take–off are the structural variables. We then analyse the space of the parameters that determine the structural conditions; simplified scenarios are identified via numerical simulations, in which patterns of aggregate growth are obtained as an emerging property of different structures of firms' organisation and production, functional composition of employment, income distribution and patterns of consumption.

Keywords: Structural change; consumption; earnings distribution; growth
JEL: O12, J31, L23, D11, O41

*The paper benefited from comments and suggestions from Willi Semmler, Graham White and participants to the International Conference on 'The Institutional and Social Dynamics of Growth and Distribution', (Lucca, December 2007). Previous drafts have been presented at the 16th International Input–Output Conference, July 2007; the 2nd Meeting of the Society for the Study of Economic Inequality (ECINEQ), July 2007; the 5th EMAEE Conference, May 2007. We thank G. Dosi, D. Fiaschi, L. Marengo, U. Witt and P.S. Ciarli for comments on previous versions of the paper. The above mentioned are responsible only for the the paper improvements.

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1 Introduction

The paper aims to answer some of the questions recently put forward as crucial – and yet unresolved – by Saviotti and Gaffard (2008): "Is there structural change during economic development? And, if so, what role does it play? Is it just a consequence or also a determinant of economic development?"

We investigates the relation between structural changes in the organisation and composition of production, changes in income distribution and different patterns of consumption as affecting economic growth and inequality. Although these dynamics are strongly inter–linked, few contributions have systematically investigated their co–dynamics, both in theoretical and applied literature. Even more so, the analysis of the micro-to-macro mechanisms behind these processes has been greatly overlooked by both mainstream and non–mainstream literature.

The ambition of this work is therefore to provide (agent–based) micro–foundation to the link between structural change and growth. We develop an evolutionary model which formalises the links between production, organisation and functional composition of the employment on the supply side and the endogenous evolution of income distribution and consumption patterns on the demand side. Numerical simulations of the model identify different scenarios of changes in the production composition of economies and aggregate growth as emerging properties of such links.

This work adds therefore to the literature on growth and structural change in two main respects. First, from a theoretical point of view, we embrace structural change of production and consumption in the belief that both should be accounted for in any attempt to explain growth dynamics, in line with the classics of Pasinetti (1981). Second, from a methodological point of view, we do so by carefully crafting firms' and consumers' micro–behaviours and identifying the resulting macro–level scenarios.

A second intended, and much needed, contribution of this work with respect to the existing literature, is the explicit introduction of income distribution as one of the main channels between changes in the organisation of firms on the one hand and changes in the consumption patterns on the other one, in the absence of product innovation. We do so in three main respects. First, we suggest and model an explicit relation between organisation, technology and wages composition at the firm–level, which goes beyond the well–known skill bias effect in determining the distribution of income at the macro–level. Second, we suggest and model the relation between changes in income distribution and changes in consumption. Third, by endogenising the role of income distribution we are able to provide a valuable tool to extend the use of the model to policy simulations and derive normative implications.

The paper provides the general framework which we draw upon, as well as the formalisation of the whole set of the above–mentioned mechanisms – at the micro– and the macro–level. However, being aware of the ambition of providing such an all–embracing model and of the space constraint, we choose in this paper to focus the analysis of the model with respect to the initial conditions of the economy that represent a selected set of changes in the structure of demand and supply. These are related to the link between the changes in the firm's organisation of production and the changes in wage and income distribution as affecting economic growth and inequality via a simplified representation of consumption. This will shed some light on how to endogenise product and organisational innovation (change), and the related evolution of consumption needs.

The remainder of the paper is organised as follows. Next section locates the contribution of this work within the context of a selected sketch of both theoretical and empirical, firm– and macro–level streams of literature relevant to the mechanisms explained by the model. Section 3 describes the model. Section 4 provides the selected results based on the numerical simulation of the model. Finally, Section 5 summarises the rationale behind the model, discusses the results and, most importantly, proposes few lines of research which the various extensions of the model might usefully contribute to.

2 Background

Cross–country divergence in growth rates has been a solid empirical stylised fact for decades (Denison, 1967; Denison, 1979; Maddison, 1987; Barro, 1991; Durlauf and Quah, 1998). What is left is to assess to what extent the (change in the) structure of the economies is responsible for it and, ultimately, what determines changes in the production structure.

Technical change, changes in the production structure and the evolution of demand might disrupt the sectoral composition of the economy (Pasinetti, 1981) and the steady path of macroeconomic growth. Despite mainly in the context of aggregative models, these issues have been largely treated by scholars in the Keynesian and Classical tradition (among others, see for instance Kurz and Salvadori, 1998; Cesaratto, Serrano, and Stirati, 2003). However, only few scholars in the evolutionary literature have attempted to look at the joint effect of supply and demand on growth and structural change (Verspagen, 1993; Verspagen, 2004; Montobbio, 2002; Llerena and Lorentz, 2004; Lorentz and Savona, 2008; Ciarli and Valente, 2005; Ciarli, 2005). Each of these contributions develops models of economic growth which encompass both technical change and demand. However, none of them attempts to specifically look at the interaction between structural changes in the production and organisation of firms and changes in consumption needs to derive results on how changes in the composition of the economy affect aggregate growth.

Recent contributions have looked at economic growth as a result of the emergence of new sectors, a phenomenon which is argued to be entirely due to the creation of product variety (Saviotti and Pyka, 2004; Saviotti and Pyka, 2006). This analysis is greatly welcome as one of the very few attempts to focus on this issue, yet we still feel uncomfortable with the representation of structural change as limited to an increased product variety, with no explicit reference to whether and to what extent the evolution of consumption and firms' effort to invent and innovate do interact in producing novelty, as it is the case, for instance, in (Malerba, Nelson, Orsenigo, and Winter, 2007).

With regard to the role of the demand side, there have been few, seminal attempts to react to the standard neoclassical consumer theory and release some of the most heroic hypotheses on the consumer's behaviour (see for instance Deaton and Muellbauer, 1980b; Deaton and Muellbauer, 1980a). Within the evolutionary stream of literature, the analysis of consumption is still at an embryonic stage. Only recently, few contributions have developed around the issue of how consumption 'needs' evolve, drawing upon interdisciplinary evidence and theory (Valente, 1999; Swann, 1999; Witt, 2001; Witt, 2006; Babutsidze, 2007), which also account for the psychological drivers of the consumption behaviour.

Demand both constraints and is constrained by the supply's response to it. Changes in the structure of demand find their natural interlocutor in whether and how firms respond to them – i.e. to what extent consumption 'needs' are met by the invention and successful commercialisation of new product on the market – as Schumpeter had already emphasised long time ago (Schumpeter, 1934). To our knowledge no one single contribution has explicitly disentangled at the micro–level the role of distributional changes as the natural channel of the evolution of consumption 'needs' into the evolution of actual demand, i.e. changes in the signals which firms receive from the market and which they respond and adapt to.

Rather, the large and consolidated literature on the two-sided link between economic growth and income distributional change remains confined to macro–level analyses, since the seminal Kuznet's curve and the works by Stiglitz (1969) and Tinbergen (1975), greatly enriched later on (Atkinson, 1997; Aghion, 2002; Galbraith, Lu, and Darity, 1999; Galbraith, 1999)[1].

Aghion, Caroli, and García-Peñalosa (1999) present an extensive review on the macro–evidence on the two–sided relation between growth and distributional changes (i.e. increase in income inequality) The authors look at both *wealth* and *wages* inequality and provide evidence and theoretical support looking at three competing explanations of wage inequality: **i)** trade (and especially import of intermediate goods from developing countries); **ii)** skill bias (which seems to prevail over trade), considering both *disembodied* (see also Aghion, 2002) and *embodied* technical change. Although there is also evidence of large inequality within homogeneous educational classes, sources of inequality are attributed to learning and inter–sectoral mobility; and **iii)** changes in firms organisation (and skill experience), though not further defined or explored. In line with Tinbergen (1975), wage dynamics and inequality are argued to follow the competing game between demand and supply of skills. Up to the 1970s skills supply has increased more than demand pushing down the relative wages. In the following period the demand for skills has increased and so have done the relative wages. The authors assume though that the only force driving the demand for skills is technical change.

A different view is proposed by Galbraith, Lu, and Darity (1999) and Galbraith (1999),

[1]Surprisingly, the role of distributional changes is largely overlooked within the evolutionary stream of literature.

according to whom inequality in income, and in earnings, is due to the country economic structure. This Keynesian approach hints at the Kuznets hypothesis and the specialisation effect on a global market. In arguing his point, Galbraith criticises the overrated explanation of wage inequalities led by skills [2]. Wage distribution ultimately depends on the specialisation of the economy, both at the international level (Prebish–Singer hypothesis) and at the national level (á la Kaldor).

Conversely, only a few empirical micro–level contributions have looked at (changes in) firms' size and organisational structure as affecting the (skill and organisational) composition of workers and executives and the corresponding wages structure, since the seminal contributions by Simon (1957), Lydall (1959), and Rosen (1982), lately extended (among others, Waldman, 1984; Abowd, Kramarz, and Margolis, 1999; Prescott, 2003). Some recent contributions on the relation between the employer size and the effects on wage distribution (Brown and Medoff, 1989), (for a review, see Criscuolo, 2000), have reprised the Simon/Lydall hypothesis of the executives wage scale (Bottazzi and Grazzi, 2007).

The keywords of this stream of contributions are firm size, number of hierarchical layers internal to the enterprise, the proportion of executives and workers and the structure of pay (e.g. wage premiums). The interesting feature of this literature is that, in line with what Galbraith suggests at the macro–level of analysis, the role of skills differentials is over–emphasised with respect to other wage factors, in determining earnings and income inequality (Prescott, 2003). One may in fact asks in what respect a specialised blue collar worker would be less skilled than a white collar one. For example, with reference to executives compensations, Caroli and Van Reenen (2001) suggest that there is a dynamic other than the skill–bias technical change, which depends on the organisational change as affecting wage and earning distributional change. Namely, an increased decentralisation of production and work organisation – for instance due to the adoption of ICTs – demands higher responsibility and an increase in wage compensation of executives follows.

We feel particularly comfortable with Galbraith's position, as it truly attempts to go beyond the somewhat bold, all–embracing explanation of technical change as responsible for skill–bias and wage polarisation. This often risks to overlook the complex set of 'collateral effects' which follows firms' decisions to adopt technology, among which changes in the functional division of labour, organisational structure and wage stratification within the firm. In this respect, Simon and Lydall's contributions – and the micro–evidence provided since – offer a useful micro–level perspective of what goes on inside the firm besides the skill–bias technical change. This stream of literature, however, does not look at the impact of changes in the wage structure on income distribution and patterns of consumption, i.e. on the disposable income and preferences. It is at the intersection of these micro– and macro–level literature that our contribution aims to be located.

Our conjecture, supported by various streams of theoretical and empirical contributions

[2] According to Galbraith it is not the use of the computer *tout court* which is responsible for wage increases. Rather, it is the working condition in which it is used, which makes an entirely new working class to emerge (computers should make jobs easier). The difference is not between users and non–users of technology, but between users and producers.

and reprised at greater length in section 3, is that changes in the economic structure and (trade and sectoral) specialisation have been accompanied by changes in the organisational structure of firms and both have brought about changes in the wage and earning structure. Both micro– and meso–level mechanisms are therefore behind changes in the consumption patterns, which in turn affect changes of the production structure both at the firm and sectoral level. In this paper we aim therefore to encompass the micro–behaviours of firms and workers/consumers and identify different patterns of aggregate growth and income inequality as emerging properties of these behaviours.

3 The Model

We model an unconstrained economy where population grows endogenously as a response to labour demand. A temporary, partially endogenous, constraint is determined by the production capacity of capital firms, which supply manufacturing firms. Yet, we assume that firms in the manufacturing sector can freely borrow on the financial market. These assumptions — heroic as may be — allow us to emphasise the role of the structural variables over the issues of growth rate of the population, labour market dynamics, and so on.

In fact, the model represents the main dimensions that define the structures of production and demand. First, firms produce a good with different quality levels of the same characteristic, representing competing technologies/designs. This allows to define product variety within one sector, or structural differences in terms of different sectors that satisfy different consumer needs.

Second, firms are defined with respect to their organisation structure both in terms of the number of hierarchical tiers of workers and executives, and of the wage differential across tiers. A minimum wage is determined at the macro level.

Third, the hierarchical structure of wages, linked to the organisation, contributes in determining the distribution of earnings and income.

Fourth, consumption behaviour adapts the theoretical construction developed by Valente (1999). Demand generates from a number of consumer/income classes, set by the wage–tier organisational structure. The composition of each class is defined in terms of consumption 'needs'. The distribution of consumers' preferences over the goods' characteristics defines the demand curve and firms' production shares.

Following existing Schumpeterian growth models (see, among others Chiaromonte and Dosi, 1993; Silverberg and Verspagen, 2005) we consider economies composed of a consumer sector and a capital sector. Finally, changes in the production processes are modelled as investment in different capital vintages. By changing vintage, firms alter the capital/labour ratio of their technology, affecting the composition of the labour market and the income distribution in the consumers market. An increase in productivity in the new vintages is linked to the ability of capital firms to accumulate enough profits to invest in research and development (R&D).

3.1 Final Good Firms

Drawing upon the work by Ciarli and Valente (2005), the micro–dynamics of production and consumption patterns rely on the product defined as a vector of characteristics, which satisfies the users' needs, in line with the Lancasterian (Gorman, 1959; Lancaster, 1966b; Lancaster, 1966a) and post–Lancasterian approach to consumer theory (Saviotti and Metcalfe, 1984; Gallouj and Weinstein, 1997). Each firm $f \in [1; F]$ produces only one product. Each product satisfies one or more consumers' needs $n \in [1; N]$, defined over a vector of characteristics $m_n \in [1; M_n]$ that quantifies the quality level of the 'service(s)' they provide $i_{n,m}$ to consumers:

$$\begin{pmatrix} i_{1,1} \\ \vdots \\ i_{n,1} \\ \vdots \\ i_{n,m} \\ \vdots \\ i_{n,M} \\ \vdots \\ i_{N,M} \end{pmatrix} \tag{1}$$

3.1.1 Production process and sales

Given the share of total demand faced by a firm (Y_t),[3] current expected sales Y_t^e are a convex combination of past expectations and actual demand faced in the previous period:

$$Y_t^e = a^s Y_{t-1}^e + (1 - a^s) Y_{t-1} \tag{2}$$

We assume a slow adaptation in sales expectations (a^s), as an outcome of agents conservative behaviour aimed at smoothing short term cycles.

In order to cover unexpected demand changes, firms maintain a desired level of inventories $\left(\bar{S} = \bar{s} Y^e\right)$.[4] Production plans $\left(Q_t^d\right)$ are then revised to adjust to changes in the expected demand (Y_t^e), existing inventories (S_t) and unfulfilled demand from the previous simulation steps (Bl_{t-1}):

$$Q_t^d = \max\left\{\bar{S} - S_t + Y_t^e + Bl_{t-1}; 0\right\} \tag{3}$$

where inventories and backlogs, meant to work as production buffers, adjust in the follow-

[3]We suppress the firm index to improve readability. It is implicit that each equation is replicated for each firm, and we refer to the definition of parameters values to identify differences across firms.

[4]We assume an inventory/sales ratio which corresponds to the minimum of the observed values (see for example McCarthy and Zakrajšek, 2000; U.S. Census Bureau, 2008), to avoid level effects that may be linked to the accumulation of inventories, as well as to reduce the propagation of business cycles.

ing way:

$$S_t = \max\{S_{t-1} + Q_t - Y_t - Bl_{t-1}; 0\} \tag{4}$$

$$Bl_t = -\min\{S_{t-1} + Q_t - Y_t - Bl_{t-1}; 0\} \tag{5}$$

Both backlogs and change in inventories, once discounted for expectations failures, are due to input constraints in inputs: labour devoted to production $\left(A_{t-1}L^1_{t-1}\right)$ and capital $\left(\bar{B}K_{t-1}\right)$. The current production is then computed as follows:

$$Q_t = \min\left\{Q^d_t; A_{t-1}L^1_{t-1}; \bar{B}K_{t-1}\right\} \tag{6}$$

where A_{t-1} is the labour productivity embodied in the capital vintages and $\bar{B}$ is the capital intensity ratio. Both depend on firms investment in capital (see section 3.1.4) and on the R&D of capital suppliers (section 3.2.3). Both input markets are assumed to be inertial but unconstrained, where the available capital is limited by the suppliers production capacity (see section 3.2.1).[5]

3.1.2 Labour

We draw upon Simon (1957), Lydall (1959), Rosen (1981) and Rosen (1982) and further extensions of it (Waldman, 1984; Abowd, Kramarz, and Margolis, 1999; Prescott, 2003) to represent the organisational structure of firms. According to this literature, firm size, number of and complexity of hierarchical organisational layers internal to the enterprise — i.e. the proportion of executives and workers — affect the structure of pay.

