INSTITUTE
OF ECONOMICS

Scuola Superiore
Sant'Anna

LEM | Laboratory of Economics and Management

Institute of Economics
Scuola Superiore Sant'Anna

Piazza Martiri della Libertà, 33 - 56127 Pisa, Italy
ph. +39 050 88.33.43
institute.economics@sssup.it

LEM

WORKING PAPER SERIES

The role of technology, organisation, and demand in growth and income distribution

Tommaso Ciarli [¶]
André Lorentz [o]
Maria Savona [§]
Marco Valente*

[¶] Max Planck institute of Economics, Jena, Germany
[o] RECITS, Universite de Technologie de Belfort-Montbeliard and BETA (UMR-CNRS 7522), France
[§] SPRU, University of Sussex, UK
* University of L'Aquila, Italy, and LEM, Pisa, Italy

2012/06 **March 2012**

ISSN (online) 2284-0400

The role of technology, organisation, and demand in growth and income distribution*

Tommaso Ciarli,† André Lorentz,‡ Maria Savona,§ Marco Valente¶

Tuesday 31st January, 2012

Abstract

The paper proposes a model that explains cross-country growth divergences over time for different aspects of structural change. The model formalises the links between production technology, firm organisation (functional composition of employment) on the supply side and the endogenous evolution of income distribution and consumption patterns on the demand side. Wage distribution is the main channel between the organisation of firms and consumption patterns, and firm selection is the main trigger of investment in new capital, productivity gains and cumulative growth. The model is able to reproduce empirical stylised facts on growth and income inequality associated with different stages of growth. We use VARs to estimate the causal relations between the three aspects of structural change. We then analyse the effect of the parameters that define the structure of an economy – and the way in which this unfolds through time – on growth and income distribution via numerical simulation. Product variety, differences in consumption preferences, organisational complexity and production technology determine whether the economy experiences a take-off or a stagnating growth, and the associated distribution of income.

Keywords: Structural change; growth; income distribution; consumption; technological change
JEL: O41, L16, C63, O14

*The paper benefited from comments and suggestions on this or previous versions from U. Witt, G. White, B. Verspagen, E. Steinmuller, W. Semmler, A. Secchi, P.P. Saviotti, G. Porcile, L. Marengo, D. Fiaschi, G. Fagiolo, G. Dosi, P.S. Ciarli, F. Castellacci and T. Barker, and from participants in the DIME Workshop on 'Markets and Firms Dynamics: from micro patterns to aggregate behaviors,' LEM Pisa, and ERMES Paris, the 'International Conference on Developments in Economic Theory and Policy,' University of Bilbao, the 'Fourth Annual Conference on Economic Growth and Development,' Indian Statistical Institute, the 'The Role of Consumption for Structural Change in the Economy' Workshop, MPI Jena, and seminar at SPRU, University of Sussex. We acknowledge financial support from the European Commission 6^{th} FP (Contract CIT3-CT-2005- 513396), project DIME - Dynamics of Institutions and Markets in Europe WP 3. We are indebted to the above-mentioned for improvements to the paper. All remaining errors are our own.

†Max Planck Institute of Economics, Jena, Germany, ciarli@econ.mpg.de

‡RECITS, Université de Technologie de Belfort-Montbéliard and BETA (UMR-CNRS 7522), France, andre.lorentz@utbm.fr

§SPRU, Science and Technology Policy Research, University of Sussex, UK; M.Savona@sussex.ac.uk

¶University of L'Aquila, and LEM, Pisa, Italy, marco.valente@univaq.it

1 Introduction

World economies have experienced dramatic cross-country growth divergencies over the past two centuries (Maddison, 2003; Hulten, 2009). Since the seminal work of Solow (1957), growth accounting exercises have shown that production factors alone can explain only part of these growth patterns and of the within-country variation in inequality associated with different growth stages (Denison, 1967, 1979; Maddison, 1987; Barro, 1991; Durlauf and Quah, 1998).

We argue that many of the candidate explanatory factors of diverging long-term growth patterns are related to the initial conditions that define the structure of an economy and the way in which this unfolds through time. We define structural change as in Matsuyama (2008): "[...] complementary changes in various aspects of the economy, such as the *sector compositions of output and employment*, the *organization of industry*, the *financial system*, *income and wealth distribution*, *demography*, political *institutions*, and even the society's *value system*" [p 1].[1] We focus on three particular aspects of the economy: production technology, the organisation of production and the composition of output. Indeed, changes in these aspects of the economy have a dramatic impact on output growth.

For instance, Hulten (1992) finds that an important part of the change in Total Factor Productivity (TFP) that followed the growth of the manufacturing industry 1949-1983 in the US is determined by embodied technological change ("investment-specific technological change"). Greenwood et al. (1997) calibrate a general equilibrium capital vintage model and show that "investment-specific technological change" explains most of the growth in labour productivity. And Cummins and Violante (2002) find that the speed of technical change in equipment and software capital goods explains "20% of growth in the United States in the postwar period and about 30% of growth in the 1990s". On the second aspect, von Tunzelmann (1995) explains the economic growth that followed the industrial revolution in Britain, the US and Japan on the basis of the changes in the organisation of production. While Desmet and Parente (2009) show how growth in firm size that followed the industrial revolution in England and the US.[2] On the third aspect, Funke and Ruhwedel (2001); Economic Commission for Europe (2004) show that countries with a higher level of per capita income are characterised by a larger variety of available goods (or a larger number of markets, as expressed by Desmet and Parente (2009)) and have a more complex production/export structure (Hidalgo and Hausmann, 2009). While Falkinger and Zweimüller (1996) and Falkinger and Zweimüller (1997) show that product variety is positively related to income and to the equality of its distribution.

In this paper we model these three aspects of structural change and their interactions, where exogenous parameters define the structure of an economy and the way in which this unfolds through time. The model has two types of firms: capital and final good producers. Both types of firm have a hierarchical structure of workers and managers, forming classes of consumers with different preferences. Production technology is captured by the speed

[1] Emphasis by the authors.

[2] According to Sokoloff (1984), such a transformation is not found only in mechanised industries.

at which capital good firms increase the productivity of new capital vintages and sell them to final good firms. The organisation of production is modelled as the number of tiers of executives necessary to manage a firm (and therefore its size) and the difference in earnings among organisational tiers. Finally, the initial variance of the distribution of products' quality and price measures the composition of production, and the variance of the preferences of different earning classes measures the composition of demand.

In the model, the interaction between the three aspects of structural change works as follows: for a given rate of investment, the larger is the increase in the productivity of capital vintages which are incorporated in the production process of final good firms, the higher is the growth of firm productivity. An increase in firm productivity leads to an increase in the relative demand for its good (via a price reduction). The increase in firm sales is followed by organisational changes toward larger production units and a higher number of management levels, and higher investment.[3] The increase in the number of organisational layers induces the formation of new consumption classes with different preferences for the goods' quality and price. For large earnings disparities this also leads to a higher purchasing power of the new classes and higher inequality.

We analyse the parameters that control the three aspects of structural change using numerical simulations. The remaining parameters are initialised with reference to empirical evidence.

The main findings identify a number of stylised facts that characterise (and explain) patterns of growth at different stages of the development cycle, from initial industrialisation to post-industrial stagnation: (i) Output growth is lessened by a high initial variety of products and demand; (ii) A larger increase in organisational complexity (firm size and number of organisational layers) coupled with faster technological change in capital goods leads to higher productivity and output growth despite being conducive of earning disparities and higher income inequality;[4] (iii) At the same time, large earning disparities, coupled with intermediate levels of organisational complexity, lead to large income inequality and to lower output growth.

A number of models study the relation between changes in some aspect of the economy and income growth. Models in the post-Keynesian tradition focus on the changes that take place at the sectoral level (e.g. Pasinetti, 1981; Sirquin, 1988; Cornwall and Cornwall, 1994; Kurz and Salvadori, 1998; Cesaratto et al., 2003). A second group of models focus on product innovation taking place in a final good sector as a function of changes in the structure of demand, where preferences change with income (Aoki and Yoshikawa, 2002; Föllmi and Zweimüller, 2008; Matsuyama, 2002). Some of these contributions analyse the relation between income distribution and growth based on the change in demand for differ-

[3] We are aware of the relevance of less hierarchical forms of organisation, such as market-based vertical relations and intermediate forms, extensively studied in the economic geography literature on clusters, districts, industrial poles and so on. However, in 2005 97.6% of US firms with less than 100 employees accounted for 38% of the total employment (Bureau of Labour Statistics, 2005).

[4] Although the latter result may be counterintuitive with respect to industrialised countries, there is a large body of literature showing an increase in inequality during the first phase of transition from low to middle income.

entiated goods. Models in the evolutionary tradition (Nelson and Winter, 1982) focus on process innovation: some contributions model technical change as ‘quasi-vintages’ (Silverberg and Verspagen, 1994b,a); others consider disembodied technical change and variation in labour productivity (Chiaromonte and Dosi, 1993; Dosi et al., 1994b), representing a two-sector economy – capital goods and consumer goods. More recently, Saviotti and Pyka (2008) propose models in which they interpret development as the creation of new sectors: they show that a larger variety of goods leads to higher economic growth. The unified growth theory (UGT) models explicitly study the transformation from a stagnant agricultural economy to a rapidly growing industrial economy, typically referring to the industrial revolution in England (Desmet and Parente, 2009; Galor, 2010; Lagerlöf, 2006; Stokey, 2001; Voigtländer and Voth, 2006). Some of these models focus on human capital formation changes in population growth and capital investment (Galor, 2010; Voigtländer and Voth, 2006, e.g.), while others focus on the joint change of consumer goods and firm size (Desmet and Parente, 2009). Finally, the new political economy models, (e.g. Acemoglu and Johnson, 2005; Acemoglu and Robinson, 2006; Adam and Dercon, 2009) focus on the institutional aspects of structural change, analysing the relation between political transition (*de facto* political power) and economic transition. Some of the contributions focus on the role of institutions in determining the organisation of production Greif (2006).

Our model abstracts from institutional dynamics but shares elements with the first four groups of models: the relation between the supply and the demand side of structural change, the evolutionary behavioural assumptions, and the long-term analysis of the UGT, particularly in its attempt to integrate different phases of growth. We depart form these models and add to the literature in the following respects.

First, to our knowledge, this is the first model that attempts to link and the analyse the interactions between technology, organisation, functional distribution of employment and consumer behaviour. Second, we make extensive use of micro foundations to model these interactions. To do so, we follow the recent advances in the study of macro economic dynamics that convincingly show the relevance of including in macro models the careful consideration of heterogeneous human agents’ behaviour (Akerlof and Shiller, 2009), and “non-routine decision making and unforeseeable changes in the social context within which individuals make decisions” (Frydman and Goldberg, 2007, citing from Phelps’s Foreword on page xviii). Third, our model is closely related to the recent attempts to study macro economic policies in an agent-based framework using insights form the Schumpeterian and Keynesian traditions (Dosi et al., 2010). In line with Dosi et al. (2010), we take a step forward with respect to the neo-Keynesian micro foundations as well as relax the assumption of the ability of economic agents to optimise, which is close to the works of, among others, Arifovic et al. (1997), Deissenberg et al. (2008), Kinsella et al. (2010), and some contributions in Dawid and Fagiolo (2008).

Our contribution can be understood as a bridge between the Schumpeterian literature, the structuralist literature, and agent-based models that address both economic agents’ transactions and “the nature of their interactions with each other and with their environment" (Howitt, 2006, p. 4).[5] For a broader overview of agent-based models in economics, we refer the reader to the special issues edited by Tesfatsion (2001), while recent discussions on the advantages of agent-based models for the study of macro economic phenomena can be found in Leijonhufvud (2006), Buchanan (2009), Farmer and Foley (2009), Dawid and Neugart (2010), Delli Gatti et al. (2010), Delli Gatti et al. (2011) and the special issue by Dawid and Semmler (2010).

The next section 2 provides a detailed description of the model and its dynamics. Section 3 briefly shows how the model replicates empirical stylised facts and explains the main mechanisms behind these benchmark results. We then analyse and discuss the impact of the parameters determining the three aspects of structural change on growth and distribution via numerical simulations (Section 4), concluding with a brief discussion and summary of our contribution (Section5). Appendix A provides details on the model sensitivity to randomness.

2 The model

At first, we provide an overview of the main components of the model and its dynamics and then describe the model in greater detail, paying particular attention to the empirical literature supporting the mechanisms modelled.

2.1 Agents, markets and dynamics

Our economy is composed of three sectors. First, a final good sector populated by firms indexed $f \in \{1; 2; ...F\}$ that serve final demand. Each firm produces a single good with a competing technology defined by quality ($i_{2,f} \sim U[\underline{i_{2,f}}, \overline{i_{2,f}}]$) and price ($i_{1,f}(t)$). Firms use a stock of different capital goods and a labour force hierarchically structured in workers and managers. Each manager coordinates a number of subordinate workers and managers: the lower this number, the larger and more *complex* the firm's organisation in terms of the number of layers. Organisational structure translates into a hierarchical structure of wages, which determines both the distribution of earnings across consumers and a firm's production costs (Brown and Medoff, 1989; Criscuolo, 2000; Bottazzi and Grazzi, 2007).

Second, a capital good sector populated by firms indexed $g \in \{1; 2; ...; G\}$. Each firm produces a single capital good with a specific embodied level of productivity. The only source of technological change and productivity gains in the final good sector – and in the economy as a whole – is innovation in the capital sector, which improves the technology and embodied productivity of capital goods. Innovation is funded by available profits and carried out by a specific class of workers, the 'engineers'. Capital good firms' only input is labour – again hierarchically structured.

Third, a household sector populated by workers/consumers pertaining to income classes indexed $z \in \{1; 2; ...; \Lambda(t)\}$. Each class is characterised by the available income and the

[5] See also Colander et al. (2008) and LeBaron and Tesfatsion (2008).

preferences on the characteristics of the final good. Preferences are assumed to be lexicographic. The available income reflects firms' hierarchical organisation in tiers.

Agents interact in three *non-Walrasian* markets (Colander et al., 2008; Dosi et al., 2010): in the final good market households spend part of their income to buy products from final good firms. Supply is constrained by a firm's production capacity and demand depending on households' available income. In terms of simulation steps, households first select firms matching their lexicographic preferences with a given demand and purchase goods from firms inventories, defining current sales. Second, final good firms align production decisions to current demand and unsold inventories in an attempt to clear the market: production takes place. Third, they estimate the demand for labour and new capital investment for the following period, based on the current disequilibrium between demand and available production capacity. Fourth and last, the difference between sales and production defines the future level of inventories. These are used by firms to estimate their expected demand at the next period.