Given the production plan, firms employ (displace) *first tier* workers (L^1_t) according to the overall labour productivity of the capital vintages at work (A_{t-1}), and in order to maintain an unused labour capacity (u^l) to cover unexpected demand:

$$L^1_t = \epsilon_L L^1_{t-1} + (1-\epsilon_L)\left[\left(1+u^l\right)\frac{1}{A_{t-1}} min\{Q^d_t; \bar{B}K_{t-1}\}\right] \tag{7}$$

where the inertial factor ϵ_L mimics labour market rigidities. We assume there is a quite low adaptation in labour markets (large ϵ_L and ϵ_K), which should be interpreted as the elasticity in matching models (see Equation 44).

On top of first tier employees, firms need to hire an 'executive' to manage every batch of ν first tier workers, and a third level executive for every group of ν second tier workers, and son on. The number of workers in each layer, given L^1_t is thus

$$\begin{aligned} L^2_t &= L^1_t \nu^{-1} \\ L^3_t &= L^1_t \nu^{-2} \\ &\vdots \\ L^\Lambda_t &= L^1_t \nu^{1-\Lambda} \end{aligned} \tag{8}$$

[5] We do not assume an infinitely elastic labour supply curve, as it will be more clear from section 3.3

where Λ is the total number of layers required to manage the firm, which can be obtained with a couple of algebraic transformations:

$$\begin{gathered}\Lambda \ln \nu - \ln \nu = \ln L_t^1 - \ln L_t^\Lambda \\ \Lambda = \frac{\ln L_t^1 - \ln L_t^\Lambda}{\ln \nu} + 1\end{gathered} \tag{9}$$

and provided that $\ln L_t^\Lambda \in [1, \nu]$,

$$\Lambda \simeq \frac{\ln L_t^1}{\ln \nu}. \tag{10}$$

And the total number of workers is

$$L_t = L_t^1 + L_t^2 + ... + L^\Lambda = \sum_{l=1}^{\Lambda} L_t^l. \tag{11}$$

In the end, labour capacity is determined only by first tier workers, and their productivity. We implicitly assume that a firm finds its best organisational configuration given the number of first tier workers, and given the organisational structure proxied by ν.

3.1.3 Wage, cost and price determination

The labour cost essentially depends on the minimum wage, endogenously determined at the macro level (see Section 3.3), and on firms' organisational structure. First tier wages are set by firms as a fixed multiple ω of the minimum wage w_{t-1}^m:

$$w_t^1 = \omega w_{t-1}^m \tag{12}$$

As we move upstream in the organisational hierarchy, the wage increases by a fixed tier multiplier b, which determines the skewness in the wage distribution, in line with Simon (1957) and Lydall (1959).

$$\begin{gathered}w_t^2 = b w_t^1 \\ w_t^3 = b w_t^2 = b^2 w_t^1 \\ \vdots \\ w_t^\Lambda = b^\Lambda w_t^1.\end{gathered} \tag{13}$$

As noted in Atkinson (2007), the exponential structure of wage–tier increase is not sufficient to explain the skewness in earnings distribution. On top of their wages, executives are paid with wage premia ψ_t^l that we interpret as stock options. When a firm's profits are not used to finance investments in new capital $\left(R_t^D\right)$, they are distributed among executives, proportionally to their wage.

$$\psi_t^l = \frac{w_t^l}{\sum_{l=1}^{\Lambda} w_t^l} R_t^D \tag{14}$$

and overall earnings correspond to $w_t^l + \psi_t^l$ (where the second term is nil for first tier workers).

Unit production costs (c_t) depend on the average wage ($\overline{w}_t$) per average firm productivity $\left(\overline{A}_t\right)$ (production capacity). The assumption acknowledges once more agents' conservative behaviour in favouring mid term indicators, rather than short term cycles.

$$c_t = \frac{\overline{w}_t}{A_t} \tag{15}$$

$$\overline{w}_t = \frac{\sum_{l=1}^{\Lambda} w_t^l L_t^l}{L_t} \tag{16}$$

$$\tag{17}$$

Note that the tier–wage structure of variable costs implies negative economies of scale, in accordance with the evidence that labour cost is higher for large firms (Idson and Oi, 1999; Criscuolo, 2000; Bottazzi and Grazzi, 2007).

The price is set at the firm level on the basis of the cost of labour and the mark–up applied on top of variable costs.[6]

$$p_t = (1 + \bar{\mu})c_t \tag{18}$$

Profits (π_t) then result as the difference between the value of sales and the variable costs of production

$$\pi_t = p_{t-1}Y_t - \sum_{l=1}^{\Lambda} w_t^l L_t^l \tag{19}$$

Assuming that firms invest in capital whenever they face a production constraint, cumulated profits (Π_t) are eroded by capital expenditure (R_t^I)

$$\Pi_t = \sum^{t} \pi - R_{t-1}^I \tag{20}$$

$$R_t^I = \sum_{\tau=0}^{t} p_{\tau-1}^k k_\tau \tag{21}$$

where $p_{\tau-1}^k k_\tau$ are the resources used for capital vintages τ completed in time t.

The residual amount of cumulated profits is then allocated to the payment of bonuses and dividends (R_t^D).

3.1.4 Capital and investment

Following Amendola and Gaffard (1998) and Llerena and Lorentz (2004), capital goods are not used as production inputs *strictu sensu*, but constitute the basis for firm's production capacity. The accumulation of capital is a pre-condition for any production activity, constraining the actual production level and affecting the efficiency of the labour force. This is also in line with some neo–Schumpeterian models (Verspagen, 1993; Llerena and Lorentz, 2004) which have reprised and provided micro–foundation to the Kaldor–Verdoorn cumulative causation mechanism (Kaldor, 1957; Verdoorn, 1949).

[6] A common assumption in evolutionary models, supported by empirical evidence that dates back to Hall and Hitch (1939), and more recently to Blinder (1991) and Hall, Walsh, and Yates (1997).

The capital stock (K_t) of a firm at the end of period t is given by the sum of the cumulated stocks k_τ of capital vintages bought in periods τ, net of capital depreciation (δ):

$$K_t = \sum_{\tau=0}^{t} k_\tau (1-\delta)^{t-\tau} \tag{22}$$

And the productivity embodied in each vintage (a_τ) returns the maximum productivity of a firm, when all its capital is put into production:

$$A_t = \sum_{\tau=0}^{t} \frac{k_\tau (1-\delta)^{t-\tau}}{K_t} a_\tau \tag{23}$$

We assume that firms can access a financial market for capital investment, and we remove profit constraints on the level of investment. The effect of an investment then hits cumulated profits, reducing the amount of distributed profit through time. This is not to conform to the Modigliani and Miller (1958) theory, and deny that the financial structure influences the investment strategy (e.g. Fazzari, Hubbard, and Petersen, 1988). We prefer to study the model behaviour without constraints that may determine the output by themselves, obscuring the effect of the variables that characterise changes in the structure ofproduction and demand. Therefore, when the available capital stock does not allow to cover expected sales (Y_t^e), the required investment in new capital units is defined:

$$k_t^e = \left(1 + u^k\right) \frac{Y_t^e}{\bar{B}} - K_{t-1} \tag{24}$$

where u^k is the ratio of unused capital to cover unexpected demand. An order of k_t^e units is then placed to a capital supplier $g \in [1; G]$ that produces a compatible technology θ among the producers in the capital sector. The g supplier is chosen with a given probability

$$\kappa_h = \left(\frac{p_{g,\tau-1}^k}{1+\overline{p}_{\tau-1}^k}\right) \left(\frac{a_{g,\tau-1}}{1+\overline{a}_{\tau-1}}\right) \left(\frac{u_{g,t}}{1+\overline{u}_t}\right) \tag{25}$$

where $p_{g,\tau-1}^k$ is the capital vintage's price, and $u_{g,t}$ a proxy of the waiting time before the capital can be delivered to the buyer (the sum of the supplier's standing orders $\left(U_t^d\right)$ weighted by the number of periods they have being queuing). Over–signed variables stand for non weighted averages across capital producing firms.

The actual number of capital units acquired in time t $\left(k_t^d\right)$ then depends on the production capacity of the capital supplier (see Section 3.2.1):

$$k_t^d = \begin{cases} k_t^e & \text{if order} \leq \text{supplier production capacity} \\ 0 & \text{if order} > \text{supplier production capacity} \end{cases} \tag{26}$$

and the firm may *not* acquire new capital before the previous order has been fulfilled. This feature of the investment dynamics has at least three important features. First, it is in line with the empirical evidence at the micro level on the lumpiness of investment (e.g Doms and Dunne, 1998). Second, it generates a trade–off between acquiring immediately a less productive vintage or waiting more time for a more productive vintage. This also smoothens the cumulative mechanism that increase the probability of first investors to become more and more productive, with respect to competitors. Third, capital realisation places a temporary constraint to economic growth which is no imposed, but depends on the accumulation of production capacity of the capital sector.

3.2 Capital sector

Capital goods are produced by machinery firms belonging to the capital sector. Each capital good is characterised by its vintage τ and embodied productivity level a_τ :

$$\begin{pmatrix} \tau \\ a_\tau \end{pmatrix}$$

3.2.1 Production process of capital goods

Machinery firms produce capital goods on the basis of the level of demand coming from final good firms. In line with the empirical evidence (see for instance 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 stocks of unsold capital.

Production plans for capital goods (K_t^d) thus aim to meet current clients' orders (k_j^d, t) and the uncovered ones from previous periods (U_{t-1}^d):

$$K_t^d = \sum_{j=1}^{J_t} k_{j,t}^d + U_{t-1}^d \tag{27}$$

where j corresponds to a generic order arrived at time t, and J_t to the last one (i.e. the number of orders).

As for the final sector, the production of a machinery firm is constrained by its production capacity ($\bar{A}^k L_{t-1}^{k1}$).

$$Q_t^k = min\left\{K_t^d; \bar{A}^k L_{t-1}^{k1}\right\} \tag{28}$$

The capital orders are treated on a 'first in first out' rule and they are not delivered to clients unless completed. Therefore, U_{t-1}^d is produced before any new order and total sales (Y_t^k) corresponds to the sum of the orders completed ($k_{z,t}$):

$$Y_t^k = \sum_{z=1}^{Z_t} k_{z,t} \tag{29}$$

where Z_t is the number of orders completed at time t, so that:

$$\sum_{z=1}^{Z_t} k_{z,t} = \begin{cases} K_t^d \text{ if } K_t^d \leq \bar{A}^k L_{t-1}^{k1} \\ \\ U_{t-1}^d + \sum_{j=1}^{\bar{J}} k_{j,t}^d \text{ if } K_t^d \geq \bar{A}^k L_{t-1}^{k} \end{cases} \tag{30}$$

for $k^d_{\bar{J},t}$ being the last order that can be entirely fulfilled before capacity constraint. The orders remaining to cover in the following periods U^d_t can be computed as follows:

$$U^d_t = \sum_{j=\bar{J}+1}^{J_t} k^d_{j,t} \tag{31}$$

Notice that from equation 28 the production capacity is not left unused: a 'piece' of capital may be built but not sold until completed.

Given labour productivity ($\bar{A}^k$), the production capacity depends on the labour force employed (L^{k1}_{t-1}) to meet the production target (K^d_t) plus the share (u^m) of unused workers to cover unexpected demand.

$$L^{k1}_t = \epsilon_M L^{k1}_{t-1} + (1-\epsilon_M)\left[(1+u^m)\frac{K^d_t}{\bar{A}^k}\right] \tag{32}$$

As for the non–capital sector, total employment result from the sum of the different layers, such that the total number of workers is

$$L^k_t = L^{k1}_t + L^{k2}_t + ... + L^{k\Lambda} = \sum_{l=1}^{k\Lambda} L^{kl}_t. \tag{33}$$

where

$$k\Lambda \simeq \frac{\ln L^{k1}_t}{\ln \nu}. \tag{34}$$

3.2.2 Wage, costs and price determination

Symmetrically to the final good sector, prices of capital goods $\left(p^k_t\right)$ are set according to a mark–up rule (μ^k). In the case of machinery firms, unit production costs include labour (workers, executives) costs plus the unitary research and development costs (i.e. the labour costs related to the engineers devoted to R&D).

$$p^k_t = (1+\mu^k)\left(\frac{\overline{w}^k_t}{\bar{A}^k} + \frac{w^E_t L^E_t}{\bar{A}^k L^{k1}_t}\right) \tag{35}$$

where $\overline{w}^k$ is the average salary across tiers, computed as in the final good sector (see equations 13 to 17), L^E_{t-1} the number of engineers involved in R&D. First tiers capital workers' and engineers' wage is also linked to the minimum wage, as a multiple of the minimum wage (ω^k and ω^E respectively):

$$w^k_t = \omega^k w^m_{t-1} \tag{36}$$

$$w^E_t = \omega^E w^m_{t-1} \tag{37}$$

The profits π^k_t are either redistributed as dividends and bonuses or cumulated for future investment in engineers

$$\pi^k_t = p^k_t Y^k_t - \overline{w}^k_t L^k_t - w^E_t L^E_t \tag{38}$$

3.2.3 R&D and Innovation in Machinery Firms

Given the amount of resources devoted to hiring researchers, the R&D activities aim to improve the characteristics of the capital good and ultimately to maintain or increase the market share of the machinery firm. The outcome of R&D activity is stochastic, though the probability of obtaining an increase in productivity $\left(p^{inn}\right)$ depends on the amount of financial resources devoted to it and therefore on the number of engineers employed (L^E_{t-1}). This is in line with Nelson and Winter (1982) and the most of the evolutionary models developed since, and follows the scheme presented in Llerena and Lorentz (2004).

$$p_t^{inn} = 1 - e^{-zL^E_{t-1}} \tag{39}$$

Firms define the number of engineers they wish to employ as a ratio ν^k of workers, constrained by the share ρ of cumulated profits they allocate to R&D:

$$L_t^E = min\left\{\nu^k L_t^k; max\left\{\rho^k R_t^E; 0\right\}\right\} \tag{40}$$

If the R&D activity is successful, the characteristics of the newly developed capital vintage are themselves randomly defined, and depend on the outcome of the past R&D efforts. The R&D routine follows a stochastic process of the following form:

1. Firms draw a number from a Uniform distribution on [0 ; 1].
2. If this number is contained in the interval [0 ; p_t^{inn}], the R&D is successful.
3. If R&D is successful, the characteristics of the newly developed vintage are randomly drawn as follows

$$a_\tau = a_{\tau-1}\left(1 + max\{\varepsilon_t^a; 0\}\right) \tag{41}$$

$$\varepsilon_t^a \sim N(0; \sigma^a) \tag{42}$$

3.3 Minimum wage

The minimum wage (w^m) is negotiated at the macro–economic level and defines the lowest bound of firms' wage setting.[7] We assume the negotiation to be linked to three main macroeconomic dynamics: (i) labour productivity growth, to keep the pace of labour value contribution; (ii) consumer prices, to hold purchasing power over the long run; and (iii) unemployment, due, for example, to efficiency wages, corporatism, or bargaining. This boils down to an outward shifting 'wage curve', a well established empirical evidence (Blanchflower and Oswald, 2006; Nijkamp and Poot, 2005). The shift component is due to full re–negotiation when the increase in both the average price $\left(\overline{P}\right)$ and aggregate

[7] We are aware that heterogeneous occurrences in the income distribution across countries are partly due to institutional differences in the minimum wage settings (e.g. Gottschalk and Smeeding, 1997; Cornia, 2003), and to the existence of an informal economy (e.g. Cornia, 2003). The present version of the model allows to study the joint role of minimum wage on income inequality, analysing the wages setting parameters that we assume in the in this paper. This study is left for further analysis.

productivity $\left(\overline{Aa}\right)$ — with respect to the previous negotiation in t_0 — exceeds a boundary ratio (respectively Ω^P and Ω^A):

$$\triangle w_t^m = \begin{cases} -\epsilon^U \triangle \overline{Um}_t & \text{If } \overline{Aa}_t \leq \overline{Aa}_{t_0}\Omega^A \text{ or } \overline{P}_t \leq \overline{P}_{t_0}\Omega^P \\ -\epsilon^U \triangle \overline{Um}_t + \epsilon^A \triangle \overline{Aa}_t + \epsilon^P \triangle \overline{P}_t & \text{If } \overline{Aa}_t > \overline{Aa}_{t_0}\Omega^A \text{ \& } \overline{P}_t > \overline{P}_{t_0}\Omega^P \end{cases} \tag{43}$$

where $\triangle \overline{Um}_t = \frac{\overline{Um}_t}{\overline{Um}_{t-1}} - 1$ is the growth in unemployment and $\triangle \overline{Aa}_t$ and $\triangle \overline{P}_t$ respectively the growth in labour productivity and consumables prices. The $\epsilon \in (0, 1)$ are the corresponding elasticities of the minimum wage with respect to a change in the three macro dynamics. We use the robust empirical estimates for ϵ^U (Blanchflower and Oswald, 2006; Nijkamp and Poot, 2005), an equal value for ϵ^A and assume a 50% indexation of wages to price changes $\left(\epsilon^P\right)$.

Changes in productivity $\left(\overline{Aa}\right)$ and consumable prices $\left(\overline{P}\right)$ are computed as moving averages of the type $\overline{X}_t = dX_{t-1} + (1-d)\,\overline{X}_{t-1}$. We thus consider that the bargaining bodies evaluate variable trends and overlook short cyclical changes — smoothing adapting expectations — and that they perceive recent changes as more relevant (assuming a small value for d).

Finally, given our earlier assumption of unconstrained labour resources, we need to derive unemployment rates as a result of labour hiring. We use another well established empirical evidence, the Beveridge Curves, that show a negative relation between the rate of vacancies — endogenously determined in the model at the micro level — and the rate of unemployment. We assume that the labour market can be represented by a matching model (Petrongolo and Pissarides, 2001; Yashiv, 2007), and use an hyperbolic form of the matching function:[8]

$$Um_t = C^H + \beta / \overline{V}_{t-1} \tag{44}$$

where C^H is the constant and β defines the relation between vacancies V_{t-1} and unemployment ($\overline{V}_{t-1}$ refers to the moving average, defined as above). Both parameters are set taking into account the mixed empirical evidence obtained in the few estimates available (Wall and Zoega, 2002; Nickell, Nunziata, Ochel, and Quintini, 2002; Teo, Thangavelu, and Quah, 2004). A mean value of these estimates is found also in Fagiolo, Dosi, and Gabriele (2004), who show that fully random matching models fail to reproduce Beveridge curves, and require to assume path dependency in labour supply and demand.

To close the minimum wage setting, we define the number of vacancies V_{t-1} as the sum of vacancies in all sectors of the economy: final firms workers ($V_{L,t-1}$), capital firms workers ($V_{k,t-1}$) and R&D employees ($V_{E,t-1}$), respectively computed as follows:

$$\begin{aligned} V_{L,t-1} &= \textstyle\sum_{l=1}^{\Lambda} V_{L,t-1}^l \\ V_{L,t-1}^1 &= \left[\left(1+u^l\right) \tfrac{1}{A_{t-2}} min\{Q_{t-1}^d; \bar{B}K_{t-2}\}\right] \\ V_{k,t-1} &= \textstyle\sum_{l=1}^{\Lambda} V_{k,t-1}^l \\ V_{k,t-1}^1 &= \left[\left(1+u^m\right) \tfrac{K_{t-1}^d}{\bar{A}^k}\right] \\ V_{E,t-1}^1 &= L_{t-1}^E. \end{aligned} \tag{45}$$

[8]Börsch-Supan (1991) provides estimates on the German labour market using the hyperbolic form.

Therefore, the friction in the hiring process (ϵ_L and ϵ_M in the labour demand equations 7 and 33)[9] determines the difference between open vacancies and actual number of workers, as shown also in Fagiolo, Dosi, and Gabriele (2004).

3.4 Demand

The demand side of the model represents the mechanisms by which disposable income, generated at the micro–level as wages and distributed profits, is turned into firms' revenues. Workers form *income–consumption classes*, which in turn amount to the aggregate demand. We assume that social and income factors identify a class of consumers, as it is often the case when households surveys are used in marketing studies (see e.g. CACI, 2005). We assume these factors to be linked to the working class, so that each tier l corresponds to a class z. However, consumers–workers classes $z \in [0; \Lambda]$ are divided in to $h_{z,t} \in [1; H_z]$ consumers *samples*, each of which undergoes a consumption routine (i.e. a purchase) with symmetric random variations.

The amount consumed by each consumer sample h_z is given by the ratio between the total amount of workers in a working class and the fixed number of samples L^z/H_z. Therefore, for a small number of consumers, the sample represents a single individual consumption routine. As the number of consumers increases, the sample represents the consumption routine of a group of individuals' (a household or a neighbourhood).

We assume that consumers in a given class allocate their expenditures across different *needs* n, where a need is a category, motivating the purchase of the consumer. We consider that any purchase satisfies a specific need, and that the consumers belonging to a certain income–consumption class maintain a constant distribution of expenditure for each of the needs.

The disposable income of a consumer sample $h_{z,t}$ in income class z to satisfy each need n is then given by

$$y_{h_z,n,t} = \frac{\xi_{n,t} C_{z,t}}{H_{z,t}} \tag{46}$$

where ξ_n is the share of income used for the n^{th} need and C_z the income of the z class in time t.

3.5 Consumers behaviour and firms demand

The choice of products follows a decisional process which includes the evaluation of the multidimensional service characteristics $i_{n,m}$ and the selection of the firm(s) offering a fulfilling product. The vectors of characteristics defining the product are relevant to each need to be satisfied. Such characteristics may be negative or positive, so that, for example, the price is a negative characteristic common to all needs.

[9]Which can also be interpreted as the labour market friction that in matching models determine the level of unemployment as a function of the number of matches and vacancies. In our model the number of matches correspond to the workers actually hired (function of ϵ_L and ϵ_K).

The purchasing routine we adopt is borrowed by the literature on experimental psychology, implementing a bounded rational algorithm featuring the properties of empirically observed behaviours (Shafir, Simonson, and Tversky, 1993; Gigerenzer, 1997; Gigerenzer and Selten, 2001). The algorithm used by each consumer sample to select products for a specific need is a form of operationalised *lexicographic preferences*, as referred to in the economic literature. It is based on the sequential filtering of options using different criteria at each step. The criteria we used is that a product must be perceived as equivalent — though not equal — to the best option available in the market, in respect of all relevant characteristics. Therefore, consumers' preferences from different classes are represented by a 'tolerance level' $\upsilon_{z,n,m} \in (0,1]$ that measures the maximum shortfall in the value of one service characteristic $i_{n,m}$, with respect to the best product offered across all firms. In other words, consumers preference reflect their subjective evaluation on the substitutability of goods, within one need. A very high tolerance — low $\upsilon_{z,n,m}$ — means that a consumer sample is almost indifferent between trademarks (firms). While a very low tolerance means that a consumer sample purchases only from the firm producing the relatively maximum value for a given service characteristic.

The consumption algorithm, for each sample within each class, then goes through the following steps:

1. The consumer observes the quality level $\tilde{i}_{n,m} \sim N\left(i_{n,m}, \varsigma \cdot i_{n,m}\right)$ of the characteristics that define the need n across all firms f^n. The random heterogeneity in the observation — with respect to the real mean value — allows to relax the assumption that a working class perfectly maps the preferences of a consumption class, and introduce some variety in consumption patterns.[10]

2. The preliminary selection is made in respect of the 'minimal requirements' that a product must respect to remain in the potential option set. The consumer only retains the set of firms $\overline{f}^n \in \overline{F}^n_{h,z}$ that satisfy $\tilde{i}_{n,m} > \underline{i}_{z,n,m}$, $\forall m_n$, where $\underline{i}_{z,n,m}$ is a class specific minimum quality threshold:

    - if $\overline{F}^n_{h,z} = \{\emptyset\}$ she saves the money, ends routine and moves to the following need
    - if $\overline{F}^n_{h,z} = \{1\}$ she buys from the only firm $\overline{f}^n$ satisfying the minimum quality $\underline{i}_{n,m}$; ends routine and moves to the following need
    - if $\overline{F}^n_{h,z} = \{a > 1\}$ she proceeds with product choice among the available firms

3. Once determined the set of firms $\left(\overline{F}^n_{h,z}\right)$ that meet the minimum requirements the consumers' sample evaluates the m_n characteristics, in the sequence that reflects her preferences. Within the set $\overline{F}^n_{h,z}$ she further shortlists a subset of firms $\hat{f}^n \in \hat{F}^n_{h,z}$ that satisfy $\tilde{i}_{n,\tilde{m}} > \upsilon_{z,n,\tilde{m}} \cdot \bar{i}_{n,\tilde{m}}$, $\forall m_n$; where $\upsilon_{z,n,\tilde{m}} \in (0,1]$ is the tolerance level.

[10]There is plenty of evidence of imitative behaviour across income classes.

- if $\hat{F}^n_{h,z} = \{1\}$ the consumers' sample spends all her income allocated to need n from the only firm $\hat{f}^n$ satisfying the consumer's preferred characteristic at least with quality $\upsilon_{z,n,\tilde{m}} \cdot \bar{i}_{n,\tilde{m}}$;
- if $\hat{F}^n_{h,z} > \{a > 1\}$ consumption $y_{\hat{h}_z,n}$ is equally shared among selected firms.

The demand for a single firm in time t closes the model allowing each firm to determine their future expected sales Y^e_{t+1}:

$$Y_t = \sum_1^Z \sum_1^{N_f} \sum_1^{\hat{H}_{z,n}} \frac{y_{\hat{h}_z,n,t}}{\hat{F}^n_{h,z}} \tag{47}$$

where $\hat{H}_{z,n}$ is the number of consumers' samples in class z that have selected the firm to satisfy (part of) need n, and N_f are the needs the firm satisfies with its product.

3.5.1 Income distribution and class consumption level

The amount of goods each consumer sample can buy from firms ($y_{h_z,n}$) depends on the total income of the class to which she pertains and the distribution of needs shares (ξ_n). The income of a class is a share of the total incomes generated by wage (W^w), premia and stock options (W^ψ) at the aggregate level of the economy:[11]

$$W_z = \chi^w_z W^w + \chi^\psi_z W^\psi \tag{48}$$

where

$$\begin{aligned} \chi^w_z &= \frac{\sum_{f=1}^F L^z_f w^z_f + \sum_{g=1}^G L^z_g w^z_g}{W^w} \\ \chi^\psi_z &= \frac{\sum_{f=1}^F L^z_f \psi^z_f + \sum_{g=1}^G L^z_g \psi^z_g}{W^\psi} \\ \chi^w_0 &= \frac{\sum_{g=1}^G L^E_g w^E_g}{W^w} \\ W^w &= \sum_{l=1}^\Lambda \sum_{f=1}^F L^l_f w^l_f + \sum_{l=1}^\Lambda \sum_{g=1}^G L^l_g w^l_g \\ W^\psi &= \sum_{l=2}^\Lambda \sum_{f=1}^F L^z_f \psi^z_f + \sum_{l=2}^\Lambda \sum_{g=1}^G L^z_g \psi^z_g \end{aligned} \tag{49}$$

and z is given by the tier of workers employed in both sectors of the economy.

We apply the widely accepted hypothesis that consumers' behaviour is driven by long–term expenditure capacity, and, therefore, short term fluctuations influence only marginally current consumer behaviour. In each period the consumed income is thus a linear combination of past consumption and current income:

$$C_{z,t} = \gamma C_{z,t-1} + (1-\gamma) W_{z,t} \tag{50}$$

The savings that amount to a consumer class in period t are the result of non consumed income due to the consumption smoothing and/or to the unavailability of goods falling within the perceived minimum quality threshold required by the specific class' consumer sample (see previous section 3.5):

$$\tilde{W}_{z,t} = \gamma (W_{z,t} - C_{z,t-1}) + \sum_{n_z=1}^{N_z} \sum_{h=1}^{H_z} y_{h_z \neq \hat{h}_z,n,t} \tag{51}$$

[11] We assume that only the employed population consumes.

In the current version of the model we simplify by assuming that savings generated by consumers are used to smooth income reductions or stored for future generations. Only firms use their profits/savings to invest.

4 Results

For the purpose of this paper we choose to focus on a selected battery of results, which are able to singling out the effects of different scenarios in terms of firms' composition and organisation of production, structure of earnings and consumption patterns on the dynamics of growth and inequality of countries.

The remainder of the section is organised as follows. We start by providing a summary of the initial conditions (Section4.1), along with a brief analysis of the model stationarity and sensitivity to different random seeds (Section 4.2). Section 4.3 provides a selected sketch of the general properties of the model dynamics. We then turn to the core of the relevant results on growth and income distribution as emerging properties at the macro–level of the selected micro–scenarios in terms of structural difference (Section 4.4).

4.1 Initial conditions

The main aim of the following section 4.3 is to analyse whether the interactions of the micro–behaviours formalised above are able to generate sensible results at the aggregate level. In order then to focus the discussion on the micro economic effects, we rely on an initialisation with minimal heterogeneity across firms. The full set of parameters values is reported in Table 2, Appendix C. In the table we report the parameters that are set to average observable values in *italics*, and parameters that are analysed in Section 4.4, in **bold**.

The economy represented in the following exercise is composed of $f = \{1, 2, ..., 50\}$ firms in the consumers sector. Each firm produces a good that satisfies one single need $n = \{1\}$ evaluated along two characteristics ($m = \{1, 2\}$). The first characteristic (i_1) is the price, and the second one (i_2) a catch–all index of quality. Firms initially differ only with respect to the quality of service provided $i_2 \sim U\,[98, 102]$, and are identical with respect to all other initial conditions: products' inventories, expected sales, initial demand, mark–up, stock of capital, vintage productivity, wage, and so on. All firms employ the number of first tier workers necessary to cover the initial demand, identical for all the firms, and an executive (second tier worker) to manage the firm. Both the tier multiplier (ν) and the wage multiplier (b) are set at average levels obtained from Simon (1957), Lydall (1959) and Prescott (2003).

The capital sector is composed of $f^k = \{1, 2, ..., 15\}$ firms, which are also initialised as homogeneous competitors, with an initial first tier worker, a firm manager, and an engineer carrying out R&D activity, paid with firms' previous profits. Capital producers initially produce the same vintage, with the same productivity, and have no capital goods in stock to sell.

On the demand side, the labour structure in the final and capital sectors define three initial classes of consumers: engineers (employed by the capital sector), first tier workers, and a tier of managers. Starting from the first period workers contribute to their class' total income with the received pay (wages, premia and bonuses). The three initial income/consumption classes are assumed to have different preferences with respect to the two products' characteristics: the first tier workers have a high tolerance toward quality $\left(i_2\left(\upsilon_{1,2} = \upsilon^{min} = 0.1\right)\right)$, 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 (δ^{υ}): $\upsilon_{z+1,2} = (1-\delta_{\upsilon})\upsilon_{z,2} + \delta_{\upsilon}\upsilon^{max}$ and $\upsilon_{z+1,1} = (1-\delta_{\upsilon})\upsilon_{z,1} - \delta_{\upsilon}\upsilon^{min}$, where υ^{max} and υ^{min} are the boundaries of the possible tolerance level with respect to product quality levels. The preferences of the engineers are drawn randomly $(\upsilon_{0,m} \sim U(0,1))$.

We further assume there is no preliminary threshold effect, and set the minimum level $\underline{i}_{z,n,m}$, for all characteristics well below firms attainment, so that all firms are included in the initial option set of all consumers. Finally, all workers/consumers classes are divided in $h_z \in \{1, 2, ..., 50\}$ samples.

The results discussed in the rest of the section, unless differently mentioned, are averages obtained over 10 simulations runs with different random properties. In the following Section we show that this is a sufficient number of runs to control for variability due to random events.

4.2 Sensitivity and stability

While an analysis of the stability against the most relevant parameters is performed in Section 4.4, here we briefly show results on the model sensitivity to different random seeds.

Figure 1 shows the results for the gross domestic output (GDP) growth at constant prices, obtained from 100 different runs with different random seeds, and the averages from random samples of different sizes.

The figure shows that, although the model generates exponential growth (see Figure 2), the growth pattern is cumulative but stable. This converges, on average, to a 1% rate per period. The figure also shows that, if we compare averages over 100, 50, 25 or 10 runs, randomly sampled, their difference is negligible. The standard deviation between the averages converges to zero when the GDP growth pattern is non exponential, and sticks to very low values also when the growth pattern becomes exponential (after period 1300). This suggests that when evaluating results from 10 runs averages, these are not biased by relevant random effect.