In the intermediate good market final good firms acquire capital goods to expand their production capacity. Again, in terms of simulation steps, capital good firms start producing a new capital good only when they receive an order from final good firms. These choose a capital good firm stochastically, following a probability function that depends on the characteristics of the capital good (price and embodied productivity) and on the waiting list; the time lag to build a new capital good depends on the capital good firm's production capacity. In turn, capital good firms estimate their labour demand based on the current mismatch between the sum of orders and their available capacity. Finally, depending on their profits, capital good firms might devote financial resources to the recruiting of new engineers to innovate and produce a new capital vintage to be available in the following period.

Third, the model represents a labour market, where the demand linearly depends on firms' sales. We assume no labour shortages in the long run and short-term inertia. In this market, the level of unemployment is determined as a function of firms' vacancies following a Beveridge curve. Along with inflation and productivity, unemployment affects the minimum wage.

Both the final and capital good markets are imperfectly competitive. In line with several recent contributions (Solow, 2008; Dosi et al., 2010), we assume persistent disequilibrium and no market clearing due to a non-coordinated demand of heterogeneous consumers and adaptive *incorrect* expectations (Phelps, 2007) of heterogeneous firms. As in (Dosi et al., 2010, p.1749), "the model meets Solow (2008) plea for micro-heterogeneity: a multiplicity of agents interact without any ex-ante commitment to the reciprocal consistency of their actions". Agents therefore take their decisions on the basis of adaptive behavioural rules and do not necessarily optimise, though they may well reach - as in (Gintis, 2007) - a Walrasian equilibrium if environmental conditions are stable. However, in a model of persistent structural change at the micro level, as defined by Matsuyama (2008), environmental conditions are, by definition, not stable over time, and an equilibrium can not be reached.[6]

2.2 Final Good Sector

2.2.1 Production

A final-good firm $f \in \{1; 2; ...F\}$ produces a single product.[7] Similarly to Chiarella (2000, Ch. 2), production is planned given current expected sales $Y^e(t)$. These are a convex combination of past expected sales $Y^e(t-1)$ and actual demand faced in $t-1$ ($Y_f(t-1)$):

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

We assume a sticky adaptation in sales expectations (a^s) to short-term cycles. Following Blanchard (1983) and Blinder (1982), production smoothing is realised through inventories $\left(\bar{s}Y^e_f(t)\right)$:[8] production decision $\left(Q^d_f(t)\right)$ is revised to adjust to changes in the expected demand $\left(Y^e_f(t)\right)$ and existing inventories ($S_f(t-1)$):

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

where:[9]

$$S_f(t) = S_f(t-1) + Q_f(t) - Y_f(t) \tag{3}$$

Output depends on the production capacity of the firm in terms of labour $L^1_f(t-1)$ and capital stock $K_f(t-1)$:

$$Q_f(t) = \min\left\{Q^d_f(t); A_f(t-1)L^1_f(t-1); D_f K_f(t-1)\right\} \tag{4}$$

where $A_f(t-1)$ is the labour productivity embodied in the capital vintages and D_f is the fixed capital intensity ratio.[10] Labour productivity depends on firm's investment in capital while the available capital is limited by its suppliers production capacity (see below).

[6] Interestingly(Saviotti and Gaffard, 2008, p.115) define structural change in a way which is similar to Matsuyama: an economy's structure is defined in terms of its components and 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." And they conclude, "What does it mean for a system to be in equilibrium when its composition keeps changing due to the emergence of qualitatively different entities?"

[7] Goods are defined as a vector of characteristics, which satisfy a user's needs in line with the Lancasterian (Gorman, 1959; Lancaster, 1966) approach to consumer theory. The rationale of this choice is made explicit in Section 2.4.

[8] We assume adaptive expectations instead of rational expectations. Here we assume an inventory/sales ratio which corresponds to the minimum of the observed values (e.g., Bassin et al., 2003; U.S. Census Bureau, 2011) to avoid level effects that may be linked to the accumulation of inventories and to reduce the propagation of business cycles.

[9] Inventories are allowed to be negative. In this case, they equate to unfulfilled demand or backlogs.

[10] In line with large empirical evidence, starting from the seminal work by Kaldor (1957), we assume fixed capital intensity.

2.2.2 Organisation

The organisation of firms is defined both in terms of the number of hierarchical tiers of workers and managers and the wage differences across tiers (Simon, 1957; Lydall, 1959; Waldman, 1984; Abowd et al., 1999; Prescott, 2003). For a given number of workers $L_f^1(t)$, firms hire workers to manage production. Every batch of ν second-tier workers requires a third tier of managers $L_f^2(t)$. Each batch of ν l-tier workers requires a $l+1$ tier of managers $L_f^{l+1}(t)$. The number of workers in each tier l is then a function of $L_f^1(t)$: $L_f^l(t) = \nu^{1-l} L_f^1(t)$ and the total number of workers is:

$$L_f(t) = \sum_{l=1}^{\Lambda_f(t)} L_f^l(t) = L_f^1(t) \sum_{l=1}^{\Lambda_f(t)} \nu^{1-l} \tag{5}$$

where Λ_f is the total number of tiers required to manage the firm f,[11] and the number of 'productive' labour in the first tier depends on production plans plus an unused labour capacity (u^l) – which insures against unexpected labour shortages:[12]

$$L_f^1(t) = \epsilon L_f^1(t-1) + (1-\epsilon)\left[\left(1+u^l\right)\frac{min\{Q_f^d(t); D_f K_f(t-1)\}}{A_f(t-1)}\right] \tag{6}$$

The labour market is assumed to be inertial, where ϵ_L represents labour market rigidities, but unconstrained.[13]

2.2.3 Capital and Investments

The capital stock of a firm, where $V_f(t)$ indicates the number of capital vintages acquired, $k_{h,f}$ and τ_h the amount of capital and date of purchase of vintage h, respectively, is computed as:

$$K_f(t) = \sum_{h=1}^{V_f(t)} k_{h,f}(1-\delta)^{t-\tau_h} \tag{7}$$

where δ is the depreciation rate.[14] The level of productivity embodied in the capital stock is computed as the average productivity across all vintages available:

$$A_f(t) = \sum_{h=1}^{V_f(t)} \frac{k_{h,f}(1-\delta)^{t-\tau_h}}{K_f(t)} a_{g,\tau_h} \tag{8}$$

[11] The increase in the number of tiers is discrete. The total number of tiers $\Lambda_f(t)$ can be approximated by:

$$\Lambda_f(t) = \frac{ln\left(L_f^1(t)\right)}{ln(\nu)} + 1$$

[12] Labour constraint on production is only determined by first tier workers and their productivity. Executives are required to organize production.

[13] We do not assume an infinitely elastic labour supply curve, as explained in Ciarli et al. (2010).

[14] The benchmark value of the one-period depreciation rate has been conservatively set following standard estimates (Hulten and Wykoff, 1981; Fraumeni, 1997).

where a_{g,τ_h} is the productivity embodied in the h vintage. Given the expected output the desired amount of new capital (expressed in production units) is:

$$k^e_f(t) = (1+u)\frac{Y^e_f(t)}{D_f} - K_f(t-1) \tag{9}$$

where u is the required percentage of unused stock.

If $k^e_f(t)$ is positive, the firm selects one of the capital producers $g \in \{1;...;G\}$ and places a corresponding order $k^d_{g,f}(t)$. The probability to select a certain capital good firm g increases with the embodied productivity ($a_{g,t-1}$) of its product, and decreases with its price ($p_{g,t-1}$) and the waiting time to deliver the new capital, relative to the average in the capital sector. The actual delivery takes place after one or more steps, depending on the capital supplier's production capacity. The final good firm f has to delay any new capital investments until the demanded capital good is delivered. Once delivered, firm f introduces the new capital vintage into its capital stock: $k_{h+1,f} = k^d_{g,f}(t)$. The level of investment of firm f in t is then given by:

$$R^I_f(t) = p_g(t-1)k^d_{g,f}(t) \tag{10}$$

2.2.4 Wages, prices and profits

As mentioned earlier, the complexity of firms' hierarchical organisation exponentially affects the structure of wages (Rosen, 1982). First-tier wages are set by firms as a fixed multiple ω of the minimum wage $w_m(t-1)$: $w^1_f(t) = \omega w_m(t-1)$. As we move upstream in the organisational hierarchy, the wages increase by a tier multiplier b, which determines the skewness in the wage distribution:[15]

$$w^l_f(t) = b^{l-1} w^1_f(t) \tag{11}$$

Firms set prices following a markup rule:[16]

$$p_f(t) = (1+\bar{\mu})c_f(t) \tag{12}$$

[15]Income distribution is therefore a direct outcome of industrial and labour structure (Aghion et al., 1999). We depart from the view that wage distribution strictly depends on labour skills and skill-biased technical change (Tinbergen, 1975), taking on board the convincing evidence that wages are determined by the composition of production at the macro level (Galbraith et al., 1999; Galbraith, 1999) and the organisation of production at the micro level (Caroli and Van Reenen, 2001; Prescott, 2003; Atkinson, 2007).

[16]This assumption is supported by empirical evidence dating back to Hall and Hitch (1939) and, more recently, to Blinder (1991) and Hall et al. (1997). For a recent review of price-setting behaviour in the euro area, see Fabiani et al. (2006).

where we approximate unit variable costs as:[17]

$$c_f(t) = \frac{w_f^1(t-1)}{A_f(t-1)} \sum_{l=1}^{\Lambda_f(t-1)} b^{l-1} \frac{\nu^{1-l}}{\sum_{l=1}^{\Lambda_f(t-1)} \nu^{1-l}} \tag{13}$$

Profits equate to the difference between the value of sales and total variable costs:

$$\pi_f(t) = p_f(t-1)Y_f(t) - \sum_{l=1}^{\Lambda} w_f^l(t)L_f^l(t) \tag{14}$$

In addition to their wages, managers are paid wage premia $\psi_f^l(t)$ that we interpret as profit shares.[18] These shares are paid out of the residual profits cumulated through time when not employed for capital investment, $R_f^D(t) = \sum_{\tau=0}^{t-1} \pi_f(\tau) - \sum_{\tau=0}^{t-1} R_f^I(\tau) - \sum_{\tau=1}^{t-1} R_f^D(\tau)$:

$$\psi_f^l(t) = \frac{b^{l-1}}{\sum_{l=2}^{\Lambda_f(t)} b^{l-1}} R_f^D(t) \ \forall l \in \{2; ...; \Lambda_f(t)\} \tag{15}$$

2.3 Capital sector

2.3.1 Production and organisation

Capital goods are produced by firms $g \in [1; ...; G]$. Each firm produces a single vintage τ of capital at a time. Each capital good produced by a firms g is characterised by its embodied productivity $a_{g,\tau}$ and price $p_g(t)$. Production plans for capital good firms $K_g^d(t)$ aim to meet current clients' orders $k_{g,f}^d(t))$ and the remaining outstanding orders from previous periods $U_g(t-1)$:

$$K_g^d(t) = \sum_{f=1}^{F} k_{g,f}^d(t) + U_g(t-1) \tag{16}$$

Capital good firms' only input is labour, for which we assume constant returns to scale:

$$Q_g(t) = min\left\{K_g^d(t); L_g^1(t-1)\right\} \tag{17}$$

We assume that the production of capital is just-in-time, with no expectation formation or accumulation of stocks of unsold capital.[19] The orders are covered following a 'first in first out' rule: unfulfilled orders $U_g(t-1)$ are produced before current demand. Changes

[17] The tier–wage structure of variable costs implies diseconomies of scale in the short run in line with evidence that labour cost is higher for large firms (Idson and Oi, 1999; Criscuolo, 2000; Bottazzi and Grazzi, 2007). In the long run, productivity gains through the accumulation of capital vintages overcome these diseconomies of scale, generating dynamic increasing returns.

[18] This assumption is justified by the empirical evidence provided in Atkinson (2007), who argues that the exponential structure of wage-tier increase is not sufficient to explain the skewness in earnings distribution.

[19] The assumption of just-in-time production is corroborated by the empirical evidences provided in Doms and Dunne (1998) and Cooper and Haltiwanger (2006).

in the level of the unfulfilled orders depend on production capacity and demand:

$$U_g(t) = max\left\{K_g^d(t) - L_g^1(t-1); 0\right\} \tag{18}$$

Capital good firms' organisation is modelled symmetrically to the one in the final good sector. For every batch of ν subordinates, firms hire one executive to coordinate their work. The total number of workers can then be expressed as:

$$L_g(t) = \sum_{l=1}^{\Lambda_g(t)} L_g^1(t)\nu^{1-l}. \tag{19}$$

where ν is assumed to be equal for both sectors.

The number of productive workers $L_g^1(t)$ hired depends on the level of output $K_g^d(t)$ and the unused labour capacity u^m:

$$L_g^1(t) = \epsilon L_g^1(t-1) + (1-\epsilon)\left[\left(1+u^l\right)K_g^d(t)\right] \tag{20}$$

where the convex combination reflects rigidities on the labour market.