Similarly, the Atkinson inequality index (Figure 19 in Appendix B) shows converging values for the cross runs averages, and a quite small between–averages standard deviation, across simulation runs.

In Appendix A we provide further results on the sensitivity analysis, on both crucial output variables for this paper, GDP growth and the inequality Atkinson index. Here it suffices to say that both series are highly stable, and that a comparison between averages

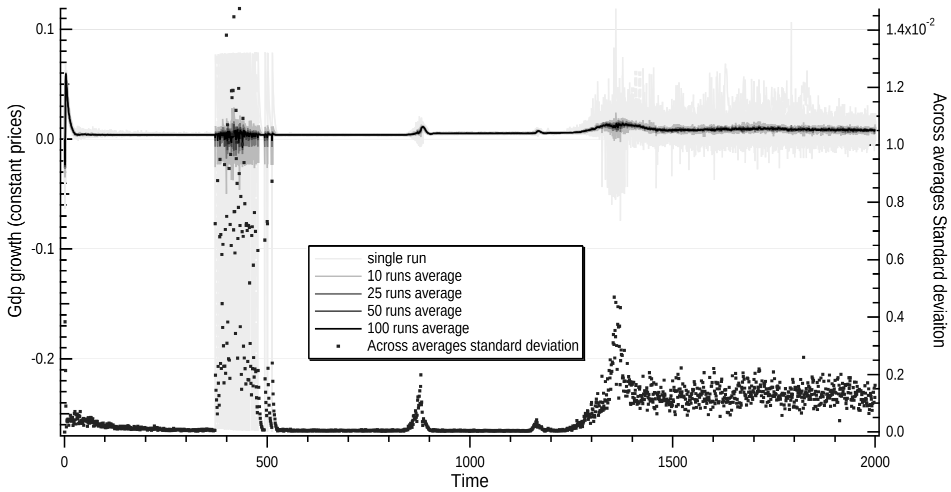


Figure 1: ***GDP growth at constant prices: 100 runs and averages****. The light series represent the GDP growth results for 100 runs with different random seeds (left y–axis). The darker series represent averages from different samples of different sizes, all converging to the same value. Finally dots report the inter–averages standard deviation (right y–axis).*

from 100, 50, 25 or 10 random runs find them all within the same confidence interval (see for example Figure 17 for the GDP).

The results of the sensitivity analysis thus allow us to trade off between larger sampling — non informative — and computational time (which increases exponentially with the number of runs), and obtain robust results on the basis of the 10 runs averages.

4.3 General properties: patterns of growth and income inequality

This section analyses the model properties in terms of growth, income distribution, and their relation, given the assumptions on the initial conditions (Section 4.1). Within a simulation context, we focus on how these aggregate properties are endogenously generated from the micro–behaviours described in the previous section. We then analyse the features of growth and distribution, focusing on the relation between changes in the structures of supply and demand.[12]

The results from the numerical simulations of the model endogenously reproduce a typical long run growth pattern, à la Maddison, which shows a steep take–off after a large number of time steps. Figure 2 shows the GDP series for 100 simulation runs — in logarithmic scale — and their average value. In our simplified model of a closed economy GDP is the sum of final firms production and investment.

The simulation results emerge with two clearly distinct growth patterns, for which the turning point is around step 1250. During the first stage the GDP is characterised

[12]We report only a small portion of the available data series for obvious reasons of space. The simulated data are available on request from the authors. The model and the Laboratory for Simulation Development platform (`http://www.business.aau.dk/~mv/Lsd/lsd.html`) are also available from the authors, to allow a replication of the analysis.

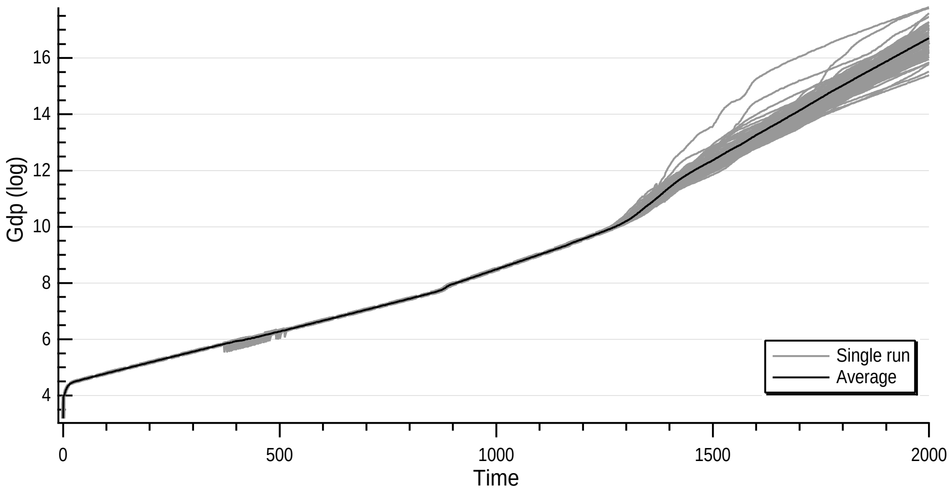


Figure 2: ***GDP (log) series: 100 runs and average***. *Series for 100 runs and average, in logarithmic scale, for 2000 time steps.*

by a stable pattern of growth. This occurs after an initial investment by manufacturing firms, which generates the initial demand. In this first stage the increase in GDP is driven by what we may call a purely *demand* 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 of equilibrium growth, investment grows at the rate of capital depreciation and increase in population (see also a summary of the main macro indicators for the first 1250 periods in Figure 20, Appendix B). Nonetheless, the growth of population is endogenous in our model, as well as savings. Firms first use their profits to invest, and redistribute the exceeding amount to consumers. The latter contribute to the expansion of demand. Notice that, differently from standard growth models, the free access to the credit market allows consumption and investments to coexist, and explains the sustainability of the stable growth pattern.

Indeed, the final demand is not large enough to generate enough profits in the capital sector — via the intermediate demand — to be spent in the hiring of R&D workers.

In the second stage of growth, the productivity starts to increase (see Figure 3), though with volatility across firms. This phase then shows an increase of variety, with growth rates differing both within and among simulation runs. The results from R&D, in fact, are stochastic, and therefore each simulation reflects the new source of volatility although, on average, all simulations show an increase in growth rate. The mechanism behind this growth rate phase of take–off is typically *kaldorian*: increase in the final demand percolate to large capital investment, which generate profits, and investment in new technology with increased productivity.

Figure 3 clearly shows that increases in the average income accompany the first stage of stable growth, and only the ignition of the take–off. The higher growth is then sustained by increases in the aggregate productivity, and the accompanying decrease in consumable prices.

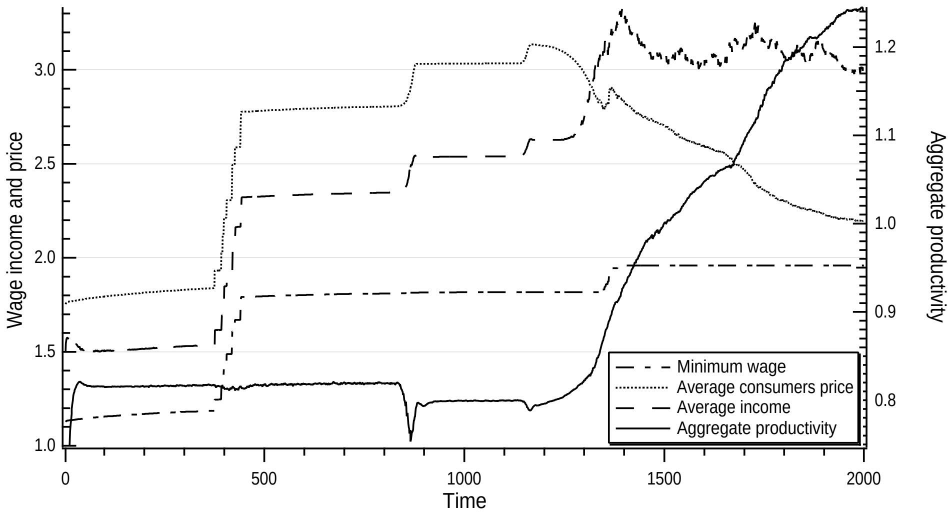


Figure 3: ***Aggregate productivity, minimum wage, average income and price.*** *The average price (left axis) results from the minimum wage (left axis), the aggregate productivity (right axis), and the increase in organisational tiers. Average income is also plotted against the left axis.*

The two stylised growth patterns are accompanied by a two–stage evolution of inequality. Figure 4 shows the series of the Atkinson index from 100 independent runs with different random behaviour, and their average. The Atksinon index of inequality (At) is computed as $1 - \frac{1}{\bar{y}} \left(\frac{1}{L+L^k} \sum_{1}^{L+L^k} y^{1-\varrho} \right)^{\left(\frac{1}{1-\varrho}\right)}$, where y is the income of individual workers, $\bar{y}$ the average income across workers, and ϱ the measure of inequality aversion. Provided that we are not measuring an empirical level of inequality, we use an intermediate value of $\varrho = 0.5$.

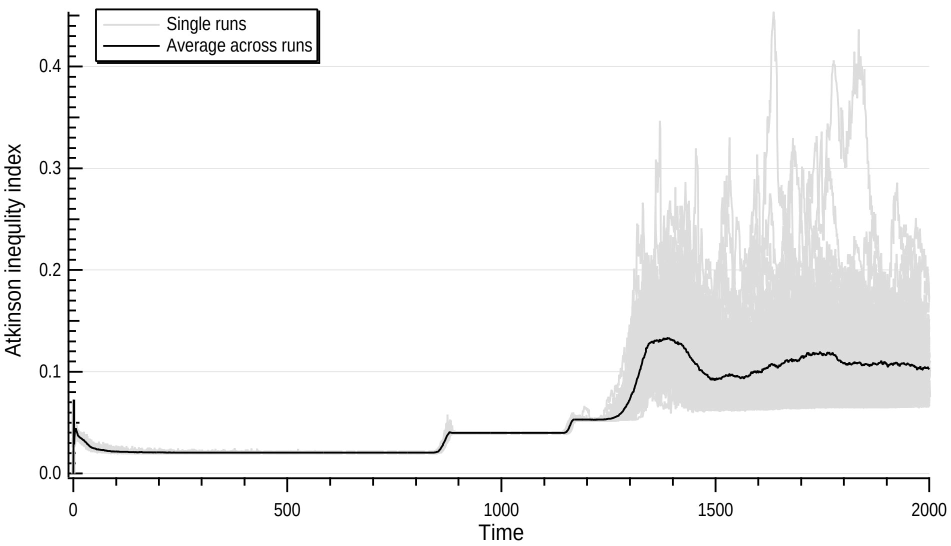


Figure 4: ***Atkinson inequality index.*** *Series for the first 2000 simulation steps for 100 independent runs, and their average.*

To the extent to which growth depends only on the 'short run' loop of workers' spending, the only source of inequality is a new class of consumers (a new tier of managers) enjoying higher salaries and bonuses. The distribution of income is then highly stable, for a given organisation of production (number of organisational tiers). However, when market concentration increases, firms begin to differentiate in terms of dimensions and profits. Therefore, there will be large income differences across managers at different hierarchical levels (besides workers), as well as large differences in distributed profits, generating the higher average inequality observed. Given the volatility characterising this stage of growth in terms of productivity and market dynamics, also income distribution will be highly volatile, and cycles through time, following the underpinning micro dynamics.[13]

The model also generates the typical Paretian distribution of top incomes, when we look at data from the last time step of the simulations.[14] In Figure 5 we plot the Lorenz curve for one illustrative simulation run. A small number of workers, in the executive tiers, concentrate most of the economic wealth.

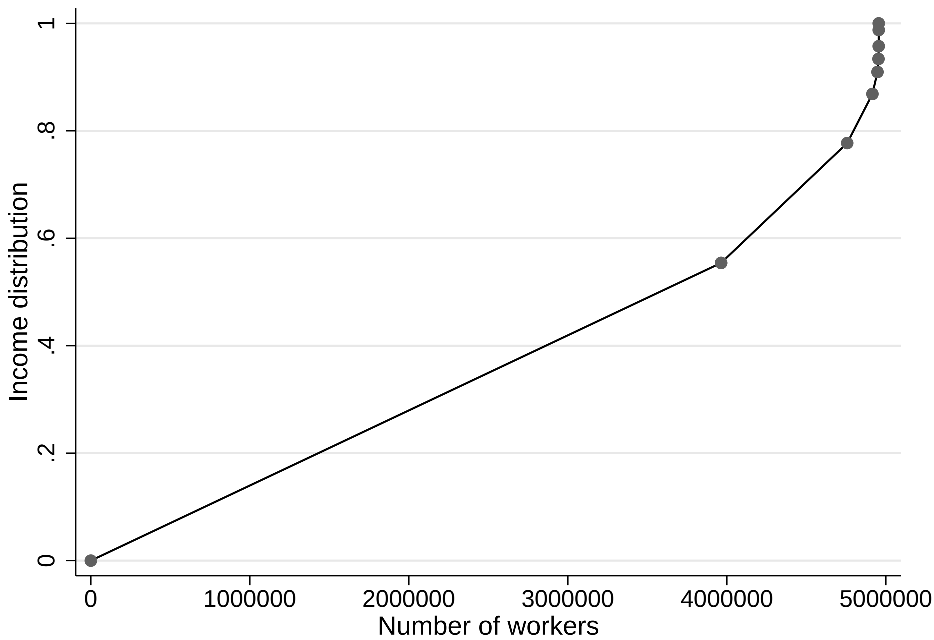


Figure 5: ***An approximation of the Lorenz curve:*** *curve computed in the last time step of the simulation (2000) for one sample run. The straight connecting lines are an outcome of the assumption that within a working class individuals have the same income.*

Moreover, as it is reported by, for example, Gottschalk and Smeeding (1997) and Cornia (2003), most of the inequality in distribution observed from our simulated data is explained by earning inequalities.[15] Our results are also in line with the finding that "Earnings

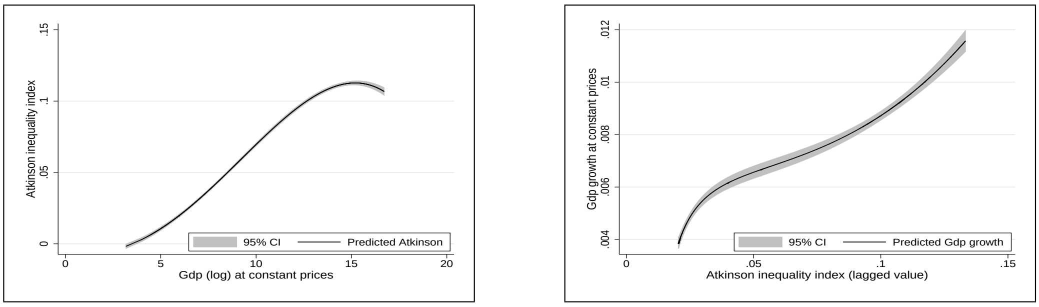
[13]An increasing, and oscillating pattern, is reported, for example, by Fiaschi and Marsili (2007) for the Gini coefficient computed on the Italian labour income. See also the evidence on earnings dispersion across the last 40 years, in different OECD countries, in Atkinson (2007).

[14]See for example Fiaschi and Marsili (2007), Clementi and Gallegati (2005) and Klass, Biham, Levy, Malcai, and Solomon (2006).

[15]Both Gottschalk and Smeeding (1997) and Cornia (2003), refer to high income countries, which we

inequality has risen also because of the fall of minimum wages relative to the average" (Cornia, 2003). This can be appreciated the series of average income and minimum wage in Figure 3. Indeed, a negative relation exists between profit shares and income inequality. As we will see, it is also the 'functional' distribution linked to to the share of profits that allow the take–off to take place. But in our model, class functions determine the demand pattern, rather than savings, and there is no presumption that the demand of a high wage class has a stronger effect on growth.

Finally, we are left with the relation between GDP and inequality. In Figure 6 we plot the predicted values of the Atkinson index, for given levels of GDP (at constant prices, in log scale) (box a), and the predicted values of GDP growth (at constant prices), for given levels of the lagged Atkinson index (box b).



(**a**) GDP against inequality

(**b**) Inequality against GDP growth

Figure 6: ***The relation between growth and inequality****. Fractional polynomial prediction of the level of inequality given the level of GDP (a) and of the rate of GDP growth given the level of inequality in t-1 (b).*

As mentioned above, it is only for relatively high levels of GDP that our results show a predicted pattern ła Kuznets, in the second stage of growth, after the take–off. The initial accumulation of wealth is accompanied by an increasing inequality. Nonetheless, a higher inequality in the previous period seems to predict also a higher rate of growth. As mentioned, this is due to the increased consumption generated by profit shares.

4.3.1 Explanatory dynamics at the micro and meso level

The analysis of the micro data of the model, summarized in Figures 3 and 7, explain the events taking place in the runs. At around time step 400, the round of wage negotiations increases the minimum wage, which quickly feeds into higher average income and price, with no immediate effect on the stable growth path.

The events at around time 900 concern the three–sided relation between aggregate growth, firms' organisation, and consumption structure. The growth of sales allows firms' size to grow (since no entry is permitted), and the assumption concerning the firms' organisational structure triggers the introduction of a new tier of managers, generating a new class of consumers. This event generates a drop in the average productivity, since the new

would observe in the last step of our simulations.

class of manager weighs on the firms' cost structure without increasing their production. Their high salary generates also an increment of average wage and of average price. This change in organisation has two crucial related effects, on growth and distribution.

Crucially, given the difference in firms' capital vintage productivity, generated by the first rounds of capital investment, firms hire a new tier of managers in different time steps. When a larger firm adds such a new layer it suddenly have to stand higher costs than smaller competitors. This generates a high price dispersion, in the short run. Given the low tolerance of the first tier workers towards a shortfall in the price characteristic, firms are selected on the basis of their lower price. The larger firms therefore quickly lose market shares. The result is a strong increase in market concentration (Figure 7). As a consequence, few firms in the final good sector experience a high boost in demand and manage to distribute a large amount of profits, cumulated in the top classes of managers. However, since higher classes have a lower tolerance towards drops in the quality index, but higher on the price characteristic, they buy from all firms, irrespective of their price. All firms eventually hire a new tier of managers, the price dispersion is re–established, and the market is again equally shared across firms. In sum, the boost in GDP growth experienced after the change in the organisation is ignited by the lower class selection, and sustained by higher classes consumption for a short period.

It is worth mentioning that, if profits were distributed equally across classes, results would not change, an we would obtain the same short term increase in GDP growth. Conversely, an increase in the demand from the lower class — with an equal distribution of profits — is likely to have an even larger effect on firms selection, and the related profits generation.

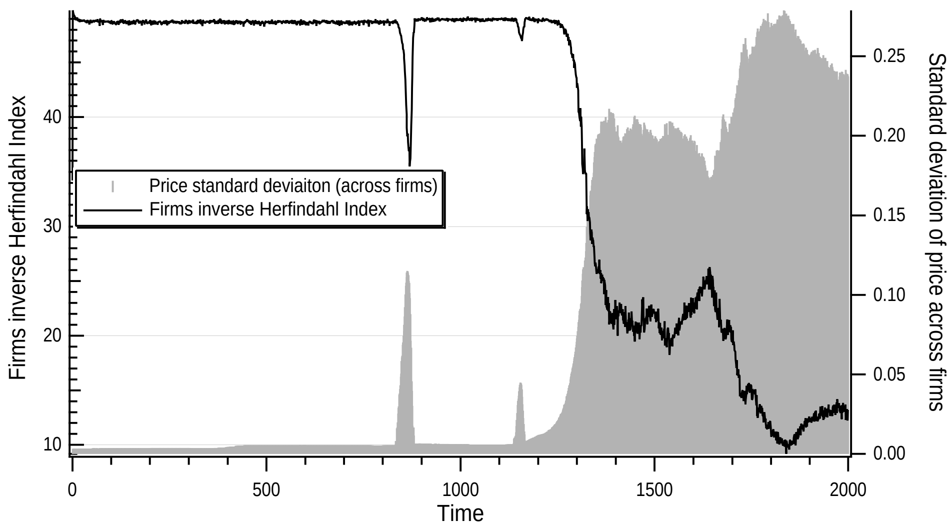


Figure 7: ***Firms dispersion and price dispersion.***

After simulation step 1200, the nature of the link between organisation, growth and distribution changes radically. The triggering event is similar to the previous one: larger firms require yet another tier of managers to deal with increasing size. This increases price dispersion, market concentration, final good firms profits and final consumptions. The difference in this case is that capital good firms have now reached sufficient levels of demand (for capital goods), to cumulate profits to be invested in R&D. The size of intermediate demand was in fact, in the previous organisational change, not sufficient to allow capital firms to devote resources to R&D and increase the vintages' productivity. At the 1200 simulation step though, the increasing dimension of the economy, heavily investing in capital goods, eventually allows the capital firms to invest in new technologies. The process innovations, embodied in the capital acquired by final good firms, increase the aggregate productivity.

In sum, once reached the threshold in the level of final demand, as previously shown, the GDP experiences the cumulative causation pattern à la Kaldor, with more demand generating more process innovation in the capital sector; process innovation increasing the price dispersion in the final good sector; price dispersion increasing market concentration, generating even more profits and accumulation of new capital vintages. And so on.

In this second stage of growth, the increasingly more productive capital purchased from innovating capital producers, changes radically the competitive conditions. In fact, firms receiving a new capital stock with higher productivity enjoy lower production costs, and are therefore likely to increase their market shares. This, in turn, feeds into higher likelihood of new capital purchases, further increasing its competitiveness. Nevertheless, two trade–offs play a role in the continuous changes in the market composition. First, the queuing system in the capital purchase, that require final good firms to select capital producers with less demand (and lower vintage productivity) if they need to meet their own demand. Second, and more importantly, the increase in the number of tiers, and labour cost, that accompanies the increase in market shares.

At a first look the two phases of growth patterns (i.e. the *demand* and *kaldorian*) differ in terms of the R&D expenditure in the capital sector, driving technological innovation and the overall 'size' of the economy. But what ultimately drives these results are the structural conditions that we have imposed in the model.

First, the *organisation of production* — given by the required number of workers that a manager can supervise — generates price dispersion, defines different wage classes, and determine the income distribution.

Second, the formation of wage classes and the related *income structure*, determine differences in consumption patterns.

Third, the differences in the *consumption patterns* play a crucial role as soon as firms dynamics generate sufficient heterogeneity in their production. Heterogeneity, together with the existence of consumption patterns, generates an oligopolistic competition, which as in the results of any standard micro model is characterised by higher profits. This in turn affects the distribution of income.

Fourth, the *composition of production* establishes the heterogeneity across firms required to allow consumers to select. In this paper we have observed only the emergence of price differences (through process innovation); an emerging differentiation in quality characteristic through product innovation, or structural differences in terms of different sectors that satisfy different needs, would stimulate the same selection mechanisms.

Given the primary role of the structural conditions in determining the model's micro and macro properties, in the next section we study their effect on GDP growth and distribution. It should be noted that the following analysis also serves the purpose of studying the model stability with respect to most crucial parameters — the full space or a wide subset of their values — that determine the structural properties.

4.4 Structural differences, growth and income inequality

In this section we analyse the effect of exogenous structural conditions of 'higher order' on structural changes in production, distribution and demand. We refer to a broad concept of structural change, as envisaged in Saviotti and Gaffard (2008): "In a systemic framework, structural change can be defined as a change in the structure of the economic system, that is, in its components and in their interactions. Components are not just industrial sectors, but also entities at lower levels of aggregation, such as particular goods or services, and other activities and institutions, such as technologies, types of knowledge, organizational forms etc.".

By higher order structural conditions we intend: (i) the composition of production and (ii) the organisation of production, on the supply side; (iii) the pay structure and (iv) the consumption patterns on the demand side. The composition of production refers to the sectoral composition, as well as the product variety in firms offer. The organisation of production refers to the hierarchical structure of firms. The pay structure is the other side of the coin of the organisation, and refers to the pay differentials across the organisation (reproduced at the level of the entire economy [16]). Finally, consumption patterns are the other side of the coin of the composition of production, and address the changes in consumption styles and habits that any economy experiences through a development process.

We analyse how the above four *initial* structural conditions affect the evolution of the production and income structure, in terms of gdp growth and take–off, market concentration, and distribution of income across classes of workers/consumers, these latter in turn generated as an outcome of firms growth. Results are discussed accordingly.

4.4.1 Composition of production and consumption patterns

It is a well established empirical evidence that development is accompanied by changes in the composition of production. This occurs both in terms of sectoral composition (e.g. Sirquin, 1988; Maddison, 2001; Dosi, Freeman, and Fabiani, 1994; Prebish, 1950), as well as in terms of an increase in product variety and quality differentiation (Saviotti, 1996). Product differentiation is accompanied by a change in consumers preferences and

[16] The assumption here is that income differentials, accrued by service sectors such as finance and real estate, bequests, and other mechanisms of cumulative income growth, have their starting point in the main source of income, wages and are fed by other sources of earning other than wage

consumption patterns (Maddison, 2001), which becomes more heterogeneous, as a result of the increased variety of production, and income classes.

With this first set of simulations we then analyse the effect of different initial levels of goods heterogeneity, and of different distributions of preferences across consumers classes. Firms are initialised with different levels of the quality characteristic i_2. We vary the value of the standard deviation of firms' characteristic distribution, to analyse the *effect of an increased product heterogeneity.* We also assume that a higher quality level (with respect to the average level across firms) allows firms to have a proportionally higher mark–up. Symmetrically, we vary the heterogeneity in consumers choice. As mentioned, we assume that the tolerance towards a shortfall in the quality characteristic i_2 is maximum — a low $\upsilon_{1,2}$ — for consumers in the class of first tier workers, and minimum — a high $\upsilon_{1,2}$ — for the higher tier of managers, decreasing for classes in between. The opposite occurs with respect to the price characteristic i_1: first tier workers have a minimum level of tolerance toward prices that are higher than the cheapest firm, while the tolerance increases with the wealthier classes. More generally, the tolerance level is bounded between a minimum level ς_{min} and a maximum level ς_{max}. We modify the difference between these two levels, to analyse the *effect of an increased consumers heterogeneity.*[17]

As discussed in the previous section 4.3, firms selection stands as one of the main conditions for economic take off, as well as for the increase in consumers inequality and wealth. Both set of parameters analysed here — on product and preferences heterogeneity — have a direct impact on the initial selection of firms, as well as on industrial dynamics. In Figure 8 we show the average level of the inverse Herfindahl Index (HI)[18] across simulation steps. By construction, the average market concentration increases sharply for high levels of heterogeneity among both consumers and goods offered. In fact, the larger the variety in good's quality and prices,[19] the larger the choice of consumers; and the larger the difference between consumers classes, the stronger their selection.

Before turning on to how the selection pattern impacts on the macro dynamics of growth and distribution, we need to consider two more results from Figure 8. Remember that we are depicting cross–time averages. Therefore, the figure reports low HI values in the cases in which high concentration is sustained through a large number of periods. This implies that economies with a very heterogeneous initial composition of production and of *potential*[20] consumption preferences experience high market concentration since the beginning of the growth process, and through out the simulation steps. Instead, economies that start with large *potential* initial differences in consumer preferences, but low product

[17]We use the distance between the minimum and the maximum tolerance level because the standard deviation is endogenous to the model, and depends on the growth pattern (and the generation of income classes). The distance allows to compare on a fixed set of possible outcomes the parameters space for high and low growth.

[18]This is HI $= \frac{1}{\sum_{f=1}^{F} z_f} \in [1; F]$, where z is firm market share and F the total number of firms.

[19]Recall that while differing only by the quality of the service characteristics, the goods are perfect substitutes.

[20]Recall that in order for consumer heterogeneity to emerge, new classes need to emerge as a consequence of firms growth.

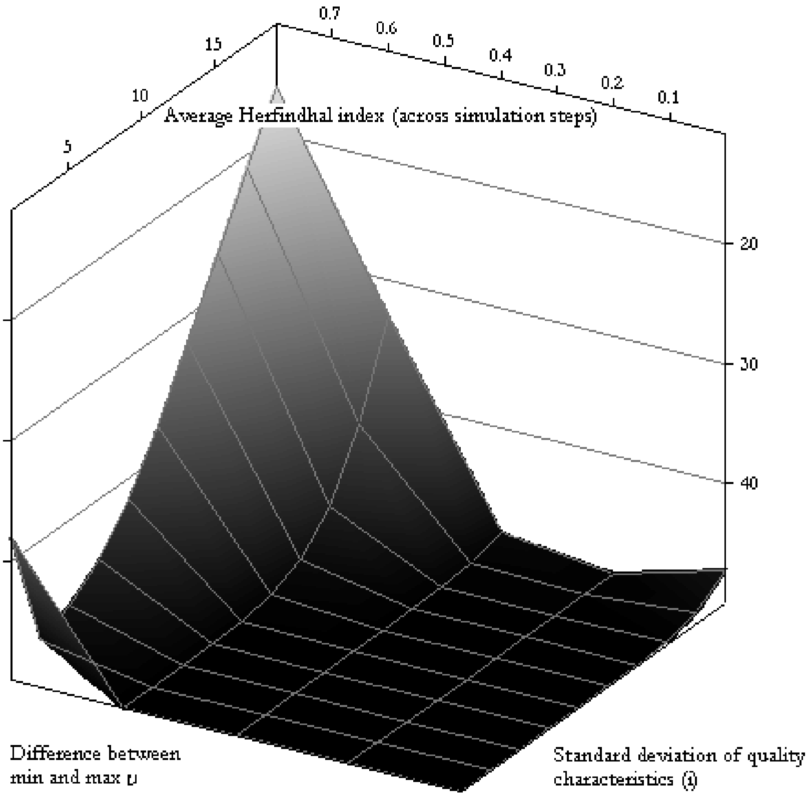


Figure 8: ***Composition of production: the effect of initial product and preferences heterogeneity on market concentration****. The figure shows the changes in the level of average inverse Herfindahl Index against different values of standard deviation of the product characteristics (x-axis), and against changing values of the difference between the minimum and maximum level of consumers tolerance toward quality shortfalls with respect to the best firm.*

variety, become highly concentrated through time (the decreasing HI that characterises the west corner of the figure). In this second case selection occurs as a dynamic process, as the economy evolves, through price differentiation — linked to initial quality differences, as well as growth of new consumer classes and changes in the organisation.

If we then turn to the effect of the composition of production on economic growth, the results from our model only partially endorse the proposition that higher variety (across both goods and consumers) is linked to faster GDP growth. In Figure 9 we show the level of GDP in the final simulation step.[21]

More precisely, the figure shows two main results: (i) an *initial* high variety in the quality of goods produced in the economy, when substitutes, induces a low growth; (ii) the heterogeneity between consumers preferences has an effect on growth only when it is very large, and is combined with an *initially* low heterogeneity of the good quality.

In other words, a too large difference between products since the beginning, does not allow a take off of the economy. In the initial periods the demand is, in fact, too low to generate an investment in new capital by firms. Therefore, the selection of firms simply

[21]The average GDP growth would show the same relation.

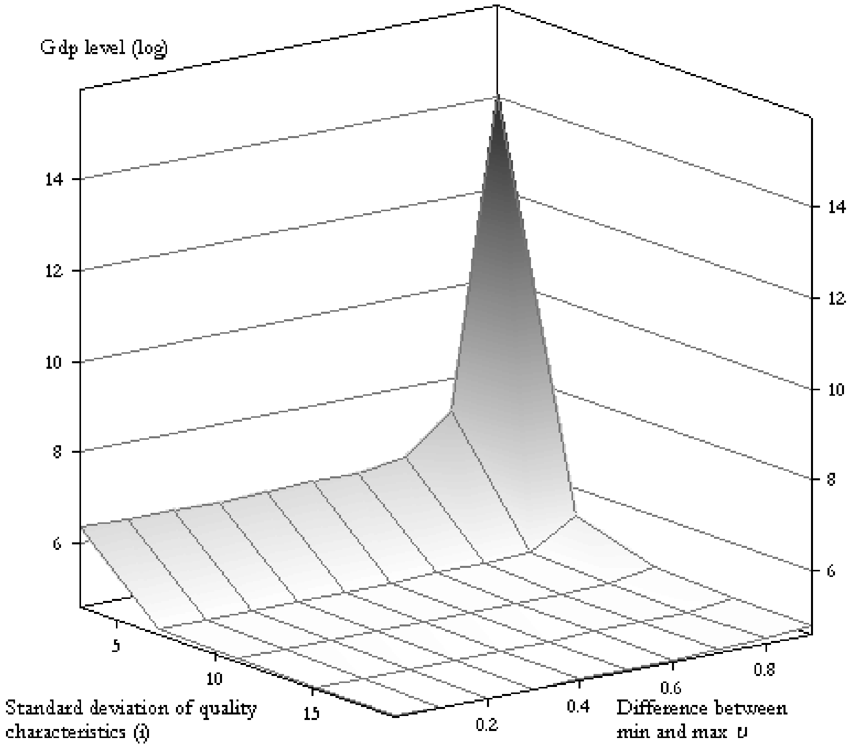


Figure 9: ***Levels of GDP (in logs) for different levels of product and preferences heterogeneity****. Levels of GDP in the final period of simulations are plotted against changes in the standard deviation of quality characteristics (and mark–up) distribution — x–axis — and changes in the difference between the minimum and maximum level of consumers tolerance for a difference in quality characteristic (or in price)*

reduces the number of vacancies, maintaining a low level of the demand (see also results on the number of workers in Figure 21 (a) in Appendix B). Without the demand effect, the cumulative process is never started and although the economy experiences an endogenous growth, this is lower the higher the initial market concentration. One can see this result also by comparing the level of population with the aggregate productivity in Figure 21 (b) in Appendix B. For medium to high levels of product heterogeneity, even with a very low number of workers hired, the aggregate productivity remains at very low levels.