2.3.2 R&D and innovation in capital vintages

As is usually the case in Schumpeterian growth models (Aghion and Howitt, 1998; Silverberg and Verspagen, 2005; Dosi et al., 2010), innovation follows a stochastic process with some probability distribution, depending on the resources invested. The productivity embodied in the capital goods is the result of uncertain firm's R&D activity (Nelson and Winter, 1982). Formally, R&D investments are represented by an increase in the number of research engineers employed by the firm $L_g^E(t)$ (Llerena and Lorentz, 2004). This affects the probability of succeeding in innovation:

$$P_g(t) = 1 - e^{-\zeta L_g^E(t-1)} \tag{21}$$

Firms devote a share ρ of their cumulated profits to employ new engineers. The number of engineers to be employed should, however, not exceed a ratio ν^E of the firm's productive labour force $L_g^1(t)$:

$$L_g^E(t) = min\left\{\nu^E L_g^1(t); \rho\left(\sum_{\tau=1}^{t}\pi_g(\tau) - \sum_{\tau=1}^{t-1}R_g^D(\tau) - \sum_{\tau=1}^{t-1}w_g^E(\tau)L_g^E(\tau)\right)\right\} \tag{22}$$

If the R&D activity is successful, the productivity embodied in the newly developed capital vintage is a random process that depends on the outcome of past R&D efforts, in line with the concept of 'local search' (Nelson and Winter, 1982):

$$a_{g,\tau} = a_{g,\tau-1}\left(1 + max\{\varepsilon_g(t); 0\}\right) \tag{23}$$

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

2.3.3 Wages, prices and profits

Symmetrically to the final good sector, prices of capital goods are set according to a markup rule μ_g on unit variable costs (labour), including also wages of the engineers:

$$p_g(t) = (1+\mu_g)\left(w_g^1(t)\sum_{l=1}^{\Lambda_g(t-1)} b^{l-1}\frac{\nu^{1-l}}{\sum_{l=1}^{\Lambda_g(t)}\nu^{1-l}} + \frac{w_g^E(t)L_g^E(t-1)}{L_g^1(t-1)}\right) \tag{24}$$

The wage structure replicates the final good firm's structure: as we move upstream in the hierarchy, the wage increases by a given multiplier b. We assume no hierarchy for engineers' wage $w_g^E(t)$, who are paid as a multiple ω^E of the minimum wage $w_m(t-1)$:

$$w_g^l(t) = \omega^k w_m(t-1)b^{l-1} \tag{25}$$

$$w_g^E(t) = \omega^E w_m(t-1) \tag{26}$$

Profits are cumulated either to be redistributed as dividends and bonuses $R_g^D(t) = (1-\rho)\left(\sum_{\tau=1}^{t}\pi_g(\tau) - \sum_{\tau=1}^{t-1}R_g^D(\tau) - \sum_{\tau=1}^{t-1}w_g^E(t)L_g^E(\tau)\right)$ or to recruit new engineers (Eq 22):

$$\pi_g(t) = p_g(t)Q_g(t) - \sum_{l=1}^{\Lambda_g(t)}\omega^k w_m(t)L_g^1(t)\left(\frac{b}{\nu}\right)^{l-1} - w_g^E(t)L_g^E(t) \tag{27}$$

The bonus distribution scheme is similar to the one for final good firms:

$$\psi_g^l(t) = \frac{b^{l-1}}{\sum_{l=2}^{\Lambda_g(t)} b^{l-1}}R_g^D(t)\ \forall l \in \{2;...;\Lambda_g(t)\} \tag{28}$$

2.4 Households

2.4.1 Income distribution

A consumer class z is defined as the class of workers in a given tier l within the firm's organisational structure. The income available to each class z is the sum of both wage and profit shares paid to the corresponding worker tier:

$$W_z(t) = \sum_{f=1}^{F}w_f^l(t)L_f^l(t-1) + \sum_{f=1}^{F}\psi_f^l(t) + \sum_{g=1}^{G}w_g^l(t)L_g^l(t-1) + \sum_{g=1}^{G}\psi_g^l(t) \tag{29}$$

Substituting in the previous equations the equation for the structure of wages (11 and 26), labour (5 and 19) and dividends (15 and 28), we obtain the following expression:

$$W_z(t) = w_m(t-1)\left(\frac{b}{\nu}\right)^{z-1}\left[\omega\sum_{f=1}^{F}L_f^1(t-1) + \omega^k\sum_{g=1}^{G}L_g^1(t-1)\right] + \left[\sum_{f=1}^{F}\frac{R_f^D(t)}{\sum_{l=2}^{\Lambda_f(t)}b^{l-1}} + \sum_{g=1}^{G}\frac{R_g^D(t)}{\sum_{l=2}^{\Lambda_g(t)}b^{l-1}}\right]b^{z-1} \tag{30}$$

where the minimum wage $w_m(t)$ is set at the macro–economic level (e.g. Boeri, 2009). We assume the wage setting to be linked to three main macro-economic dynamics: (i) labour productivity growth, to keep the pace of labour value contribution; (ii) consumer prices, to insure a long-run stability of purchasing power; and (iii) employment level, to keep track of labour market dynamics in the negotiations (efficiency wages, corporatism or bargaining).The formalisation of minimum wage dynamics proposed here is equivalent to a wage curve (Blanchflower and Oswald, 2006; Nijkamp and Poot, 2005) with outward shifts that follow increases in aggregate productivity and consumer prices. While we derive the unemployment level from a Beveridge curve, with the rate of vacancies endogenously determined by firms' demand of new labour (Börsch-Supan, 1991; Nickell et al., 2002; Yashiv, 2007).[20]

2.4.2 Consumption

The distribution of income across classes and consumer preferences over the good's characteristics define the demand curve and a firm's output share. Aggregate demand is then determined endogenously by the expenditure and income of consumption classes. Consumer spending is driven by long-term consumption smoothing (Krueger and Perri, 2005): the consumed income is a linear combination of past consumption and current income:[21]

$$C_z(t) = \gamma C_z(t-1) + (1-\gamma)\, W_z(t) \tag{31}$$

As mentioned in section 2.1, interdisciplinary evidence and theories on consumption (Valente, 1999; Swann, 1999; Witt, 2008; Babutsidze, 2007) and satisfying behaviour (Shafir et al., 1993; Gigerenzer, 1997), have established that consumers rank goods with respect to their relative position rather than their absolute value using lexicographic preferences. Consumers/workers classes $z \in [0; \Lambda]$ are first divided in $h_z(t) \in [1; H_z]$ consumer *samples*, each of which undergoes a purchase routine with symmetric random variations. The disposable income of each of these samples is $\frac{C_z(t)}{H_z}$. We then implement an algorithm based on lexicographic preferences.[22] Once the available products have been ordered according to their perceived quality $\hat{i}_{2,f,h_z}(t)$ and price $\hat{i}_{1,f,h_z}(t)$, the consumer is indifferent between products that are equivalent to the product perceived as the best in the market.[23]

Consumer's preferences across classes are represented by a 'tolerance level' $v_{j,z} \in [0; 1]$ that measures the maximum shortfall value of each perceived characteristic $\hat{i}_{j,f,h_z}$ with

[20] A formal representation of macro dynamics is left out of this paper for the sake of readability and can be found in Ciarli et al. (2010).

[21] Savings of a consumer in period t derive from non-consumed income due to consumption smoothing and/or the unavailability of goods satisfying consumer needs. For the sake of simplicity, we assume that savings are used to smooth the effect of income reduction to fit equation 31 and are not used to fund firms' investments. We leave the introduction of a financial market to further extensions of this model.

[22] The purchasing routine we adopt is borrowed from the literature on experimental psychology, implementing a bounded rational algorithm featuring the properties of empirically observed behaviours (Shafir et al., 1993; Gigerenzer, 1997; Gigerenzer and Selten, 2001).

[23] See for example Dawar and Parker (1994) and reference therein: "With neither infinite time horizons nor the incentive to perform thorough comparative studies prior to purchase, consumers are likely to rely on heuristics to gauge quality across competitive products" [p. 83].

respect to the best perceived product ($max_f \left\{\hat{i}_{j,f,h_z}\right\}$). An exceedingly high tolerance (low $\upsilon_{j,z}$) means that the consumer is indifferent between a large range of products with respect to characteristic j, while when the tolerance tends to 0 the consumer purchases only from the best firm for a given characteristic $j \in \{1;2\}$. We assume that consumers working in the first tier are almost indifferent toward quality $\left(\upsilon_{2,1} = \upsilon^{min} = 0.1\right)$ and strictly prefer low price goods ($\upsilon_{1,1} = \upsilon^{max} = 0.9$). As we move upwards in the tiers/consumption classes (as z increases), the tolerance toward price differences increases, while the quality tolerance reduces by a multiplier δ^{υ}: $\upsilon_{2,z+1} = (1-\delta_{\upsilon})\upsilon_{2,z} + \delta_{\upsilon}\upsilon^{max}$ and $\upsilon_{1,z+1} = (1-\delta_{\upsilon})\upsilon_{1,z} + \delta_{\upsilon}\upsilon^{min}$.[24]

More formally, for each consumer sample h_z within each class z, the purchasing algorithm is described as follows. First, consumers perceive the value $\hat{i}_{j,f,h_z}(t)$ for each of the characteristics $j = \{1;2\}$:

$$\hat{i}_{j,f,h_z}(t) \sim N\left(i_{j,f}, \varsigma i_j\right) \tag{32}$$

with an observational error with variance ςi_j.[25] Second, consumers short-list a subset of firms $\hat{F}_{h_z}(t)$ with a good matching their preferences:

$$\hat{F}_{h_z}(t) \mid (1-\upsilon_{j,z})max_f \left\{\hat{i}_{j,f,h_z}(t)\right\} > |\hat{i}_{j,\hat{f},h_z}(t) - max_f \left\{\hat{i}_{j,f,h_z}(t)\right\}| \; \forall f \in F; \forall j = \{1;2\} \tag{33}$$

Third, purchases are equally spread among the products short listed. The level of sales of each firm for a given consumer sample h_z is given by:

$$Y_{f,h_z}(t) = \begin{cases} \frac{1}{\hat{F}_{h_z}(t)} \frac{C_z(t)}{H_z} & \forall f \in \hat{F}_{h_z}(t) \\ \\ 0 & \forall f \notin \hat{F}_{h_z}(t) \end{cases} \tag{34}$$

The demand for a single firm at time t is obtained by aggregating consumption from the samples of these individual purchases:

$$Y_f(t) = \sum_{z=1}^{\Lambda} \sum_{h_z=1}^{H_z} \frac{1}{\hat{F}_{h_z}(t)} \frac{C_z(t)}{H_z} \tag{35}$$

[24]See for example Zheng and Henneberry (2011): "for most of the studied food groups, the demand of the high-income group is found to be less responsive to own price and income changes than the low- and medium-income groups, while the demand of the low-income group is found to be more responsive to own-price and income changes than the medium- and high-income groups." [p. 111] With no preliminary expectation for the engineers consumer class, we have drawn the tolerance randomly ($\upsilon_{0,m} \sim U(0,1)$). Given the very low ratio of engineers with respect to the rest of the population in our model, the impact of their consumption choice is negligible.

[25]There is ample evidence on consumer difficulty in assessing a product quality (Celsi and Olson, 1988; Hoch and Ha, 1986; Rao and Monroe, 1989). Similarly with respect to prices: see or example the review in Zeithaml (1988).

3 Empirical validation and model dynamics

We present here a set of empirical stylised facts on growth and distribution generated by the model initialised on the basis of the benchmark configuration summarised in Table 1.[26] Building on this evidence, we then illustrate the main macro and micro economic relations that generate these results.

3.1 Empirical stylised facts

Figure 1 displays output growth patterns endogenously emerging from the model,[27] similar to what we find in Maddison's empirical description of the long-run growth of Western Europe and its 'offshoots' (e.g. Maddison, 2003; Hulten, 2009). A long period of stable though limited growth – which we call *demand*-led regime – characterises the first 1100 periods. This is followed by a take-off and further exponential growth, which we call *Kaldorian* regime.[28]

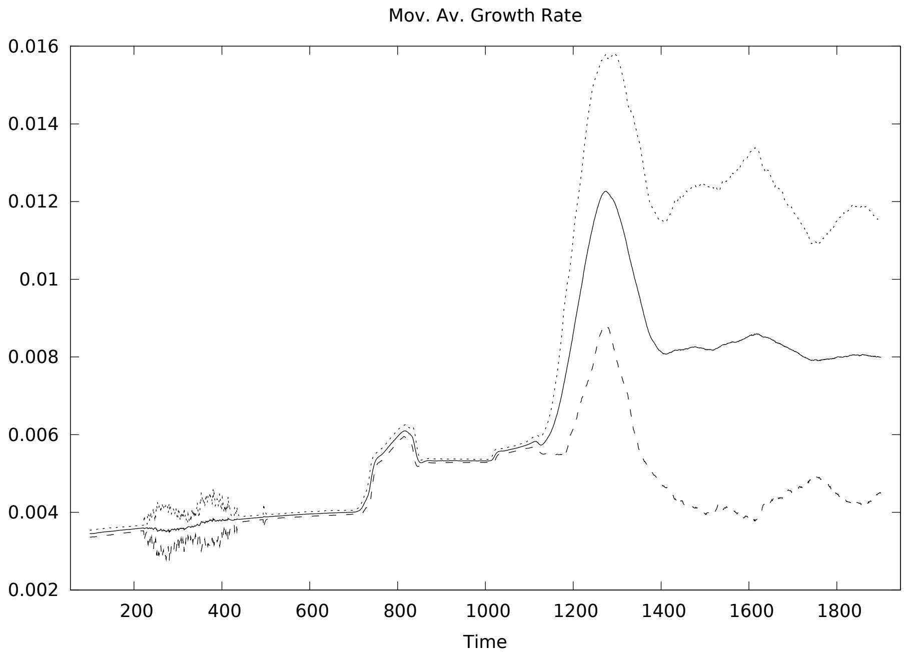


Figure 1: ***Growth rates for the economy output across time steps****; data from moving averages computed over punctual growth rates. For each time step the series reports the average value across 100 replications together with inter-replication confidence intervals set at 1.96 standard deviations.*

With respect to income distribution, a well-known empirical fact of countries' early stages of growth is the inverted U-shaped relation between income growth and inequality,

[26]We validate the model using 100 replicates of the benchmark configuration to control for the influence of random events.

[27]We plot the moving average of growth – with confidence intervals – $\hat{\dot{Y}}_t = \frac{\sum_{h=0}^{L} \dot{Y}_{t-h}}{L+1}$, where $\dot{Y}_t$ is the output growth rate at constant prices, to smooth short-term cycles.

[28]We come back to a detailed explanation of the two regimes in the following section.

Parameter	Description	Value	Data
$\underline{i_2}$	Minimum quality level	98	Analysed
$\overline{i_2}$	Maximum quality level	102	Analysed
a^s	Adaptation of sales expectations	0.9	–[a]
$\bar{s}$	Desired ratio of inventories	0.1	[0.11 - 0.25][b]
u^l	Unused labor capacity	0.05	0.046[c]
u	Unused capital capacity	0.05	0.046[c]
$\bar{\mu}$	Markup	0.2	[0-0.28]; [0.1, 0.28]; [0.1, 0.39][d]
δ	Capital depreciation	0.001	[0.03, 0.14]; [0.016, 0.31][e]
$\frac{1}{D}$	Capital intensity	0.4	D = [1.36, 2.51][f]
ϵ	Labor market friction	0.9	0.6; [0.6, 1.5]; [0.7, 1.4]; [0.3, 1.4][g]
ω	Minimum wage multiplier	1.11	[1.6, 3.7][h]
b	Executives wage multiplier	2	Analysed
ν	Tier multiplier	5	Analysed
$1-\gamma$	Smoothing parameter	0.2	[.04, .14]; [.06, .19][i]
ςi_j	Error in the consumer's evaluation of characteristics	$j=1$: 0.05; $j=2$: 0.1	–[j]
δ_ς	τ inter-class multiplier	0.2	[-0.8, 2.4] Mean: 0.18[k]
$\upsilon^{min}=\upsilon_{2,1}$	Highest = first tier quality tolerance	0.1	Analysed
$\upsilon^{max}=\upsilon_{1,1}$	Lowest = first tier quality tolerance	0.9	Analysed
z	Parameter innovation probability	10000	–[l]
σ^a	Standard deviation productivity shock	0.01	Analysed
ρ	R&D investment share	0.7	–[m]
ω^E	Engineers' wage multiplier	1.5	[1.2, 1.4][n]
F	Final good firms	50	–
G	Capital good firms	15	–
H_z	Consumer samples	50	–

[a]Empirical evidence not available: the parameters has no influence on the results presented here. [b]U.S. Census Bureau (2011); Bassin et al. (2003). [c]Coelli et al. (2002) with reference to the 'optimal' unused capacity. [d]Marchetti (2002); De Loecker and Warzynski (2009); Joaquim Oliveira et al. (1996). [e]Nadiri and Prucha (1996); Fraumeni (1997) non residential equipment and structures. We use the lower limit value, (considering one year as 10 simulation steps) to avoid growth in the first periods to be determined by the replacement of capital. [f]King and Levine (1994). [g]Vacancy duration (days or weeks) over one month: Davis et al. (2010); Jung and Kuhn (2011); Andrews et al. (2008); DeVaro (2005). [h]Ratio with respect to the average wage (not minimum) in OECD countries Boeri (2009). [i]Krueger and Perri (2005); Gervais and Klein (2010). [h]Empirical evidence not available to the best of our knowledge. Parameters set using the qualitative evidence in Zeithaml (1988). [k]Change in price elasticity for food product categories (Zheng and Henneberry, 2011) (inverted signs, as we use the increase in tolerance rather than the reduction in price elasticity). [l]Set to a value that ensures that innovation in the capital sector occurs. [m]Empirical evidence with respect to profits not available to the best of our knowledge. [o]Relative to all College Graduates and to accountants Ryoo and Rosen (1992)

Table 1: ***Parameters setting***. *Parameter's (1) name, (2) description, (3) value, and (4) empirical data range when its effect is not analysed in section 4*

the Kuznets curve. When countries, starting from a low income level, experience output and income growth, income inequality increases. Once they complete the transition phase and reach a middle-income level, inequality decreases until it starts rising again when countries reach high-income levels. Figure 2 plots the relation between the Atkinson inequality index and (log) output.[29] As shown in the figure, our model reproduces a

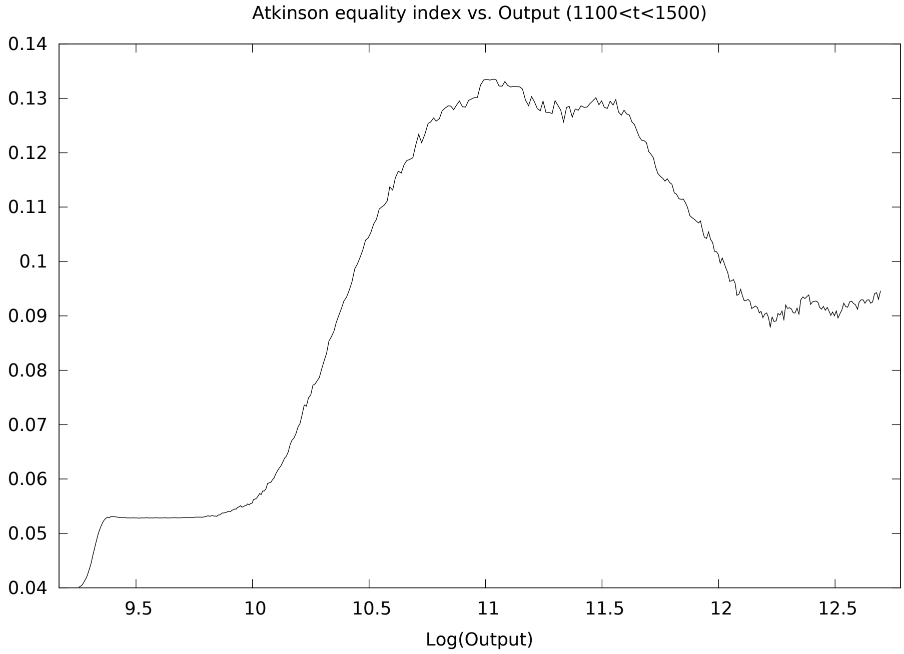


Figure 2: ***Atkinson inequality index vs. output (log)***. *Sample of data in* $t \in [1100 : 1500]$ *(around take-off)*.

Kuznets curve during the period of transition from low to high income when the economy experiences take-off and, after slowing down, enters a phase of stable sustained growth.

The model reproduces other fundamental empirical regularities, the so-called Kaldor stylised facts, with respect to the relation between output growth (ΔY), labour productivity growth (ΔA) and capital deepening (i.e. increases in the capital-labour ratio) ($\Delta K/L$).[30]

In Table 2, we estimate the Kaldor-Verdoorn (K-V) law for the whole period and find significant evidence of the positive relation between productivity growth and output growth.[31] When we turn to the same relation for different sub-periods (Table 11 in Appendix), there is even more evidence of the presence of a *Kaldorian* regime that occurs after a structural change in firm organisation and production technology, preceding the take-off, and is based on dynamic increasing returns and sustained investment in technol-

[29] The Atkinson index is computed as $\mathcal{AT}_t = 1 - \frac{1}{\sum_{z=1}^{Z} \frac{W_{z,t}}{L_{z,t}}} \left[\frac{1}{\sum_{z=1}^{Z} L_{z,t}} \sum_{z=1}^{Z} \left(\frac{W_{z,t}}{L_{z,t}} \right)^{1-\varrho} \right]^{\frac{1}{1-\varrho}}$ where $W_{z,t}$ is the total income for consumer class z, $L_{z,t}$ is the total number of workers in class z and ϱ is the measure of inequality aversion. Provided we are not measuring an empirical level of inequality, we use an intermediate value of $\varrho = 0.5$.

[30] "[I]nvestigations have also revealed that whilst in the course of economic progress the value of the capital equipment per worker (measured at constant price) and the value of the annual output per worker (also in constant price) are steadily rising [...]" (Kaldor, 1960, p. 260).

[31] The Kaldor-Verdoorn Law states the existence of a positive correlation between productivity growth and output growth. This relationship, initially identified by Verdoorn (1949) and restated by Kaldor (1966), has been discussed ever since, in both the development and empirical growth literatures. See McCombie et al. (2002) for a survey and Knell (2004) and Lorentz (2005) for recent estimates of the Kaldor-Verdoorn Law.

ogy. In the early stages of (stagnating) growth, the low pace of change in organisation and technology does not increase the production capacity to a level sufficient to generate sustained productivity gains. We show below how this empirical fact in our model depends on endogenous technical change generating self-reinforcing growth dynamics.[32]

		$\Delta Y(2000)/Y(1)$	R^2	R^2_{corr}	Obs.
(OLS)	$\Delta A(2000)/A(1)$	0.117***	0.44	0.434	100
		(0.013)			
(LAD)	$\Delta A(2000)/A(1)$	0.125***			100
		(0.030)			

Standard errors (computed with 500 bootstraps) in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table 2: ***Kaldor-Verdoorn Law*** *Overall Estimations*

Finally, the model reproduces the empirical evidence on capital deepening, i.e. a constantly increasing ratio of capital per worker for a growing output. In Table 3, we show LAD estimates of the effect of an increase in the capital labour ratio ($\Delta K/L$) on the output growth rate of output for the whole period. Capital deepening in our model is

	$\Delta Y(2000)/Y(1)$	Const.	$PseudoR^2$	Obs.
$\frac{\Delta K/L(2000)}{K/L(1)}$	10.67***	2.981***	0.299	100
	(0.505)	(0.529)		

Standard errors (computed with 400 bootstraps) in parentheses;
*** p<0.01, ** p<0.05, * p<0.1

Table 3: ***Capital deepening and growth***. *LAD estimates of the growth of K/L ratio over the 2000 periods.*

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

3.2 Model dynamics

In the following, we illustrate in more detail the model dynamics that reproduce the empirical facts discussed above and will enable us to isolate the parameters representing the core of our analysis. We test the causal structure underlying the growth rate of macro economic variables using a Vector Autoregressive (VAR) analysis on the fundamentals of our model. Growth relations are estimated using LAD for three lags, where the sample is again the 2000 period series of the benchmark configuration, averaged over 100 replicates. In order to reduce the effect of short term cyclical behaviour we analyse ten periods growth.

[32] For a more detailed discussion of the cumulative causation nature of the post-take-off period generated by our model, see Ciarli et al. (2010).

The variables of the reduced model are (1) output Y, (2) labour productivity A, (3) the price index P, (4) market concentration, measured with the inverse Herfindahl Index IHI and (5) inequality $\mathcal{A}T$ – Atkinson index (Table 4).

Variables	(1) $\Delta Y/Y(t)$	(2) $\Delta A/A(t)$	(3) $\Delta P/P(t)$	(4) $\Delta IHI/IHI(t)$	(5) $\Delta AT/AT(t)$
$\Delta Y/Y(t-1)$	1.23***	0.03	0.05	0.31	0.38***
	(0.07)	(0.02)	(0.03)	(0.20)	(0.12)
$\Delta A/A(t-1)$	0.00	1.04***	-0.02**	1.18***	-0.44**
	(0.01)	(0.04)	(0.01)	(0.31)	(0.19)
$\Delta P/P(t-1)$	-0.56***	-0.03**	1.01***	-0.02	-0.02
	(0.03)	(0.01)	(0.07)	(0.05)	(0.04)
$\Delta IHI/IHI(t-1)$	0.03***	0.01***	-0.01***	0.53***	-0.24***
	(0.00)	(0.00)	(0.00)	(0.06)	(0.03)
$\Delta AT/AT(t-1)$	0.01***	-0.01***	-0.00	0.02	0.77***
	(0.00)	(0.00)	(0.00)	(0.03)	(0.04)
$\Delta Y/Y(t-2)$	-0.11	-0.01	-0.08	-0.42**	-0.34***
	(0.09)	(0.03)	(0.06)	(0.20)	(0.12)
$\Delta A/A(t-2)$	-0.04**	0.25***	-0.01	0.54	-0.26*
	(0.02)	(0.05)	(0.01)	(0.33)	(0.15)
$\Delta P/P(t-2)$	0.84***	0.03	0.04	0.33**	0.27**
	(0.06)	(0.02)	(0.06)	(0.16)	(0.12)
$\Delta IHI/IHI(t-2)$	-0.03***	-0.01***	0.00	0.31***	0.09**
	(0.01)	(0.00)	(0.00)	(0.04)	(0.04)
$\Delta AT/AT(t-2)$	-0.00	0.00**	-0.00	-0.04	0.05
	(0.00)	(0.00)	(0.00)	(0.03)	(0.06)
$\Delta Y/Y(t-3)$	-0.13**	-0.02	0.02	0.08	-0.03
	(0.05)	(0.02)	(0.03)	(0.07)	(0.05)
$\Delta A/A(t-3)$	0.04***	-0.32***	0.00	-1.51***	0.41**
	(0.02)	(0.04)	(0.01)	(0.31)	(0.19)
$\Delta P/P(t-3)$	-0.27***	-0.00	-0.05	-0.31**	-0.26***
	(0.05)	(0.02)	(0.06)	(0.14)	(0.10)
$\Delta IHI/IHI(t-3)$	0.00	-0.01***	-0.00	0.11*	0.09***
	(0.00)	(0.00)	(0.00)	(0.06)	(0.03)
$\Delta AT/AT(t-3)$	-0.00	0.00*	-0.00	0.00	0.14***
	(0.00)	(0.00)	(0.00)	(0.02)	(0.04)
Constant	0.00	-0.00**	-0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	1950	1950	1950	1950	1950
Pseudo R^2	0.98	0.89	0.91	0.6	0.72

Standard errors in parentheses ; *** p<0.01, ** p<0.05, * p<0.1

Table 4: **Dynamic correlation between selected macro-level indicators (VAR)**

For all 2000 periods we observe a significant momentum in growth rates: output, productivity and prices exhibit a significant cumulative causation process, which is at the core of the endogenous growth in our model. Output confirms the cyclical behaviour observed in the growth figure, productivity is autocatalytic (reversing effect after three ten-periods lags), and market concentration is strongly persistent over time. Prices are instead affected by short run changes only. The results also confirm some expected dynamics: an increase in market concentration (decrease in IHI) increases prices and income inequality; price growth induces output growth after one lag, while inequality has only a marginal effect on output, as this changes over the different phases of growth, as discussed above.

Having confirmed the main macro dynamics, table 4 also suggests some insightful results on the micro-macro relations in our model. First, while the Kaldor-Verdoorn Law holds in the long and medium run (Tables 2 and 11 in the Appendix for sub-periods) and particularly for the post-take-off period, in the short run and accounting for the overall period, output growth has no significant effect on productivity growth. However, we observe a direct positive significant effect, albeit small and with three lags, of productivity growth on output growth. This lagged relation from productivity to output is relatively straightforward to explain in our model: an increase in output occurs only after removing factor constraints. Therefore firms first invest in new capital, which may bring an increase in productivity, and then accommodate demand with an output increase.

The VAR results shed light also on the microeconomic causal relations which are at the core of our analysis. In particular, we observe that three variables dominate the causal relations, and affect different aspects of the model dynamics: aggregate productivity (A), market concentration (IHI) and inequality (AT).

First, aggregate productivity growth first reduces concentration of production and income and then - 2 lags after - induces a concentration in both variables. On the one hand an increase in productivity stems from one or more firms investing in new capital vintages with higher embedded productivity (Eq. in 2.2.3). Investing firms grow in size (Eq. 2.2.1), which may require to hire a new tier of workers (Eq. in 2.2.2). Indeed, capital investment increases output and size of capital firms as well (Eq. in 2.3.1). In both cases, demand increases more than proportionally, due to the emergence of new classes of workers/consumers, and to the higher wages of the new class of executives (Eq. in 2.2.4 and 2.3.3). The changes in firm size and compensation thus explain the lagged increase in inequality. On the other hand an increased productivity reduces the cost (price) of the investing firms (for a given size), attracting more demand from the first consumer classes (the most populated) and increasing market concentration.

The second causal link then goes from market concentration to income inequality with one lag: the large increase in demand for a few selected firms requires new tiers of managers, which by assumption earn more than the existing workers, and receive more bonuses from firm profits (Eq. 11, 15). The increased demand due to market concentration than lead to further investment and increase in productivity, as already shown in Table 4.

Third, inequality has a modest effect on productivity: at first it causes productivity to decrease, following the reduced investment in new machinery, whereas the increased consumer heterogeneity that accompanies a raise in inequality has a modest positive effect on productivity.

The VAR results contribute to explaining how micro heterogeneity is responsible for the two growth regimes – the *demand*-led and the *Kaldorian* regimes – identified above. The initial phase of *demand*-led growth originates from an initial investment of firms increasing the number of workers (population), demand for final consumption, income, firm size and further demand for labour. During this first period, investment occurs at the rate of capital depreciation and population growth. The second stage of exponential growth is related to market concentration and a sudden increase in capital investment by the few firms that start leading the market. The large capital investment of these firms induces large jumps in aggregate productivity, which sets off a cumulative causation process of the Kaldorian type (Kaldor, 1966): price reduction, increased profits, increase in final demand, sustained investment in R&D and new capital vintages, with increasing productivity embedded in the capital that sustains the exponential pattern.