Conversely, if a low initial heterogeneity is required, with no emergence of consumers selection, on the basis of different preferences, no take–off occurs.

To sum up, product heterogeneity has to develop through time, after the economy has already experienced a growth in production and demand. And product heterogeneity is necessary, but not sufficient, to obtain an economic take–off. It has to be accompanied by an emerging differentiation among consumers.

At the microeconomic level, as firms initially grow, they generate both demand and new consumers classes. The first increases the level of output, requiring more production and investment, while the increase in consumers classes determine the conditions for firms selection, in the medium run. Both demand and supply side effects are at work here, but they both depend on an initial growth ignition, which has to be sufficiently high to turn firm selection into a positive effect for growth. Otherwise, firms selection poses a ceiling to the level of GDP reached by the economy.

The effect of the initial composition of production on income inequality is non linear (Figure 10). The economy experiences the highest level of inequality in the presence of large initial product heterogeneity. Inequality increases again for very low levels of product heterogeneity. The differences in the pattern of consumption among consumer classes has a quite small effect.

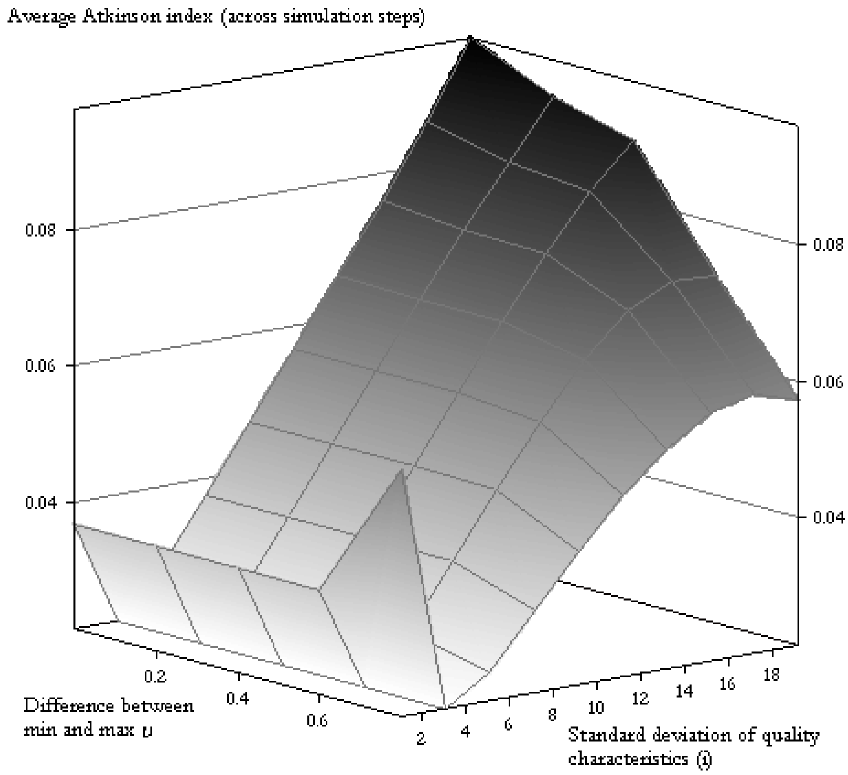


Figure 10: ***The effect of the initial composition of production and demand preferences on income inequality: the Atkinson index.***

We can the reassess the relation between economic growth and inequality. As expected from the general properties of the model discussed in Section 4.3, higher levels of GDP are associated also with higher inequality. But here we show that very low levels of GDP can be characterised by a much higher inequality. This is the case of high initial product heterogeneity.

In both cases of high and low GDP, the inequality is due, mainly, to the income generated by profits shares (distributed as stock options to executives above the first tier) (Figure 22 (b) in Appendix B). In particular, we can distinguish two main opposite scenarios: a stagnant and highly unequal economy, and a virtuous, less unequal, growing economy. In the first case of high *initial* product heterogeneity, a small population enjoys a high average income (Figure 22 (a) in Appendix B) generated through non invested profits, and unequally distributed. In the second case of low *initial* product heterogeneity and high (potential) difference in preferences, a large population enjoys a quite high average income (a good share of which is generated through non invested profits). Given the lower level of inequality, the population is definitely better off in this second scenario.

The bottom line from these results is that product variety has a positive effect when it is generated through a development process, and in the preferences of *evolving* consumers preferences. Otherwise, it generates no structural change *per se*. Loosely speaking, our results support an Hirschmanian view of development through stages of disequilibria, rather than a Big Push à la Rosenstein–Rodan — although this may change for different initial levels of economic development. In other words, even when using economic growth lenses, development appears as a lengthy process that requires endogenous changes rather than exogenous recipes.

4.4.2 Organisation and production technology

The second set of simulations analyses the influence of final good firms' production and organisational structure on economic growth and income distribution. Production structure is intended here as the capital structure of the firms, while the organisation depends on the labour force structure (i.e. the number of layers). We therefore focus our analysis on the joint effect of two parameters:

- ν: The tier multiplier defines the ratio of workers between tiers: the lower ν, the higher the number of layers in a firm, *ceteris paribus*.
- σ^a: The standard deviation in the outcome of R&D of the capital good firms. This parameter affects final goods' firms productivity level by both (i) increasing the potential heterogeneity in productivity among firms and (ii) increasing the potential productivity gains through capital investments.

At the firm level, these two parameters have opposite effects. A higher number of layers — associated with a small tier multiplier — increases the production costs and reduces firms productivity. A wider distribution of the R&D outcome increases productivity as a result of the investment in potentially more productive capital goods, and thus reduces the number of workers required to produce the same level of output.

At the industry level, larger potential productivity gains should lead the most efficient firm to dominate the market, as a result of the cumulative nature of productivity gains. Nonetheless, a trade off exists between size and production costs. A large number of tiers implies an increase in the production costs and a loss of market shares that reduces the market concentration.

Finally, at the macro–level, both structural conditions (large organisations and potential productivity gains) should positively affect growth via the effective demand: (i) a higher number of layers extends both the total income available for consumption and the number of consumer classes, and (ii) productivity gains reduce prices. Similarly, and in accordance with the general properties of the model, the two structural conditions should increase inequality among households: (i) a higher number of layers generates a higher dispersion in income distribution, by construction; (ii) higher productivity allows for higher profits to benefit the higher layers of workers, amplifying the disparities in income; finally, (iii) a higher productivity may raise the minimum wages, thus increasing the overall income available, and reinforcing the two previous mechanisms through a higher effective demand — triggering both the size of the firms and the number of layers and the productivity due to higher investments.

Figure 11 confirms the expectations on economic growth. The figure shows the Log of the GDP levels, at constant prices, after 2000 simulation steps, for various values of the selected parameters. An increase in σ^a positively affects GDP, while an increase in ν — reducing the number of layers, *ceteris paribus* — negatively affects GDP.

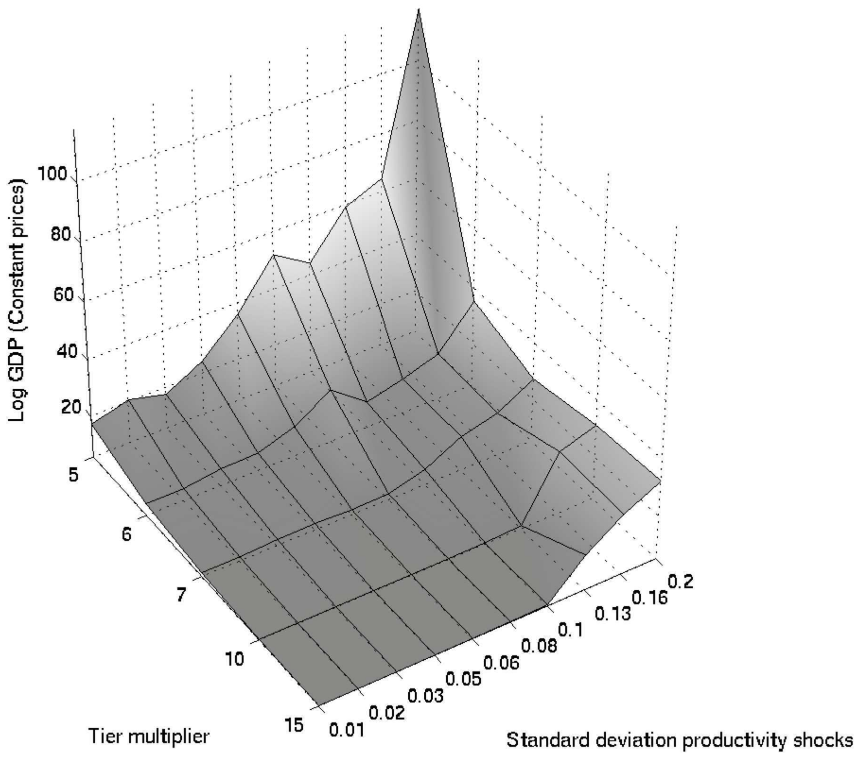


Figure 11: ***Log GDP at constant prices with changes in production and organisation structure.***

The income inequality, though, exhibits a non linear pattern. Figure 12 presents the average Atkinson index over the 2000 simulation runs. As expected, for a given σ, an increase in the tier multiplier (ν) implies a lower level of inequality, due to a slower increase in the number of organisational layers for an equal increase in firm size. The relation is then reverted for large values of ν: as the organisational structure flattens,[22] the pace of GDP growth is very low, and inequality raises again. As discussed for the previous results set (Section 4.4.1), the economy is in a condition of very low consumer differentiation and low demand, which does not induce firms selection and the demand trigger for the cumulative causation to occur. Therefore, the very low investment in capital, does not ignite any productivity change, and designate firms profits to unproductive bonus shares.

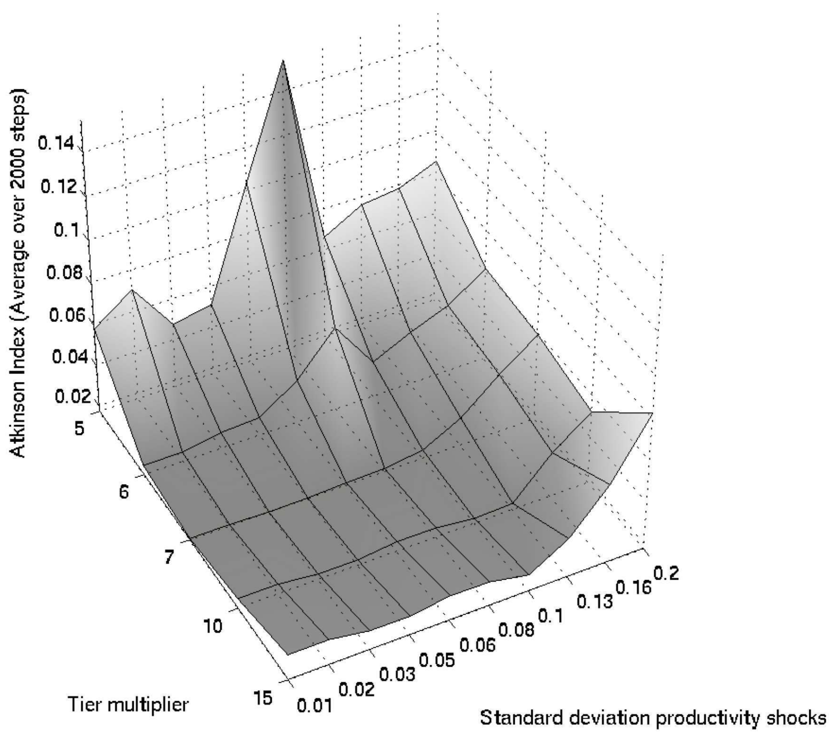


Figure 12: ***Atkinson index with changes in production structure.***

Conversely, a higher spread of productivity gains (σ) generate a higher dispersion of income, but for the case of the two lower values of ν. In both these cases, income inequality reaches a peak for average values of productivity dispersion ($\sigma \approx 0.08$).

Once more, these results are explained under the lenses of the relation between investment, growth, profit distribution, and demand. To appreciate this, we first need an understanding of the aggregate productivity dynamics. Figure 13 shows the productivity level after 2000 simulation steps, as a function of both ν and σ. A part from the southern quarter of the diagram (low σ and high ν), productivity changes present a pattern very similar to the Atkinson index. At the firm level, the layer effect, by reducing the efficiency of firms' production process, limits the role of potential productivity gains. In other words,

[22] We analyse an interval of the worker/executive ratio (ν) which exceeds the values reported, for example, in Simon (1957).

productivity gains tend to erode: for high values of σ the lower ν (i.e. the larger the number of layers, *ceteris paribus*) the lower aggregate productivity (see figure 13). This is confirmed by looking at the employment dynamics (see figure 23 in Appendix B). Large productivity changes are responsible for a large economic growth, which is accompanied, and spurred, by large increases in the population (demand). Those increases keep firms under pressure, requiring large capital investments, which reduce the opportunity to share profits with executives.

The peak in productivity then explains the peak in the Atkinson index through a peak in profit levels that only benefits the higher tiers in the organisational structure.

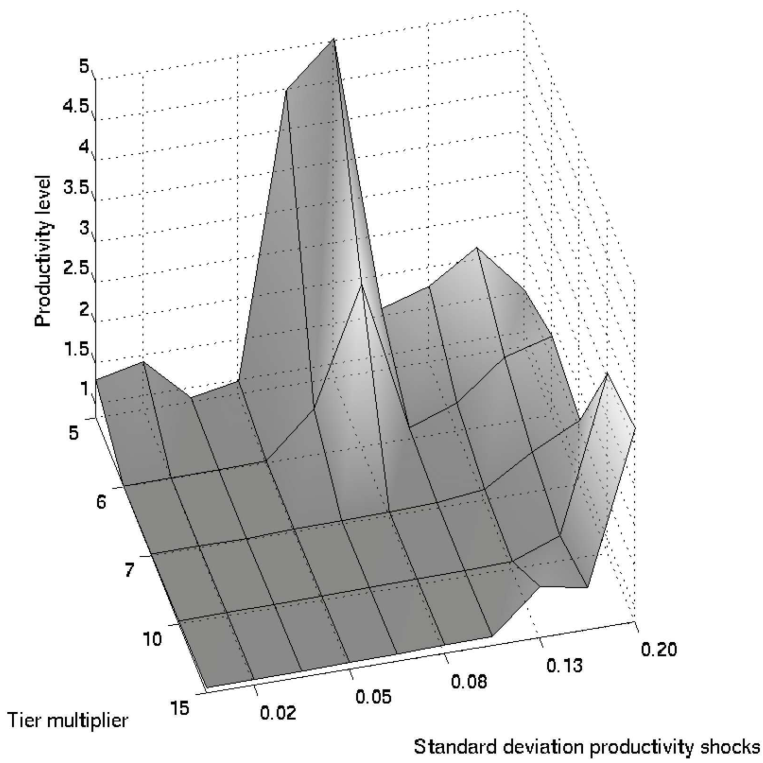


Figure 13: ***Productivity levels with changes in production structure.***

To summarise briefly these findings, reinforcing structural change in organisation and production through an increase in the number of firms layers, or through the unevenness of productivity gains embodied in capital goods, leads to higher GDP levels, and wider income disparities among households. These disparities are however reduced when too uneven potential productivity gains limit the aggregate productivity, constraints the distribution of profits, and spur employment and demand.

4.4.3 Organisation and wage structure

This last set of simulations focuses of the effect of the organisational and pay structure on income disparities and economic growth. We focus our analysis on the joint effect of the two parameters controlling these structures:

- ν: The tier multiplier defines the ratio of workers between tiers: the lower ν, the higher the number of layers in a firm, *ceteris paribus*.