In the following section we analyse how the the initial conditions that define the structure of an economy and the way in which this unfolds through time affect output growth and income inequality. The effect of productivity (A) is captured by the parameter that defines the speed at which capital good firms increase the productivity embodied in new capital goods, σ^{α} (Eq. 23). The effect of market concentration is captured by the parameter that defines the organisation of production, i.e., the pace at which new tiers of workers and managers are created for a given increase in production capacity, increasing firm size and final demand, ν (Eqs. 5 and 19). We then distinguish between direct and indirect effect of inequality. The first one, observed in the linear relations analysed in the VAR, is captured by the wage multiplier, b (Eqs. 11 and 26). The second effect is due to the changes in consumption patterns following the emergence of new classes of consumers and is captured by both the across-class differences in consumer preferences, υ^{min} and υ^{max}, and the initial variety in the characteristics of the products they select, $i_{2,f}$ and $i_{1,f}(t)$.

4 Simulation results: structural differences in technology, organisation and demand

We now turn to the analysis of the effect of exogenous structural conditions on output growth and income distribution. In particular, we focus on the effect of the following combinations of parameters defining the different aspects of the structure of an economy:

Composition of production and demand: variance of the distribution of a product's quality and price (standard deviation (sd) of $i_{2,f}$) and variance in the preferences of different earning classes ($|\upsilon^{max} - \upsilon^{min}|$) (Section 4.1). The relation between the speed of technological change in capital vintages (σ^{a}) and in the firm organisational structure (number of tiers for a given number of shop floor workers, ν) (Section 4.2).

The relation between the firm organisational structure (ν) and the distribution of wages and premia (b) (Section 4.3).

For each combination of the parameters we ran 20 replicates with different random seeds for 2000 time periods and report the average over the replicates. In Appendix A, we show that 20 replicates are sufficient to wipe out the effect of random initialisations. We then estimated if the result of each combination of parameters is significantly different form the benchmark case with a bootstrapped quantile regression of the type $\ln Y = \alpha + \beta_{ij} D1_i D2_j + \epsilon$, where the $D1_i D2_j$ are all the possible two way interactions of the pair of analysed parameters, except for the benchmark which is the reference value.

4.1 Composition of production and demand

It is a well-established empirical finding that income growth is accompanied by changes in the composition of production in terms of sectoral specialisation and product variety through quality differentiation (e.g. Sirquin, 1988; Maddison, 2001; Dosi et al., 1994a; Prebish, 1950; Hidalgo and Hausmann, 2009; Saviotti, 1996). Accordingly, product differentiation is accompanied by a change in consumer preferences and consumption patterns (Maddison, 2001), which become more heterogeneous across consumers as a result of the increased variety of production and income classes.

Here we analyse the joint effect of the initial good's quality differentiation across firms and of the emerging different distributions of preferences across consumer classes. With reference to the model, we vary the value of the standard deviation of product quality distribution across firms $\left(s.d.\ i_2 \sim U[\underline{i_2}, \overline{i_2}]\right)$ – assuming that a relatively higher quality is related to a proportionally higher markup[33] – and the difference in the tolerance level across consumer classes $\left(\upsilon^{max} - \upsilon^{min}\right)$.[34]

Table 5 shows the level of output (log) for different combinations of sd i_2 and $\upsilon^{max} - \upsilon^{min}$ and whether the difference is statistically significant with respect to the benchmark case (low product variety and high consumer heterogeneity).[35] Our findings only partially support the proposition that a higher initial variety (across both goods and consumers) is linked to faster output growth. The table shows two main results: (i) a high *initial* variety in the quality of goods induces a low growth when goods are substitutes, as in our model; (ii) the heterogeneity between consumer preferences increases output growth only when it is very large and its effect is not dwarfed by the counter-effect of an initially large product variety.

These results are explained by the fact that too large a variety of products during the initial time periods does not spark the take-off. In the initial periods, aggregate demand is, in fact, too low to be an incentive for firms to invest in new capital. Therefore, firm selection induced by high variety has the only effect of reducing the number of overall vacancies, keeping demand low. With no demand effect, the cumulative process never gets started, and although the economy experiences an endogenous growth, this is the lower, the higher the initial market concentration. This result is confirmed by the low aggregated labour productivity observed for a very low number of workers, in the presence of high product heterogeneity.[36]

In other words, in order to induce the take off, product variety should develop over time, once the economy has already undergone a growth in demand such that firms have

[33] Several industry studies support this hypothesis, e.g. Deltas et al. (2011), Corrocher and Guerzoni (2009) and Verboven (1999).

[34] 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 the parameters' space for high and low growth on a fixed set of possible outcomes.

[35] The significance of each combination was estimated with a bootstrapped quantile regression. Results of the regression are available from the authors.

[36] Figures are available from the authors.

s.d. i_2	$\upsilon^{max} - \upsilon^{min}$ 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1.15	13.43	13.44	13.44	13.44	13.44	13.45	13.46	14.00	**15.06**	16.24
3.15	6.34	6.30	6.32	6.33	6.31	6.34	6.30	6.38	6.83	9.80
5.15	4.75	4.75	4.75	4.75	4.75	4.75	4.74	4.75	4.85	5.83
7.16	4.71	4.71	4.70	4.71	4.71	4.71	4.72	4.72	4.75	5.05
9.16	4.69	4.69	4.68	4.69	4.69	4.70	4.69	4.69	4.71	4.84
11.17	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.69	4.77
13.17	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.67	4.67	4.72
15.17	4.63	4.64	4.64	4.64	4.64	4.64	4.64	4.65	4.66	4.70
17.18	4.61	4.62	4.62	4.62	4.63	4.64	4.63	4.63	4.66	4.69
19.18	4.63	4.60	4.61	4.63	4.62	4.63	4.63	4.64	4.67	4.71

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 5: ***Level of output (Log) at constant prices for different values of product quality and heterogeneity of preferences***. *Levels of output in the final period of simulations for different combinations of the sd of i_2 across firms and of the difference between the minimum and the maximum tolerance level towards product characteristics – quality and price*

an incentive to invest in new technology and it has to be accompanied by an emerging differentiation among consumers. If this is not the case, firms' selection acts as a cap on output growth.

The effect of supply and demand heterogeneity on income inequality is non-linear (Table 6): the economy experiences the highest level of inequality in the presence of large initial product heterogeneity and very low output. Inequality increases again for very large levels of output associated with low initial variety. In both cases of high and low output, inequality is mainly due to the income generated by profit shares (Figure 7 (b) in Appendix B). The heterogeneity of preferences across consumer classes has very little and hardly significant effect.

In particular, we can distinguish two opposite scenarios: a stagnant and highly unequal economy and a virtuous, less unequal, growing economy. In the first scenario, characterised by high initial product heterogeneity, a small population enjoys a high average income (Figure 7 (a) in Appendix B), unequally distributed and generated through non-invested profits. In the second scenario, marked by low initial product heterogeneity and a high (potential) difference in preferences, a large population enjoys a relatively higher average and more equally distributed income.

Our findings qualify the evidence mentioned above: variety exerts a positive effect on growth only when it is generated through time – the development process, and in the presence of evolving consumer preferences. Otherwise, an initially large product variety might not be sufficient to generate either structural change or growth and have negative effects on the distribution of income.

s.d. i_2	$\upsilon^{max} - \upsilon^{min}$ 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1.15	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.07	**0.08**	0.09
3.15	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.05
5.15	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
7.16	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03
9.16	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04
11.17	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05
13.17	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06
15.17	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06
17.18	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.06
19.18	0.10	0.10	0.10	0.10	0.09	0.08	0.08	0.08	0.07	0.07

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 6: ***Atkinson index for different values of product quality and heterogeneity of preferences***. *Levels of output in the final period of simulations for different combinations of the sd of i_2 across firms and of the difference between the minimum and the maximum tolerance level towards product characteristics – quality and price*

4.2 Organisation and production technology

We then analyse the joint effect of production technology (σ^a) and organisational structure (ν). Production technology refers to the capital structure of firms, while the organisational structure reflects the hierarchical structure of labour.

At the firm level, a higher number of layers (low ν), *ceteris paribus*, increases the number of workers and the production costs while a wider distribution of the R&D outcome (high σ^a) reduces the number of workers.At the industry level, larger potential productivity gains should result in the most efficient firm growing and dominating the market However, the cost associated with an increase in the number of management layers imposes a trade-off between capital investment and growth. Finally, at the macro level both parameters should positively affect growth via effective demand. The two parameters are expected to increase inequality as well: (i) a higher number of tiers generate a higher dispersion in income distribution by construction; and (ii) higher productivity allows for higher profits to benefit the higher tiers of workers.

Table 7 confirms the expectations on economic growth. It shows the Log of output levels at constant prices after 2000 simulation steps for various values of the parameters defining organisational structure and production technology. The table also shows whether output is significantly different from the benchmark case for each value's combination. An increase in σ^a positively and significantly affects output, while an increase in ν – reducing the number of layers, *ceteris paribus* – negatively affects output. The results clearly demonstrate that small reductions in organisational complexity require large changes in production technology to achieve the same level of output growth. Finally, the reduced significance of the difference with respect to the benchmark is due to the increased volatility in the outcome of R&D investments: large values of σ^a increase the variance of output across replicates, showing that a higher output for large σ^a is conditional on increasing

σ^α	ν 5	6	7	10	15
0.01	**17.05**	9.64	6.50	4.77	4.66
0.02	18.13	9.67	6.53	4.79	4.67
0.03	20.52	9.85	6.58	4.80	4.69
0.04	22.94	11.27	6.67	4.85	4.71
0.05	23.53	12.99	6.84	4.90	4.74
0.06	28.13	14.50	6.81	4.94	4.77
0.08	35.01	19.83	7.43	5.21	4.93
0.1	49.53	26.12	9.58	5.64	5.29
0.13	49.90	38.17	11.69	6.09	5.32
0.16	70.45	50.10	17.45	9.62	8.11
0.2	90.28	71.69	56.11	14.98	14.33

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1:

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 7: ***Level of output (Log) at constant prices for different values of process innovation (σ^α) and organisational layers (ν)***

the effectiveness of R&D investment.

Table 8 presents the effect of these parameter on the average Atkinson index over 2000 simulation steps. The table also reports the significance of the differences between these outcomes and the benchmark case (in bold). As expected, for a given σ^α an increase in the tier multiplier (ν) reduces inequality, while σ^α increase inequality. Inequality increases again for very high values of ν suggesting a non-linear relation between inequality and organisational structure.

Taken together, our results show that a higher organisational complexity and faster changes in production technology lead to higher output and wider income disparities. This is implicit in the assumption that as an economy grows, so does corporate size and organisation, increasing the number of executives and their relative remuneration with respect to shop floor workers. Admittedly, this is not so different from the experience of the industrialised world in the last few decades.[37] As we make no assumption on the saving/consumption propensity of the different classes of consumers (only on their preferences) nor on the institutional structure that acts on the distribution of income, an increase in corporate size also leads to an increase in demand and output, irrespective of the class distribution.

As noted earlier (Section 3.2), growth in output and inequality are not always positively related, and an increase in inequality has little effect on output growth, changing sign for different phases of growth. Here we qualify these results, identifying the conditions under which the economy reaches relatively high output, *despite* the relatively high inequality.

[37] See, e.g., the evidence in Gabaix and Landier (2008), while Bakija et al. (2010) use tax return data to show that 60% of the top 0.1 taxpayers in the US are executives, managers or financial managers/professionals.

σ^α	ν 5	6	7	10	15
0.01	**0.058**	0.022	0.017	0.017	0.023
0.02	0.064	0.022	0.017	0.017	0.023
0.03	0.079	0.022	0.017	0.017	0.023
0.04	0.092	0.028	0.017	0.017	0.022
0.05	0.095	0.035	0.017	0.018	0.022
0.06	0.113	0.042	0.017	0.018	0.022
0.08	0.142	0.067	0.018	0.018	0.023
0.1	0.182	0.092	0.027	0.019	0.024
0.13	0.173	0.134	0.035	0.021	0.024
0.16	0.192	0.156	0.061	0.034	0.036
0.2	0.195	0.175	0.138	0.058	0.069

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1:

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 8: ***Atkinson index for different values of process innovation (σ^α) and organisational layers ν.*** *Atkinson index averaged across the 2000 simulation steps*

4.3 Organization and wage structure

To realise a better understanding of the effect the parameters that directly determine changes in the income distribution in our model, we focus on the joint effect of the determinants of the organisation (ν) and the wage (b) structure. The two parameters have two symmetric effects on the supply and the demand side of the economy. On the supply side, a higher number of layers (lower ν) and/or a higher wage multiplier (higher b) directly increase the firm's cost. This may also result in a higher dispersion of prices across firms over time. On the demand side, a reduction in ν and an increase in b increases aggregate income and income disparities, and increase the heterogeneity in demand preferences and the range of affordable products.

Table 9 shows the effect of the organisational complexity and wage dispersion on the log of output at constant price after 2000 simulation steps. It also reports the significance of the differences between the outcomes under each parameter combination and that of the benchmark (in bold). On the one hand, the higher the organisational complexity, the higher is the output growth: the increase in the number of consumers directly translates into higher effective demand with a direct positive effect on growth. On the other hand, the higher the wage multiplier, the lower is the output growth: assuming no direct effect of wages on productivity, the increase in cost generated by high disparities in wages slows down long-run growth. However, this second effect is not significant overall.

In Table 10, we observe the impact of the organisational and payment structure on inequality (Atkinson index averaged over 2000 simulation steps) and their significance with respect to the benchmark case (in bold). As expected, increasing the wage multiplier mechanically raises the income disparities across households. The effect of the tier multiplier

b	ν 5	6	7	10	15	20	25	50
1	17.69	10.78	6.83	5.17	4.99	4.96	4.94	4.92
1.25	17.44	9.86	6.73	4.81	4.63	4.61	4.60	4.59
1.5	17.53	9.82	6.78	4.72	4.55	4.53	4.52	4.51
1.75	17.15	9.82	6.84	4.80	4.60	4.55	4.54	4.52
2	**17.18**	9.85	6.91	4.92	4.65	4.59	4.57	4.54
2.25	17.25	9.90	6.97	5.04	4.73	4.63	4.60	4.56
2.5	17.09	9.94	7.02	5.16	4.81	4.66	4.62	4.58

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1:

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 9: ***Level of output (Log) for different values of*** b ***and*** ν

b	ν 5	6	7	10	15	20	25	50
1	0.008	0.002	0.000	0.001	0.007	0.014	0.019	0.038
1.25	0.016	0.002	0.002	0.003	0.008	0.013	0.017	0.031
1.5	0.028	0.007	0.005	0.005	0.007	0.010	0.013	0.023
1.75	0.039	0.013	0.010	0.009	0.010	0.013	0.016	0.025
2	**0.056**	0.021	0.017	0.014	0.012	0.013	0.015	0.022
2.25	0.075	0.029	0.024	0.019	0.015	0.016	0.017	0.021
2.5	0.093	0.038	0.031	0.025	0.019	0.019	0.019	0.022

Benchmark case in **Bold**

p<0.01, p<0.05, p<0.1:

Standard errors of the joint difference of each cell with respect to the benchmark computed with a quantile regression (400 bootstraps)

Table 10: ***Atkinson index for different values of*** b ***and*** ν. *Average over 2000 time steps*

ν on income disparities across classes confirms the U-shaped form, which we discussed in the previous sections. On the one hand, when the multiplier is low, the large number of layers amplifies even small wage disparities among layers, generating higher inequality. On the other hand, when the wage multiplier is high, a very small number of layers emerge – due to a low output growth (Table 9) – and the high-income classes absorb the high rate of redistributed profits, causing large inequality even in the presence of low earning disparities.

To summarise, the conditions that induce wage disparities and large increase in the number of layers directly increases income inequality, as one would expect. While generating inequalities, these structural conditions may also limit economic growth: although a large number of layers sustains effective demand (despite the higher firm costs), high wage differences between layers increase the price level in the economy (and the difference between price and minimum wage), yielding no other benefits and slowing economic growth.

5 Concluding remarks

A large and diverse literature has pointed to solid empirical evidence suggesting mutual effects on the relations between structural changes in different aspects of the economy and economic growth. We argue that the structure of production and the way in which it is organised by firms, together with the structure of demand, are the main candidates to explain the growth differences we observe across countries and within countries over time.

We propose a model that accounts for these three different dimensions of structural change, generating different patterns of growth and income distribution. The relations between the different aspects of structural change on the supply and the demand side of the economy occur through the micro behaviour of firms and consumers.

We show that the model is able to replicate a number of stylised facts. We then analyse the main causal relations between the different aspects of structural change and find that productivity growth, firm size and market concentration, and the distribution of income across income classes dominate the causal relations and affect most aspects of the model dynamics. First, firm selection generates an oligopolistic competition in the final good sector which is accompanied by a high growth in capital investments by the expanding firms. Second, it is this concentration of demand and investments that produces high R&D investments in the capital sector, leading to rapid changes in the *production technology*, quickly absorbed by final good firms. Third, firm selection and market concentration result from the variety in the *composition of production* in terms of cost and quality differences, and from the heterogeneity of *consumption patterns* that emerges across consumer classes. Fourth, the *organisation of production* – number of managerial tiers – is what generates cost differences and price dispersion across firms, and different wage classes. The *earning structure* amplifies these differences. Capital investment introduces more heterogeneity in the model, leading to more selection and market concentration, sustaining this cumulative causation dynamics.

For given values of the parameters that define the three aspects of the structure of an economy and the way in which this unfolds through time, these recursive dynamics generate the take-off and what we called the *Kaldorian* phase of growth. Indeed, the concentration of production on a reduced number of firms also affects the distribution of income.

In the last part of the paper we analyse the conditions under which these parameters generate the take-off and find the following main results. Product variety plays a relevant role in the economic growth of an economy only when it is generated through time and when it is accompanied by a broad heterogeneity in consumer preferences. When product heterogeneity is broad during the initial stages of stagnant growth, strong firm selection before the expansion of demand level and variety hinders the cumulative feedbacks discussed above. The economic quasi-stagnation is also accompanied by a large inequality due to the low incentive to invest and the consequent high proportion of distributed profits. Stretching the argument a little further in a long-run growth perspective, an economy gains from diversifying once it has built an industrial base sufficient to induce a high internal demand and investment. An initial big push toward industrial diversification is not conducive to high growth.

Organisational structures that lead to a large number of organisational tiers, as well as large productivity gains embodied in capital goods, lead to higher output levels, despite generating higher income inequality, which after the take-off has a negative effect on growth. However, the number of organisational tiers has a non linear effect on inequality, which increases again for very flat organisations. This is again due to a condition of stagnating economy where profits are distributed as bonuses and not invested.

Firms' organisational and earning structures affect economic growth both via the level of aggregate demand and income disparities. Despite increasing average wages and prices, complex hierarchical structures sustain aggregate demand in the long run, inducing demand-led cumulative causation growth. However, the increase in earning disparities and inequality in this case limits growth, due to the high cost of (managerial) labour with respect to the minimum wage which reduces the purchasing power of the large bulk of the consumers, lower investments and slow productivity changes.

References

Abowd, John M., Francis Kramarz, and David N. Margolis, "High Wage Workers and High Wage Firms," *Econometrica*, 1999, *67* (2), 251–333.

Acemoglu, Daron and James A. Robinson, "Economic Backwardness in Political Perspective," *American Political Science Review*, 2006, *100* (01), 115–131.

_ and Simon Johnson, "Unbundling Institutions," *Journal of Political Economy*, October 2005, *113* (5), 949–995.

Adam, Christopher and Stefan Dercon, "The political economy of development: an assessment," *Oxford Review of Economic Policy*, 2009, *25* (2), 173–189.

Aghion, Philippe and Peter Howitt, *Endogenous Growth Theory*, Vol. 1 of *MIT Press Books*, The MIT Press, December 1998.

_ , Eve Caroli, and Cecilia García-Pe nalosa, "Inequality and Economic Growth: The Perspective of the New Growth Theories," *Journal of Economic Literature*, Dec 1999, *37* (4), 1615–1660.

Akerlof, George A. and Robert J. Shiller, *Animal spirits: how human psychology drives the economy, and why it matters for global capitalism*, Princeton University Press, 2009.

Andrews, Martyn J., Steve Bradley, David N. Stott, and Richard Upward, "Successful Employer Search? An Empirical Analysis of Vacancy Duration Using Micro Data," *Economica*, 2008, *75* (299), 455–480.

Aoki, Masanao and Hiroshi Yoshikawa, "Demand saturation–creation and economic growth," *Journal of Economic Behavior & Organization*, 2002, *48*, 127–154.

Arifovic, Jasmina, James Bullard, and John Duffy, "The Transition from Stagnation to Growth: An Adaptive Learning Approach," *Journal of Economic Growth*, July 1997, *2* (2), 185–209.

Atkinson, Anthony B., "The distribution of earnings in OECD countries," *International Labour Review*, 2007, *146* (1-2), 41–60.

Babutsidze, Zakaria, "How Do Consumers Make Choices? A Summary of Evidence from Marketing and Psychology," Technical Report, INTECH United Nations University 2007.

Bakija, Jon, Adam Cole, and Bradley T. Heim, "Jobs and Income Growth of Top Earners and the Causes of Changing Income Inequality: Evidence from U.S. Tax Return Data," Department of Economics Working Papers 2010-24, Williams College 2010.

Barro, Robert, "Economic Growth in a Cross Section of Countries," *Quarterly Journal of Economics*, 1991, *106(2)*, 407–443.

Bassin, William M., Michael T. Marsh, and Stefanie Walitzer, "A Macroeconomic Analysis Of Inventory/Sales Ratios," *Journal of Business & Economics Research*, 2003, *1* (10), 37–45.

Blanchard, Olivier J., "The Production and Inventory Behavior of the American Automobile Industry," *Journal of Political Economy*, 1983, *91* (3), pp. 365–400.

Blanchflower, David G. and Andrew J. Oswald, "The Wage Curve: An Entry Written for the New Palgrave, 2nd Edition," Discussion Paper 2138, IZA, Bonn May 2006.

Blinder, Alan S., "Inventories and Sticky Prices: More on the Microfoundations of Macroeconomics," *The American Economic Review*, 1982, *72* (3), 334–348.

_ , "Why are prices sticky? Preliminary results from an interview study," *American Economic Review*, 1991, *81* (2), 89–96.

Boeri, Tito, "Setting the Minimum Wage," IZA Discussion Papers 4335, Institute for the Study of Labor (IZA) July 2009.

Börsch-Supan, Axel H., "Panel Data Analysis of the Beveridge Curve: Is There a Macroeconomic Relation between the Rate of Unemployment and the Vacancy Rate?," *Economica*, Aug 1991, *58* (231), 279–297.

Bottazzi, Giulio and Marco Grazzi, "Wage structure in Italian Manufacturing firms," LEM Working Paper Series 2007/05, Laboratory of Economics and Management, Sant'Anna School of Advanced Studies, Pisa February 2007.

Brown, Charles and James Medoff, "The Employer Size–Wage Effect," *Journal of Political Economy*, October 1989, *97* (5), 1027–1059.

Buchanan, Mark, "Economics: Meltdown modelling. Could agent-based computer models prevent another financial crisis?," *Nature*, 2009, *460*, 680–682.

Bureau of Labour Statistics, "New Quarterly Data From BLS on Business EmploymentDynamics By Size of Firm," News, United States Department for Labor, Washington December 2005. Accessed on 06.11.2010.

Caroli, Eve and John Van Reenen, "Skill–Biased Organizational Change? Evidence from a Panel of British and French Establishments," *Quarterly Journal of Economics*, 2001, *116* (4), 1449–1492.

Celsi, Richard L. and Jerry C. Olson, "The Role of Involvement in Attention and Comprehension Processes," *Journal of Consumer Research*, 1988, *15* (2), 210–224.

Cesaratto, S., F. Serrano, and A. Stirati, "Technical Change, Effective Demand and Employment," *Review of Political Economy*, 2003, *5(1)*, 33–52.

Chiarella, Carl, *Disequilibrium, growth, and labor market dynamics: macro perspectives*, Springer, 2000.

Chiaromonte, Francesca and Giovanni Dosi, "Heterogeneity, Competition, and Macroeconomics Dynamics," *Structural Change and Economic Dynamics*, 1993, *4(1)*, 39–63.

Ciarli, Tommaso, André Lorentz, Maria Savona, and Marco Valente, "The Effect of Consumption and Production Structure on Growth and Distribution. A Micro to Macro Model," *Metroeconomica*, 2010, *61* (1), 180–218.

Coelli, Tim, Emili Grifell-Tatjé, and Sergio Perelman, "Capacity utilisation and profitability: A decomposition of short-run profit efficiency," *International Journal of Production Economics*, 2002, *79* (3), 261–278.

Colander, D., P. Howitt, A. Kirman, A. Leijonhufvud, and P. Mehrling, "Beyond DSGE models: toward an empirically based macroeconomics," *American Economic Review*, 2008, *98* (2), 236–240.

Cooper, R.W and J.C. Haltiwanger, "On the Nature of Capital Adjustment Costs," *Review of Economic Studies*, 2006, *73(3)*, 611–633.

Cornwall, John and Wendy Cornwall, "Growth Theory and Economic Structure," *Economica*, 1994, *61* (242), 237–251.

Corrocher, Nicoletta and Marco Guerzoni, "Product variety and price strategy in the ski manufacturing industry," *Journal of Evolutionary Economics*, August 2009, *19* (4), 471–486.

Criscuolo, Chiara, "Employer Size - Wage Effect: A Critical Review and an Econometric Analysis," *SSRN eLibrary*, 2000.

Cummins, Jason G. and Giovanni L. Violante, "Investment-Specific Technical Change in the United States (1947-2000): Measurement and Macroeconomic Consequences," *Review of Economic Dynamics*, 2002, *5* (2), 243 – 284.

Davis, Steven J., R. Jason Faberman, and John C. Haltiwanger, "The Establishment-Level Behavior of Vacancies and Hiring," Working Paper 16265, National Bureau of Economic Research August 2010.

Dawar, Niraj and Philip Parker, "Marketing Universals: Consumers' Use of Brand Name, Price, Physical Appearance, and Retailer Reputation as Signals of Product Quality," *The Journal of Marketing*, 1994, *58* (2), 81–95.

Dawid, Herbert and Giorgio Fagiolo, "Agent-based models for economic policy design: Introduction to the special issue," *Journal of Economic Behavior and Organization*, 2008, *67* (2), 351–354.

— **and M. Neugart**, "Agent-based Models for Economic Policy Design," *Eastern Economic Journal*, 2010, *37*, 44–50.

— **and Willy Semmler**, "Introduction to the special issue: Computational perspectives in economics and finance: Methods, dynamic analysis and policy modeling," *Journal of Economic Dynamics and Control*, 2010, *34* (9), 1529 – 1530. ¡ce:title¿Computational perspectives in economics and finance: Methods,dynamic analysis and policy modeling¡/ce:title¿.

Deissenberg, C., S. Van Der Hoog, and H. Dawid, "EURACE: A massively parallel agent-based model of the European economy," *Applied Mathematics and Computation*, 2008, *204* (2), 541–552.

Delli Gatti, Domenico, Edoardo Gaffeo, and Mauro Gallegati, "Complex agent-based macroeconomics: a manifesto for a new paradigm," *Journal of Economic Interaction and Coordination*, 2010, *5*, 111–135. 10.1007/s11403-010-0064-8.

— **, Saul Desiderio, Edoardo Gaffeo, Pasquale Cirillo, and Mauro Gallegati**, *Macroeconomics from the Bottom-up*, Vol. 1 of *New Economic Windows*, Milan: Springer, 2011.

Deltas, George, Thanasis Stengos, and Eleftherios Zacharias, "Product line pricing in a vertically differentiated oligopoly," *Canadian Journal of Economics*, 2011, *44* (3), 907–929.

Denison, E. F., "Why growth rates differ," Technical Report, Brooking Inst. Washington D.C. 1967.

— , "Accounting for slower economic growth," Technical Report, Brooking Inst. Washington D.C. 1979.

Desmet, Klaus and Stephen L. Parente, "The evolution of markets and the revolution of industry: A quantitative model of England's development, 1300-2000," Working Papers 2009-06, Instituto Madrileño de Estudios Avanzados (IMDEA) Ciencias Sociales May 2009.

DeVaro, Jed, "Employer Recruitment Strategies and the Labor Market Outcomes of New Hires," *Economic Inquiry*, 2005, *43* (2), 263–282.

Doms, M. and T. Dunne, "Capital Adjustment Patterns in Manufacturing Plants," *Review of Economic Dynamics*, 1998, *1*, 409–429.

Dosi, Giovanni, Chris Freeman, and Silvia Fabiani, "The Process of Economic Development: Introducing Some Stylized Facts and Theories on Technologies, Firms and Institutions," *Industrial and Corporate Chance*, 1994, *3* (1), 1–45.

_ **, Giorgio Fagiolo, and Andrea Roventini**, "Schumpeter Meeting Keynes: A Policy–Friendly Model of Endogenous Growth and Business Cycles," *Journal of Economic Dynamics and Control*, 2010, *34*, 1748–1767.

_ **, Silvia Fabiani, Roberta Aversi, and Mara Meacci**, "The Dynamics of International Differentiation: A Multi-Country Evolutionary Model," *Industrial and Corporate Change*, 1994, *3* (1), 225–242.