- b: The wage multiplier defines the ratio between the wages of two sequential layers.

These two parameters have two symmetric effect on the supply and the demand side of the economy. On the supply side, a higher number of layers (i.e. lower ν, *ceteris paribus*), and/or a higher wage multiplier (i.e. higher b), directly increase the firms cost structure.[23] This may also result in a higher dispersion of across firms prices, through time.[24]

On the consumer side, the effect is two–fold. First, a reduction in ν and an increase in b modify the structure of earnings, increasing the overall income (more workers, with higher salaries, on average) and the disparity between the classes (more wage classes, with higher wage disparity). Second, as a consequence of the increase in the number of wage classes, they induce structural changes in aggregate demand, increasing the heterogeneity in demand preferences (on both quality and price) and the range of affordable products.

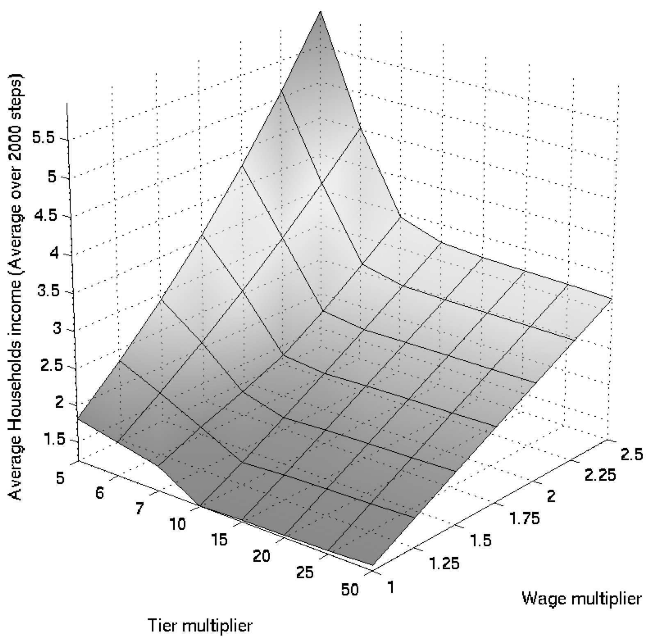


Figure 14: ***Average households income with organisational changes.***

[23]Given that these parameters are set homogeneously across firms as initial conditions, they do not distort the initial competition but simply raises the overall price levels.

[24]See also the explanation of the general properties of the model (Section 4.3.1).

Figures 14 and 15 show the effect of the organisation and pay structure on, respectively, the average households income and the average Atkinson index over 2000 simulation steps. As expected, increasing the wage multiplier mechanically raises the average income among households (figure 14). It also directly translates into higher income disparities: the higher the wage multiplier the higher the Atkinson index (figure 15).

Quite close to our expectations, a higher tier multiplier leads to a lower number of layers and lower average income. This effect, however, becomes less significant for high values of the multiplier, and is counterbalanced by a higher rate of shared profits, in the presence of low growth with no capital investment.[25]

More articulated is the effect of the tier multiplier on income disparities between classes. For different values of the wage multiplier, the Atkinson index exhibits a U–shaped form as the tier multiplier increases (figure 15). Extreme values of the tier multiplier correspond to high income disparities. When the multiplier is low, the large number of layers amplifies even small wage disparities among layers, and generates inequality. When the multiplier is high, a very small number of layers emerge, the upper classes absorb the high rate of redistributed profits, and these generate high dispersion between classes of income, even–so the wage dispersion is low.

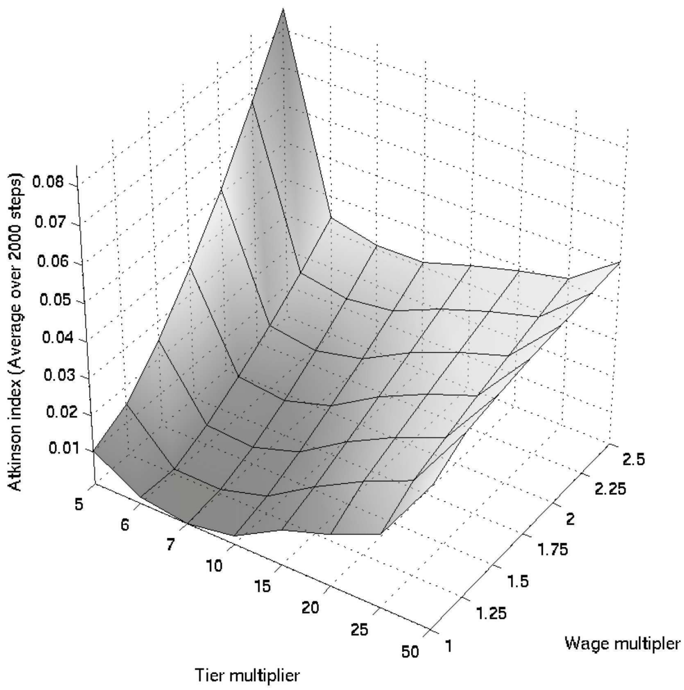


Figure 15: ***Atkinson index with organisational changes.***

Finally, figure 16 presents the average GDP growth at constant prices, for selected values of the tier multiplier and the wage multiplier. The figure shows that the larger

[25] As illustrated extensively above, in the presence of low demand–induced growth, the lack of capital investment is associated, by construction, to the full share of profits.

the number of layers (i.e. the smaller the tier multiplier) the higher the GDP growth. In other words, the increase in the number of consumers directly translates in higher effective demand and therefore positively affect growth.

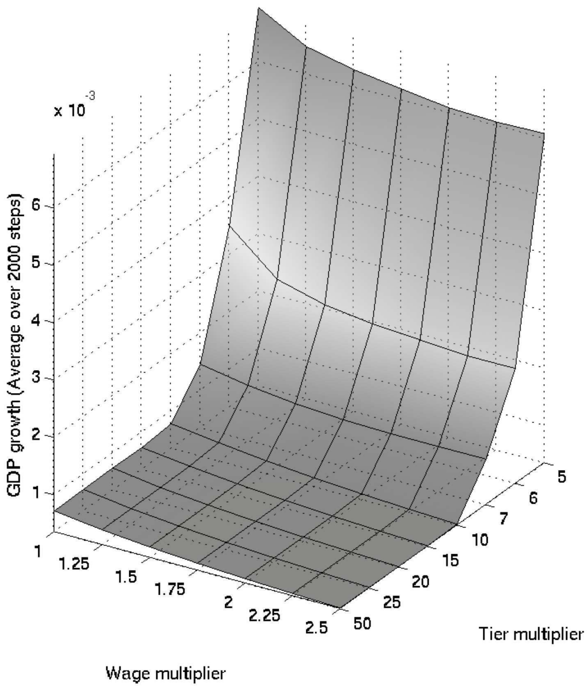


Figure 16: ***Average GDP (constant prices) growth with organisational changes***.

On the other hand, the higher the wage multiplier the lower the GDP growth. The increase in cost generated by high disparities in wages tends to slow down long run growth. In other words the overall increase in prices limits GDP growth. This is due to the minimum wage dynamics (Figure 24 (a) in Appendix B): the larger the discrepancies between earnings (across tiers), the lower is the minimum wage, due to the slower increase in aggregate productivity (a main determinant of shifts in the minimum wage), and to the lower employment.[26] When large differences between the price and the minimum wage (we show the average difference across simulation steps in Figure 24 (b) in Appendix B) are accompanied by the large demand of large organisations employees, growth is sustained. Otherwise, the economy experiences both high inequality and a low economic growth.

To summarise briefly these last findings, enhancing earning disparities through wage disparities and the number of layers directly increase income inequality, as one would expect. While generating inequalities, these mechanisms can also limit the expansion of the economy. Indeed, a large number of layers sustains effective demand (notwithstanding an increase of firms cost structure) but high wage differences between layers increase the price level in the economy (and the difference between price and the minimum wage), with

[26] As Cornia (2003) put forward, the stickiness of the minimum wage, and the increasing differences with top salaries, are the main determinants of the observed inequality.

no benefits and slow economic growth.

5 Concluding remarks

In this paper we investigate the relation between technological and organisational change, dynamics of consumption related solely to income changes, macro–economic growth and income distribution and. A large and diverse literature has pointed to strong empirical evidence suggesting mutual effects and providing partial theoretical explanations on some of these links. However, we reckon that little work has been done on integrating a formal and coherent theoretical tool accounting for interactions among the above phenomena. For example, there are very few theoretical efforts that analyse growth and development dynamics as an outcome of the changes in the underlying structure of an economy. In this work we propose an approach based on the use of an agent–based simulation model representing a macro–economic system. We report on both the description of the model and on some of the results produced.

The model is based on the description of the micro–actors of an economic system, firms and consumers, that we implement following the literature on industrial dynamics and industrial organisation. We then add features of structuralist growth models, like, e.g., endogenously defined consumers' classes and a capital sector. Micro behaviour is carefully crafted, making reference to the available empirical literature to define initial conditions and behaviour. Finally, we 'close' the model by explicitly implementing the interactions between the sectors of the model, expressing the multiple effects of any event on the whole system.

We can then analyse the aggregate dynamics inspecting the overall properties of the time patterns generated and, crucially, link the emergence of specific features to the whole set of underlining conditions. In particular, we explore the micro explanations defining the role of structural conditions in determining the aggregate output. We can observe how economic growth stems from a cumulative causation process that involves demand shifts and technological change in the capital sector. Within this context we can individuate and study the interaction between income distribution (and consumption patterns) on the demand side, and the firms' organisation and technical change on the supply side. We can therefore not only reproduce commonly observed features of economic growth, but also reconstruct the complex generational patterns eventually leading to those features. We particularly focus on the determinant that hint to the structural conditions at the micro and meso level.

We finally focus the analysis on the effects of the initial structural conditions, testing the model stability against the crucial parameters that influences the growth and distributional outcomes. We summarise the main findings of the paper as follows:

1. Product heterogeneity, in terms of sectoral composition of an economy, or in terms of quality differences in the characteristics of the produced goods, plays a relevant role on the economic growth of an economy, and on the distribution of its economic

wealth. The heterogeneity in consumers preferences is also relevant, but it needs to be large to be effective. Nevertheless, such heterogeneity has to be built through time, and cannot be the outcome of an initial planning. When product heterogeneity is large since the beginning, in fact, selecting out firms hinders the cumulative feedbacks that allow a take–off of GDP. In both the extreme cases of initial stagnation — due to a high initial heterogeneity — and of economic take off — due to a differentiation in the products smoothed through time — the economy experiences an increase in inequality. Yet, in the case of high growth the inequality effect is much less pronounced.

2. Organisational structures that induce the spur of a large number of firms organisational tiers, as well as large and uneven productivity gains embodied in capital goods, lead to higher GDP levels but are also responsible for higher income inequality. Unequal distribution, in turn, might have a negative feedback effect by slowing down GDP growth.

3. Firms' organisational and earning structures affect economic growth both via the level of aggregate demand and via disparities of income structures. The complexification of firms' hierarchical structure, despite increasing average wages and prices, sustains aggregate demand in the long run, inducing demand–led cumulative causation growth. Conversely, the sole increase in earnings disparities has a large negative effect on both inequality (increasing inequality) and growth, due to low investments, non productivity changes, and a sticky minimum wage.

The methodology used for this paper, based on a flexible and modular simulation model, allows to envisage many possible extensions of the work presented. Once accepted its main features and properties, the model allows to investigate, e.g., the relation between inequality and growth. For example, with reference to Cornia (2003) one may extend and generalise the analysis on to which extent the determination of the minimum wage affects inequality, and the relation with growth.

The model proposed in this work allows as well to investigate a set of mechanisms, which are relevant for policy scenarios, and represent our future research agenda on the link between changes in the structure and organisation of firms' production, changes in income distribution and final demand as affecting economic growth. The future work that we envisage points to the extension of the model by endogenising some of the presently parametrised structural conditions, in order to analyse the states under which structural changes emerge, and their dynamic effect. According to the principle that "*a model must be as simple as possible, but not too simple*", we plan to introduce those features one at a time. Future steps of our research agenda based on the use of the model include:

1. Analyse the micro–foundations of the relation between variety and growth, along the lines already proposed in the literature, though at a macro–level only (Saviotti and Pyka, 2004; Saviotti and Pyka, 2006). Such an objective requires the introduction in the model of product innovation (across product characteristics) and, more

importantly, the conditions for their emergence. This has to go along with features to account for novelty introduction on the demand side (e.g. new needs and/or new ways to fulfil old needs, namely the evolution of consumers preferences). The model can take into account product innovation in a two–fold way. First, the incremental change shown in the present paper – firms produce a good with different quality levels of the same service characteristic, representing competing technologies/designs. Second, product changes defined by a limited set of radical and incremental changes in the vector of characteristics and needs which define the product itself. The model is able to envisage the creation of a new product (both final and intermediate) as pulled by the occurrence of a new need and defined in terms of a new/different vector.

2. Accordingly, the between classes and within classes changes in the patterns of consumption, defined as changes in the distribution of needs across workers/consumers.

3. Finally, in line with the recent literature on industrial organisation and technological change, we need to define the conditions under which firms modify their organisational and pay structure, in terms of outsourcing. From a product–characteristics point of view, organisational change involves the creation of new (intermediate) products, or the internalisation of production phases. The occurrence of new products on the intermediate market represents the very essence of structural change in the production.

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A Appendix: Sensitivity analysis

In what follows we briefly discuss the random properties of the model, showing that results from averages over 10 random runs are sufficiently robust. We concentrate on the two main aggregate output used in the analysis of this paper: GDP growth and the Atkinson inequality index.

The GDP growth Figure (17) shows that, when we compare the confidence area of an average of 100 independent random runs, with the confidence areas of ten random averages from 10 independent subsamples of runs from the same overall sample of 100, there is no difference.

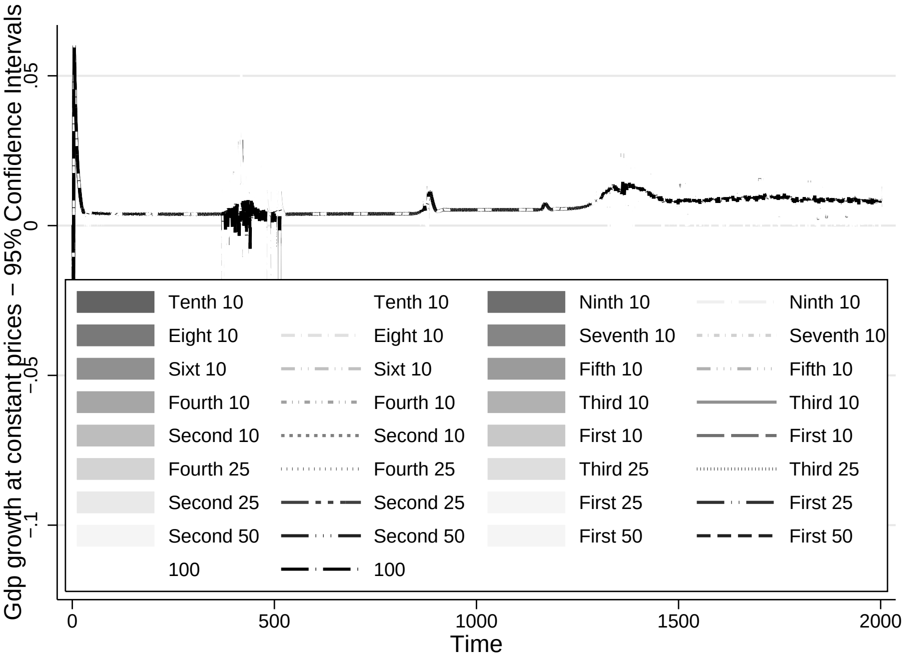


Figure 17: ***GDP growth at constant prices: averages and confidence intervals****. The figure shows the confidence areas of the different averages (over samples of 100, 50, 25 and 10 runs), superimposed one over the other, starting from 10 runs averages. The grey scale goes from dark grey for 10 runs averages to white for the 100 runs average. The figure then shows that no section of the 10 runs confidence area exceeds the 100 runs confidence area (and obviously no 10 runs average falls out the 100 runs average confidence area).*

In Figure 17 the confidence areas are superimposed one over the other, and none of the ten average areas, which lie below the 100 runs average confidence area, is visible. This allows us to infer that any 10 runs average do not generate a higher random variety than a 100 average.