Durlauf, Steven N. and Danny T. Quah, "The New Empirics of Economic Growth," Discussion paper 384, Centre For Economic Performance January 1998. Prepared for the 'Handbook of Macroeconomics', Taylor J. and Woodford M. (eds.).

Economic Commission for Europe, *Economic Survey Of Europe, 2004*, United Nations, 2004.

Fabiani, Silvia, Martine Druant, Ignacio Hernando, Claudia Kwapil, Bettina Landau, Claire Loupias, Fernando Martins, Thomas Mathä, Roberto Sabbatini, Harald Stahl, and Ad Stokman, "What firms' surveys tell us about price-setting behaviour in the euro area.," *International Journal of Central Banking*, 2006, *2*, 3–47.

Falkinger, Josef and Josef Zweimüller, "The cross-country Engel curve for product diversification," *Structural Change and Economic Dynamics*, 1996, *7* (1), 79 – 97.

_ **and** _ , "The Impact of Income Inequality on Product Diversity and Economic Growth," *Metroeconomica*, October 1997, *48* (3), 211–237.

Farmer, J. Doyne and Duncan Foley, "The economy needs agent-based modelling," *Nature*, August 2009, *460* (7256), 685–686.

Föllmi, Reto and Josef Zweimüller, "Structural change, Engel's consumption cycles and Kaldor's facts of economic growth," *Journal of Monetary Economics*, October 2008, *55* (7), 1317–1328.

Fraumeni, B, "The Measurement of Depreciation in the U.S. National Income and Product Accounts," Survey of Current Business, Bureau of Economic Analysis July 1997.

Frydman, Roman and Michael D. Goldberg, *Imperfect Knowledge Economics: Exchange Rates and Risk*, Princeton University Press, 2007.

Funke, Michael and Ralf Ruhwedel, "Product Variety and Economic Growth: Empirical Evidence for the OECD Countries," *IMF Staff Papers*, 2001, *48* (2), pp. 225–242.

Gabaix, Xavier and Augustin Landier, "Why has CEO Pay Increased So Much?," *The Quarterly Journal of Economics*, 2008, *123* (1), 49–100.

Galbraith, James K, "Globalization and Pay," *Proceedings of the American Philosophical Society*, Jun 1999, *143* (2), 178–186.

_ **, Jiaqing Lu, and William A. Darity**, "Measuring the Evolution of Inequality in the Global Economy," UTIP Working Paper 7, University of Texas at Austin - Lyndon B. Johnson School of Public Affairs 1999.

Galor, Oded, "The 2008 Lawrence R. Klein Lecture Comparative Economic Development: Insights from Unified Growth Theory," *International Economic Review*, 2010, *51* (1), 1–44.

Gervais, Martin and Paul Klein, "Measuring consumption smoothing in CEX data," *Journal of Monetary Economics*, 2010, *57* (8), 988–999.

Gigerenzer, G., "Bounded Rationality: Models of Fast and Frugal Inference," *Swiss Journal of Economics and Statistics*, 1997, *133* (2).

_ **and R. Selten**, *Bounded rationality: The adaptive toolbox*, MIT Press, 2001.

Gintis, Herbert, "The Dynamics of General Equilibrium," *Economic Journal*, October 2007, *117* (523), 1280–1309.

Gorman, W. M., "Separable Utility and Aggregation," *Econometrica*, 1959, *27.*

Greenwood, Jeremy, Zvi Hercowitz, and Per Krusell, "Long-Run Implications of Investment-Specific Technological Change," *The American Economic Review*, 1997, *87* (3), pp. 342–362.

Greif, Avner, *Institutions and the path to the modern economy: lessons from medieval trade* Political economy of institutions and decisions, Cambridge University Press, 2006.

Hall, R.L. and C.J. Hitch, "Price theory and business behaviour," *Oxford Economic Papers*, 1939, *2*, 12–45. Reprinted in Wilson T and Andrews PWS (ed.), Oxford Studies in the Price Mechanism. Clarendon, Oxford. 1951.

Hall, S., M. Walsh, and A. Yates, "How do UK companies set prices?," Working Paper 67, Bank of England 1997. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=114948.

Hidalgo, César A. and Ricardo Hausmann, "The building blocks of economic complexity," *Proceedings of the National Academy of Sciences*, 2009, *106* (26), 10570–10575.

Hoch, Stephen J. and Young-Won Ha, "Consumer Learning: Advertising and the Ambiguity of Product Experience," *Journal of Consumer Research*, 1986, *13* (2), 221–233.

Howitt, Peter, "Coordination Issues in Long–Run Growth," in Leigh Tesfatsion and Kenneth L. Judd, eds., *Handbook of Computational Economics*, Vol. 2 of *Handbook of Computational Economics*, Elsevier, December 2006, chapter 35, pp. 1605–1624.

Hulten, Charles R., "Growth Accounting When Technical Change is Embodied in Capital," *The American Economic Review*, 1992, *82* (4), pp. 964–980.

_ , "Growth Accounting," NBER Working Paper 15341, National Bureau of Economic Research, Cambridge, MA 2009.

_ **and Frank C. Wykoff**, "The Estimation of Economic Depreciation Using Vintage Asset Prices," *Journal of Econometrics*, 1981, *15 (April)*, 367–396.

Idson, Todd L. and Walter Y. Oi, "Workers Are More Productive in Large Firms," *American Economic Review*, May 1999, *89* (2, Papers and Proceedings), 104–108.

Jung, Philip and Moritz Kuhn, "The era of the U.S.-Europe labor market divide: what can we learn?," MPRA Paper 32322, University Library of Munich, Germany July 2011.

Kaldor, N., "A Model of Economic Growth," *Economic Journal*, 1957, *December*, 65–94.

_ , *Essays on Economic Stability and Growth*, Free Press, 1960.

_ , *Causes of the Slow Rate of Growth in the United Kingdom*, Cambridge: Cambridge University Press, 1966.

King, Robert G. and Ross Levine, "Capital fundamentalism, economic development, and economic growth," Policy Research Working Paper Series 1285, The World Bank April 1994.

Kinsella, Stephen, Matthias Greiff, and Edward J. Nell, "Income Distribution in a Stock-Flow-Consistent Model with Education and Technological Change," *Eastern Economic Journal*, 2010, *Forthcoming.*

Knell, M., "Structural Change and the Kaldor-Verdoorn Law in the 1990s," *Revue d'Economie Industrielle*, 1st trimester 2004 2004, *105*, 71–84.

Krueger, Dirk and Fabrizio Perri, "Understanding Consumption Smoothing: Evidence from The U.S. Consumer Expenditure Data," *Journal of the European Economic Association*, 2005, *3* (2/3), 340–349.

Kurz, H. D. and N. Salvadori, *The Elgar Companion to Classical Economics*, Aldershot, Edward Elgar, 1998.

Lagerlöf, Nils-Petter, "The Galor-Weil model revisited: A quantitative exercise," *Review of Economic Dynamics*, 2006, *9* (1), 116 – 142.

Lancaster, K. J., "A New Approach to Consumer Theory," *Journal of Political Economy*, 1966, *14*, 133–156.

LeBaron, Blake and Leigh Tesfatsion, "Modeling Macroeconomies as Open-Ended Dynamic Systems of Interacting Agents," *American Economic Review*, May 2008, *98* (2), 246–50.

Leijonhufvud, Axel, "Agent-Based Macro," in L. Tesfatsion and K.L. Judd, eds., *L. Tesfatsion and K.L. Judd, eds.*, Vol. 2 of *Handbook of Computational Economics*, Elsevier, 2006, pp. 1625 – 1637.

Llerena, P. and A. Lorentz, "Cumulative Causation and Evolutionary Micro-founded Technical Change: On the Determinants of Growth Rates Differences," *Revue Economique*, November 2004, *55* (6), 1191–1214.

Loecker, Jan De and Frederic Warzynski, "Markups and firm-level export status," NBER Working Papers 15198, National Bureau of Economic Research, Inc July 2009.

Lorentz, André, "Essays on the Determinants of Growth Rates Differences Among Economies: Bringing Together Evolutionary and Post-Keynesian Growth Theories." PhD dissertation, Université L Pasteur Strasbourg & S'Anna School Pisa 2005.

Lydall, H. F., "The Distribution of Employment Incomes," *Econometrica*, January 1959, *27* (1), 110–115.

Maddison, Angus, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, 1987, *XXV*, 649–698.

_ , *The World Economy: A Millennial Perspective*, Paris: OECD, 2001.

_ , *The World Economy: Historical Statistics*, OECD, 2003.

Marchetti, Domenico, "Markups and the Business Cycle: Evidence from Italian Manufacturing Branches," *Open Economies Review*, January 2002, *13* (1), 87–103.

Matsuyama, Kiminori, "The Rise of Mass Consumption Societies," *Journal of Political Economy*, 2002, *110* (5), 1035–1070.

_ , "Structural Change," in Steven N. Durlauf and Lawrence E. Blume, eds., *The New Palgrave Dictionary of Economics*, Basingstoke: Palgrave Macmillan, 2008.

McCombie, J., M. Pugno, and B. Soro, *Productivity Growth and Economic Performance: Essays on the Verdoorn's Law*, MacMillan, 2002.

Nadiri, M. Ishaq and Ingmar R. Prucha, "Estimation of the Depreciation Rate of Physical and R&D Capital in the U.S. Total Manufacturing Sector," *Economic Inquiry*, 1996, *34* (1), 43–56.

Nelson, R.R. and S.G. Winter, *An Evolutionary Theory of Economic Change*, Harvard University Press, 1982.

Nickell, Stephen, Luca Nunziata, Wolfgang Ochel, and Glenda Quintini, "The Beveridge Curve, Unemployment and Wages in the OECD from the 1960s to the 1990s," Working Paper, CEPR, LSE, London 2002.

Nijkamp, Peter and Jacques Poot, "The Last Word on the Wage Curve?," *Journal of Economic Surveys*, July 2005, *19* (3), 421–450.

Oliveira, Martins Joaquim, Stefano Scarpetta, and Dirk Pilat, "Mark-Up Ratios in Manufacturing Industries: Estimates for 14 OECD Countries," OECD Economics Department Working Papers 162, OECD Publishing 1996.

Pasinetti, L. L., *Structural Change and Economic Growth: A Theoretical Essay on the Dynamics of the Wealth of the Nations*, Cambridge: Cambridge University Press, 1981.

Phelps, Edmund S., "Macroeconomics for a Modern Economy," *American Economic Review*, June 2007, *97* (3), 543–561.

Prebish, Raul, *The economic Development of Latin America and its Principal Problems*, New York: United Nations, 1950.

Prescott, Edward Simpson, "Firms, Assignments, and Earnings," *Federal Reserve Bank of Richmond Economic Quarterly*, Fall 2003, *89* (4), 69–81.

Rao, Akshay R. and Kent B. Monroe, "The Effect of Price, Brand Name, and Store Name on Buyers' Perceptions of Product Quality: An Integrative Review," *Journal of Marketing Research*, 1989, *26* (3), 351–357.

Rosen, Sherwin, "Authority, Control, and the Distribution of Earnings," *Bell Journal of Economics*, Autumn 1982, *13* (2), 311–323.

Ryoo, Jaewoo and Sherwin Rosen, "The Market for Engineers," Working Paper 83, University of Chicago - George G. Stigler Center for Study of Economy and State, Chicago 1992.

Saviotti, Pier Paolo, *Technological evolution, variety, and the economy*, Edward Elgar, 1996.

_ **and Andreas Pyka**, "Technological Change, Product Variety and Economic Growth," *Journal of Evolutionary Economics*, 2008, *18* (3-4), 323–347.

_ **and Jean Luc Gaffard**, "Preface for the special issue of JEE on 'Innovation, structural change and economic development'," *Journal of Evolutionary Economics*, 2008, *18* (2), 115–117.

Shafir, E., I. Simonson, and A. Tversky, "Reason-based Choice," *Cognition*, 1993, *49*, 11–36.

Silverberg, Gerald and Bart Verspagen, "Collective Learning, Innovation and Growth in a Boundedly Rational, Evolutionary World," *Journal of Evolutionary Economics*, 1994, *4*, 207–226.

_ **and** _ , "Learning, Innovation and Economic Growth: A Long–Run Model of Industrial Dynamics," *Industrial and Corporate Chance*, 1994, *3* (1), 199–223.

_ **and** _ , "Evolutionary Theorizing on Economic Growth," in Kurt Dopfer, ed., *The Evolutionary Foundations of Economics*, Cambridge University Press, 2005, chapter 16, pp. 506–539.

Simon, Herbert A., "The Compensation of Executives," *Sociometry*, March 1957, *20* (1), 32–35.

Sirquin, Moshe, "Patterns of Structural Change," in H. B. Chenery and T. N. Srinivasan, eds., *Handbook of Development Economics*, Vol. 1, Amsterdam: North–Holland, 1988, pp. 203–273.

Sokoloff, Kenneth L., "Was the transition from the artisanal shop to the nonmechanized factory associated with gains in efficiency?: Evidence from the U.S. Manufacturing censuses of 1820 and 1850," *Explorations in Economic History*, 1984, *21* (4), 351 – 382.

Solow, M. Robert, "Technical change and the aggregate production function," *Review of Economics and Statistics*, Aug 1957, *39* (3), 312–320.

_ , "The state of macroeconomics," *Journal of Economic Perspectives*, 2008, *22*, 243–246.

Stokey, Nancy L., "A quantitative model of the British industrial revolution, 1780-1850," *Carnegie-Rochester Conference Series on Public Policy*, 2001, *55* (1), 55 – 109.

Swann, G.M.P., "An Economic Analysis of Taste-A Review of Gary S. Becker: Accounting for Tastes," *International Journal of the Economics of Business*, 1999, *6(2)*, 281–296.

Tesfatsion, Leigh, "Introduction to the special issue on agent-based computational economics," *Journal of Economic Dynamics and Control*, 2001, *25* (3-4), 281 – 293.

Tinbergen, Jan, *Income Distribution: Analysis and Policies*, North-Holland Pub. Co, 1975.

U.S. Census Bureau, "Manufacturing and Trade Inventories and Sales," http://www.census.gov/mtis/www/mtis.html 2011.

Valente, Marco, "Evolutionary Economics and Computer Simulation. A Model for the Evolution of Markets (Vol. 1: Consumer Behaviour and Technological Complexity in the Evolution of Markets?)," 1999. DPhil Dissertation, University of Aalborg, 1999.

Verboven, Frank, "Product Line Rivalry and Market Segmentation – with an Application to Automobile Optional Engine Pricing," *The Journal of Industrial Economics*, 1999, *47* (4), 399–425.

Verdoorn, P.J., "Fattori che Regolano lo Svilluppo della Produttività del Lavoro," *L'Industria*, 1949, *1*, 45–53.