When we undergo the same exercise for the Atkinson inequality index we obtain a very similar result (Figure 18). The difference between the confidence areas is well below one standard error.

Overall we fill confident that we can undergo a robust analysis of the model using

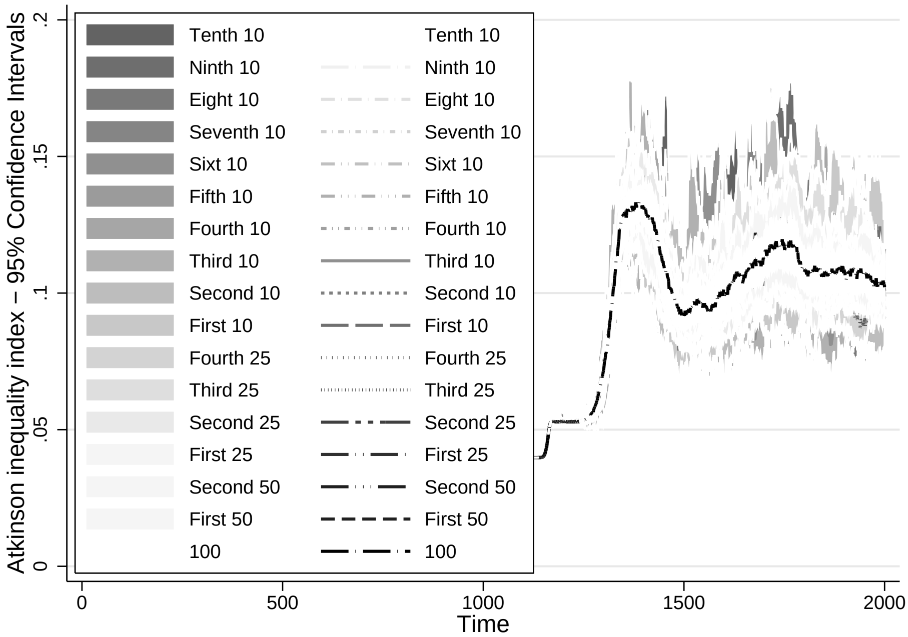


Figure 18: ***Atkinson inequality index: averages and confidence intervals***. *The figure shows the confidence areas of the different averages (over samples of 100, 50, 25 and 10 runs), superimposed one over the other, starting from 10 runs averages. The grey scale goes from dark grey for 10 runs averages to white for the 100 runs average. The figure then shows that very small sections of the 10 runs confidence area exceed the 100 runs confidence area, amounting to a very small difference between the confidence areas of the different averages (and obviously no 10 runs average falls out the 100 runs average confidence area).*

averages over ten different runs, and reducing by an exponential factor the computational time needed to create average for 100 different random runs.

B Figures

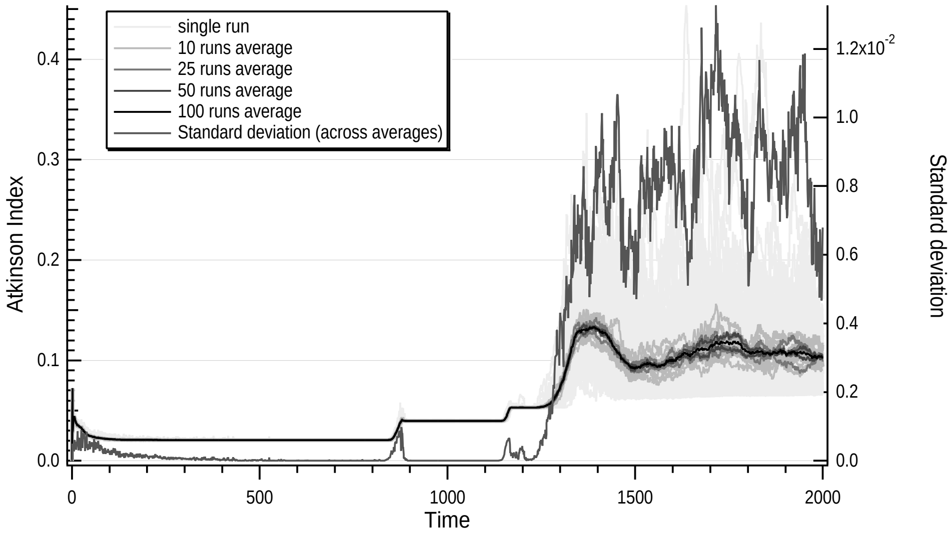


Figure 19: ***Atkinson inequality index: 100 runs and averages***. *The light series represent the results for 100 runs with different random seeds (left y–axis). The darker series represent averages from different samples of different sizes, all converging to the same value (left y–axis). Finally, dots report the inter–averages standard deviation (right y–axis).*

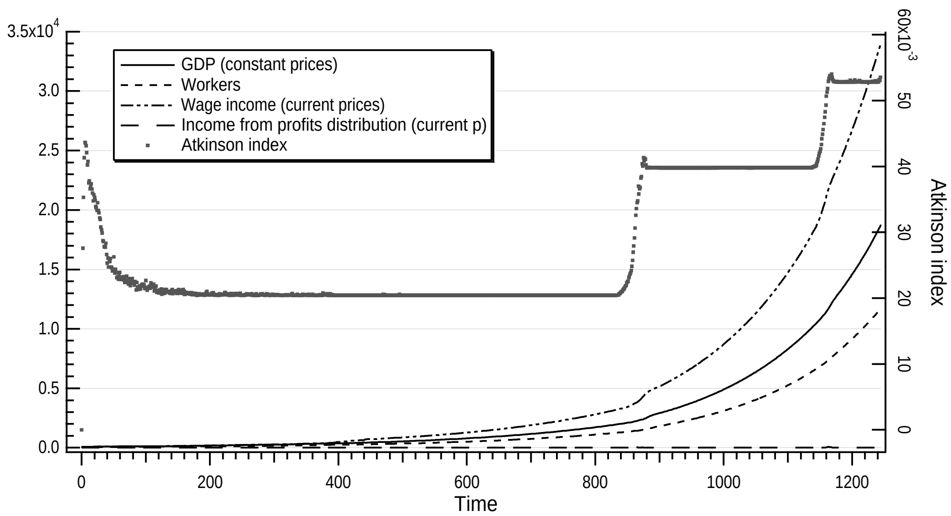
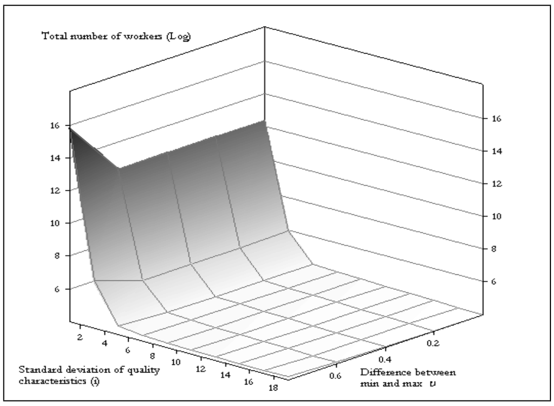
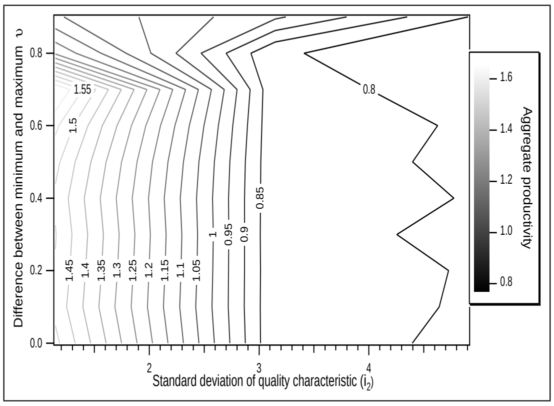


Figure 20: ***Main output form general average conditions: GDP, population, income and inequality — first 1200 periods***.

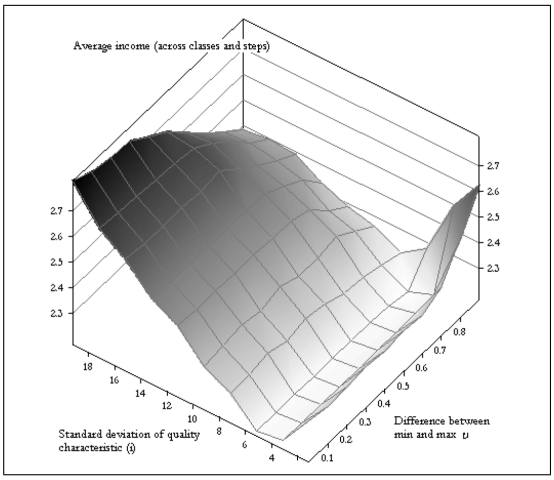


(**a**) Number of workers

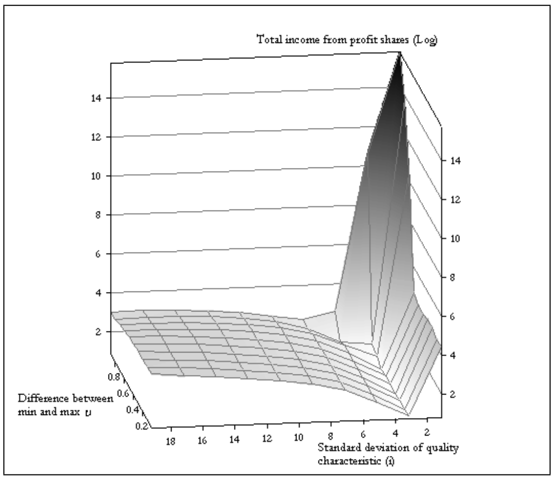


(**b**) Aggregate productivity

Figure 21: ***Composition of production: the effect of initial product and preferences heterogeneity on employment and aggregate productivity**. The figure shows the changes in the level of hired workers (**a**) and of aggregate productivity (**b**), against different values of standard deviation of the product characteristics (x-axis), and against changing values of the difference between the minimum and maximum level of consumers tolerance toward quality shortfalls with respect to the best firm.*



(**a**) Average income (across population and time)



(**b**) Total income from profit shares

Figure 22: ***Composition of production: initial product and preferences heterogeneity against income and profit shares**. The figure shows the changes in the level of average income, across workers, and across time (**a**) and in the level of total income from profit shares (**b**), against different values of standard deviation of the product characteristics (x-axis), and against changing values of the difference between the minimum and maximum level of consumers tolerance toward quality shortfalls with respect to the best firm.*

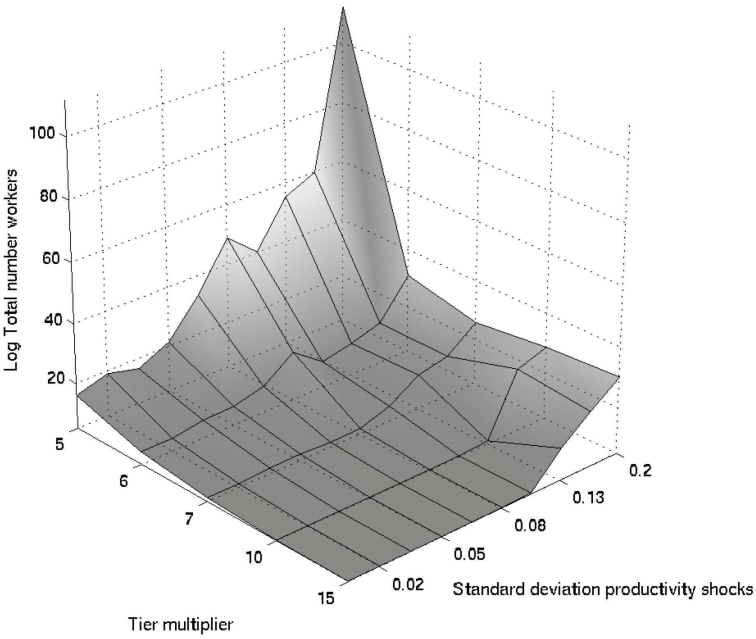
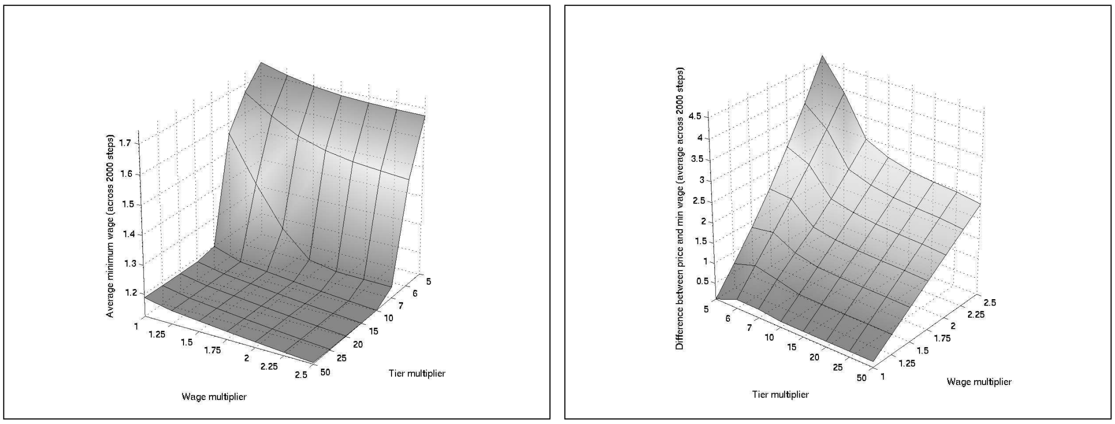


Figure 23: ***Log Employment with changes in production structure.***



(**a**) Minimum wage (average across time steps)

(**b**) Difference between price and minimum wage (average across time steps)

Figure 24: ***The effect of minimum wage dynamics on growth and inequality****. The figure shows the effect of the tier multiplier, and of the wage multiplier, on the macro dynamics of the minimum wage (****a****), and the difference between the average price and the minimum wage (****b****). Both figures report the average value across the 2000 simulated time steps.*

C Tables

Table 1: Parameters setting: lagged variables' initial values

Var_{t-1}	Description	Value
W_0^w	Wage Income	50
W_0^ϕ	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 productivity (capital good)	1

Table 2: Parameters setting: parameter values

Parameter	Description	Value[a]
ϵ^U	Wage curve unemployment elasticity	*0.1*
ϵ^P	Wage curve inflation elasticity	*0.5*
ϵ^A	Wage curve productivity elasticity	*0.1*
Ω^A	Increase in average productivity for a wage renegotiation to occur	0.05
Ω^P	Increase in average price for a wage renegotiation to occur	0.05
d	Smoothing parameter in the computation of the moving averages	*0.05*
C^L	Beveridge curve constant	*0.2*
β	Beveridge curve parameter	*6*
min_x	minimum quality level	**98**
max_x	maximum quality level	**102**
a^s	Speed of adaptation of sales expectations	*0.9*
$\bar{s}$	Desired ratio of inventories	*0.1*
u^l	Unused labour capacity	0.05
u^k	Unused capital capacity	0.05
$\bar{\mu}$	Markup	**0.2**
δ	Capital depreciation	0.001
$\frac{1}{B}$	Capital intensity	0.4
ϵ_L	Labour market friction (final firms)	*0.9*
ω	Minimum wage multiplier	1.11
b	Executives wage multiplier	***2***
ν	Tier multiplier	*5*
γ	Smoothing parameter	0.8
$\underline{i}_{z,n,m}$	Param: Minimum quality threshold	*500; 10*
$\varsigma \cdot i_{n,m}$	Variance in the consumers evaluation of characteristics	0.05; 0.1
δ_{ς}	τ inter-class multiplier	0.2
$\underline{\upsilon}$	minimum tolerance level	***0.1***
$\overline{\upsilon}$	maximum tolerance level	***0.9***
$\upsilon_{1,\tilde{2}}$	first tier income class tolerance toward the quality characteristic	***0.1***
$\upsilon_{1,\tilde{1}}$	first tier income class tolerance toward the price characteristic	***0.9***
z	Parameter innovation probability	10000
σ^a	Standard deviation productivity shock	**0.01**
ρ^k	R&D investment share	0.7
μ^k	Markup (capital firm)	0.5
ω^k	Wage multiplier in the capital sector	**1**
ϵ_M	Labour market friction (capital firms)	*0.9*
u^m	Unused labour capacity in the capital sector	0.2
$\bar{A}^k$	Labour productivity (capital firm)	1
ν^k	tier multiplier (capital firm)	**5**
ω^E	Engineer's wage multiplier	1.5

[a]Parameters that are set to average observable values are in *italics*, and parameters that are analysed in Section 4.4, are in **bold**