Voigtländer, Nico and Hans-Joachim Voth, "Why England? Demographic factors, structural change and physical capital accumulation during the Industrial Revolution," *Journal of Economic Growth*, December 2006, *11* (4), 319–361.

von Tunzelmann, G. Nick, *Technology and Industrial Progress: The Foundations of Economic Growth*, Aldershot: Edward Elgar, 1995.

Waldman, Michael, "Workers Allocation, Hierarchies and the Wage DIstribution," *The Review of Economic Studies*, 1984, *51*, 95–109.

Witt, Ulrich, "Evolutionary Economics and Psychology," in A. Lewis, ed., *The Cambridge Handbook of Psychology and Economic Behaviour*, Cambridge: Cambridge University Press, 2008, pp. 493–511.

Yashiv, Eran, "Labor Search and Matching in Macroeconomics," Discussion Paper 2743, IZA April 2007.

Zeithaml, Valarie A., "Consumer Perceptions of Price, Quality, and Value: A Means-End Model and Synthesis of Evidence," *The Journal of Marketing*, 1988, *52* (3), 2–22.

Zheng, Zhihao and Shida Rastegari Henneberry, "Household food demand by income category: evidence from household survey data in an urban chinese province," *Agribusiness*, 2011, *27* (1), 99–113.

A Sensitivity and stability

While an analysis of the stability against the most relevant parameters was performed in the paper, in this appendix we briefly show results on the model's sensitivity to different random seeds.

Unless differently specified, the results discussed in this paper average 20 simulation runs with different random seeds in order to control for random variability and make sure that results do not depend on random shocks. In what follows, we show that with our model averaging over 20 replicates is sufficient to wash away the randomness allowing to compromise between very large computational time and sensitivity to random effects.

Figure 3 shows the results for the output growth at constant prices, obtained from 100 different replicates with different random seeds, and the averages from random samples of different sizes. The figure shows that if we compare averages over 100, 50, 25, or

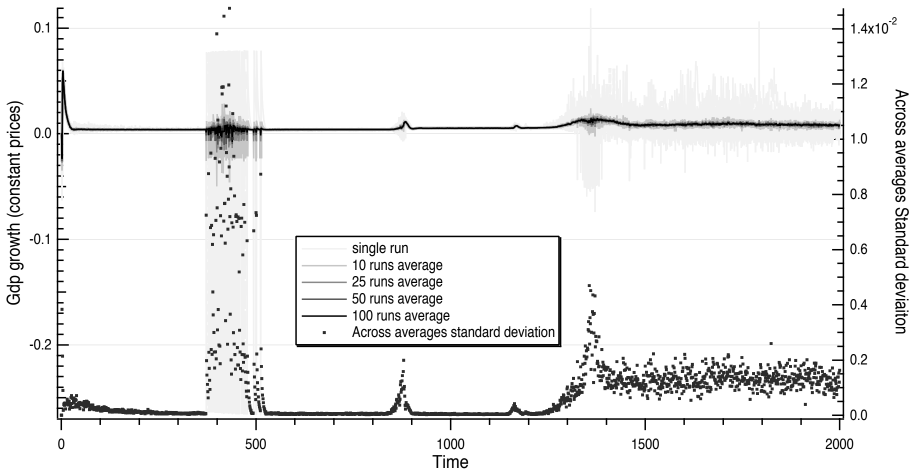


Figure 3: ***Output growth at constant prices: 100 replicates and averages***. *The light series represent the output growth results for 100 replicates with different random seeds (left y-axis). The darker series represent averages from different samples of different sizes, all converging to the same value. Finally, dots report the inter-averages standard deviation (right y-axis).*

10 replicates randomly sampled, their difference is negligible. The standard deviation between the averages converges to zero when the output growth pattern is nonexponential and sticks to very low values even when the growth pattern becomes exponential (after period 1,300). This suggests that when model results are evaluated from 20 replicates' averages, they are not biased by significant random effects.

Similarly, the Atkinson inequality index (Figure 4) shows converging values for the across runs averages and a quite small between-averages standard deviation across replicates.

To show that averages over 20 replicates are sufficiently robust, we draw on the same graph the averages of output growth and their confidence interval (CI) (Figures 5 and 6). Confidence intervals are represented by an area with different grey scales: the larger the number of random replicates averaged, the lighter the colour of the CI area. For example, if the average over 10 replicates significantly differs from the average over 100 replicates,

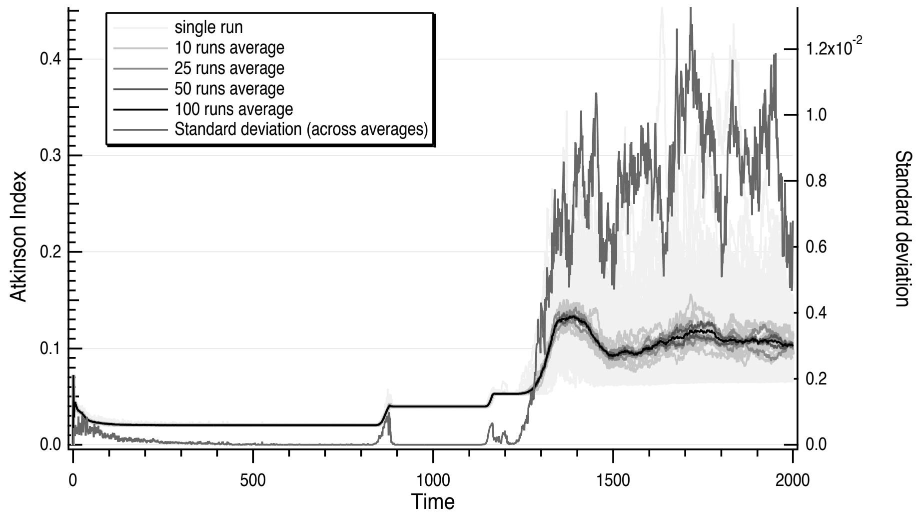


Figure 4: ***Atkinson inequality index: 100 replicates and averages***. *The light series represent the results for 100 replicates with different random seeds (left y-axis). The darker series represent averages from different samples of different sizes, all converging to the same value (left y-axis). Finally, dots report the inter-averages standard deviation (right y-axis).*

one should see the confidence area of the 10 replicates average emerging below the white CI. Otherwise, if the confidence areas of the 10 replicates' averages are completely covered by the lighter confidence area – of the 100 replicates average – we expect no significant difference. When we compare the confidence area of an average of 100 independent random

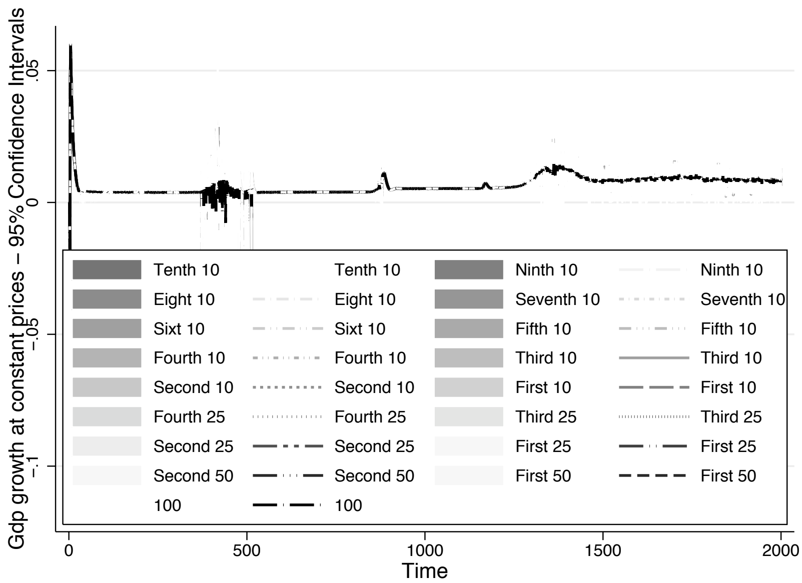


Figure 5: ***Output growth at constant prices: averages and confidence intervals***. *The figure shows the confidence areas of the different averages (over samples of 100, 50, 25, and 10 replicates) superimposed one over the other, starting from 10 replicates's averages. The grey scale goes from dark grey for 10 replicates' averages to white for the 100 replicates' average. The figure shows that no section of the 10 replicates' confidence area exceeds the 100 replicates' confidence area.*

replicates with the confidence areas of 10 random averages from 10 independent subsamples of replicates from the same 100 series, there is no difference in the CI of output growth (Figure 5). None of the 10 average areas which lie below the 100 replicates confidence area is visible. This allows us to infer that any 10 replicates' average do not generate a higher random variety than a 100 replicates average, and even less so if we average over 20 replicates.

When we perform the same exercise for the Atkinson inequality index, we obtain a very similar result (Figure 6). The difference between the confidence areas is well below one standard error. Overall, we feel confident that we can perform a robust analysis of the model using averages over 20 different replicates, reducing by an exponential factor the computational time needed to create averages for 100 different random seeds.

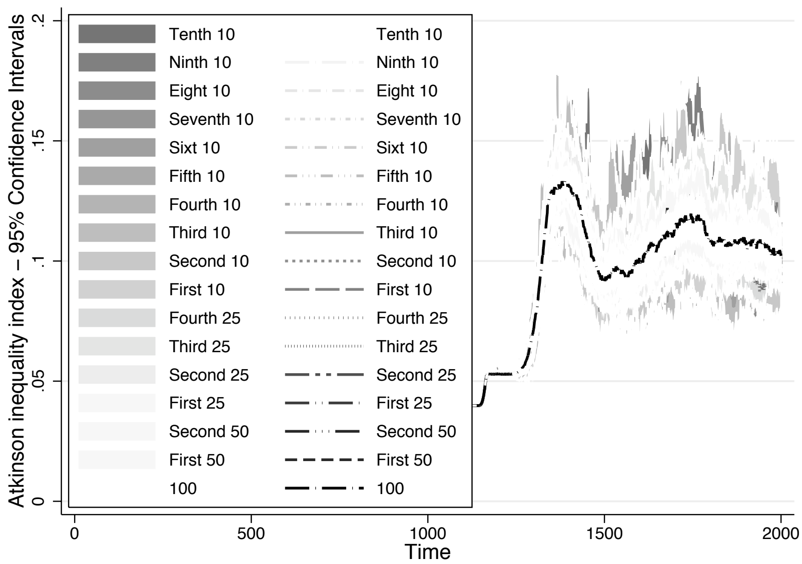


Figure 6: ***Atkinson inequality index: averages and confidence intervals***. *The figure shows the confidence areas of the different averages (over samples of 100, 50, 25, and 10 replicates) superimposed one over the other, starting from 10 replicates' averages. The grey scale goes from dark grey for 10 relicates' averages to white for the 100 replicates average. The figure then shows that very small sections of the 10 replicates' confidence area exceed the 100 runs confidence area, amounting to a very small difference between the confidence areas of the different averages.*

B Tables and Figures appendix

		$\Delta Y(200)/Y(1)$	Const.	Obs.
(1)	$\Delta A(200)/A(1)$	1.1905***	-0.0101***	100
		(0.1569)	(0.0019)	
		$\Delta Y(400)/Y(200)$	Const.	Obs.
(2)	$\Delta A(400)/A(200)$	0.0580	0.0002	100
		(0.0796)	(0.0003)	
		$\Delta Y(600)/Y(400)$	Const.	Obs.
(3)	$\Delta A(600)/A(400)$	-0.0149	7.5e-05	100
		(0.0870)	(0.0003)	
		$\Delta Y(800)/Y(600)$	Const.	Obs.
(4)	$\Delta A(800)/A(600)$	-0.1711	0.0007	100
		(0.1690)	(0.0007)	
		$\Delta Y(1000)/Y(800)$	Const.	Obs.
(5)	$\Delta A(1000)/A(800)$	0.0112	-0.0001	100
		(0.0503)	(0.0003)	
		$\Delta Y(1200)/Y(1000)$	Const.	Obs.
(6)	$\Delta A(1200)/A(1000)$	0.0605	-0.0003	100
		(0.0415)	(0.0002)	
		$\Delta Y(1400)/Y(1200)$	Const.	Obs.
(7)	$\Delta A(1400)/A(1200)$	0.0880***	-1.4e-05	100
		(0.0129)	(0.0001)	
		$\Delta Y(1600)/Y(1400)$	Const.	Obs.
(8)	$\Delta A(1600)/A(1400)$	0.1603***	-0.0008***	100
		(0.0079)	(7.6e-05)	
		$\Delta Y(1800)/Y(1600)$	Const.	Obs.
(9)	$\Delta A(1800)/A(1600)$	0.1675***	-0.0009***	100
		(0.0148)	(0.0001)	
		$\Delta Y(2000)/Y(1800)$	Const.	Obs.
(10)	$\Delta A(2000)/A(1800)$	0.1333***	0.0007***	100
		(0.0225)	(0.0002)	

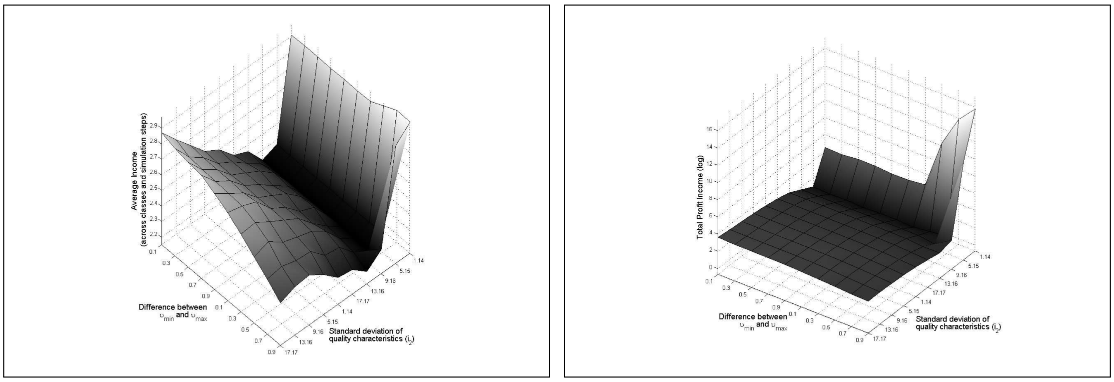
Standard errors in parentheses

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

Least Absolute Deviation: Estimates computed using the Barrodale-Roberts simplex algorithm.

Standard errors derived using the bootstrap procedure with 500 drawings.

Table 11: ***Kaldor-Verdoorn Law Sub-Period Estimations***. *Least Absolute Deviation*



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

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

Figure 7: ***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 time (**a**) as well as in the level of total income from profit shares (**b**) against different values of standard deviation of the product characteristics (x-axis) as well as against changing values of the difference between the minimum and maximum level of consumer tolerance toward quality shortfalls with respect to the best firm.*