On the Complex Dynamics of Structural Change and Growth: the role of consumption, innovation and finance

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Abstract

The present work explores the dynamics of growth and structural change by developing an agent-based computational economic (ACE) model where the dynamics of structural change is governed by demand and supply factors simultaneously. The objective of our analysis is twofold. First, to explore the macroeconomic properties of growth, business cycles and structural change that emerge from the interactions of heterogeneous firms with a financial sector. Second, to show that if one assumes the existence of demand saturation, even in the presence of increasing income and productivity, unless there is a process of product creation, economic growth with full employment of labour may not be sustained in the long run. The model replicates the dynamics of structural change, where labour reallocation among sectors is driven by demand and supply factors simultaneously. The results of our simulation indicate that growth, structural change and financial crises can emerge endogenously from the interaction between demand saturation and technical progress derived from innovation and pricing competition between heterogeneous firms.

Resumo

O presente trabalho explora as dinâmicas de crescimento e mudança estrutural através do desenvolvimento de um modelo econômico computacional baseado em agentes (ACE), onde a dinâmica de mudança estrutural é determinada simultaneamente por fatores de demanda e oferta. O objetivo da nossa análise possui dois aspectos. Primeiro, explorar as propriedades macroeconômicas de crescimento, ciclos econômicos e mudança estrutural que emergem das interações de firmas heterogêneas com o setor financeiro. Segundo, mostrar que, se assumirmos a existência de saturação de demanda nos setores, mesmo na presença de crescimento positivo da renda e da produtividade, a menos que haja um processo de criação de novos produtos/setores, o crescimento econômico com pleno emprego de trabalho pode não ser sustentável no longo prazo. O modelo reproduz a dinâmica de mudança estrutural, onde a realocação do trabalho entre os setores é determinada simultaneamente por fatores de demanda e oferta. Os resultados da simulação indicam que crescimento, mudança estrutural e crises financeiras podem emergir endogenamente da interação entre saturação de demanda e progresso técnico derivado da competição, via preços e via inovação, entre firmas heterogêneas.

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Área 2: Desenvolvimento Econômico

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1. Introduction

Although the process of economic growth might seem stable in the aggregate in the long-run, in historical perspective, the decline of the agricultural sector and the expansion of the industrial and the service sectors have led to a massive transformation of the economic landscape. The change in the relative importance of these three broadly defined sectors (agriculture, manufacturing, and services) that have accompanied the process of economic growth is one way to narrowly define structural change. However, structural change is a broader economic process that encompasses changes in the structure of production and employment within and between all sectors[1] of the economy as well as the emergence of new sectors and the disappearance of old ones.

In a broader perspective, structural change has been a phenomenon as important as economic growth. It not only changed the size and share of sectors in the economy, but also the size of cities and ultimately our way of life. One can imagine the effects of the migration of tens or hundreds of millions of people from the countryside to urban areas during the industrial revolution, or the effects of de-industrialization and the expansion of the services sector in developed economies. The first empirical evidence about the phenomenon of structural change was given by Fischer (1939), Clark (1940), Kuznets (1957), Chenery (1960).

Despite its prominence, in a theoretical perspective the study of structural change has been given less attention than that of economic growth. Only in the last two decades that the subject of structural change has gained more prominence and has become a relevant research area. The literature has focused on the explanation of the sources of structural change and has led to the development of two apparently competing hypothesis, one based on consumption evolution and another based on innovation and technical progress.

These two channels seek to explain the process of structural change by means of different mechanisms. The first channel relies on differences in income elasticities of demand across sectors. This explanation suggests that if one assumes that sectors differ in their income elasticities of demand, then increases in real per-capita income levels affect the sectoral expenditure shares leading to the reallocation of expenditure across sectors. This income effect for instance may decrease the expenditure shares of necessities and increase the expenditure shares of luxuries even at constant relative prices. Many authors rely on income effects to explain the process of structural change, including Matsuyama (1992), Echevarria (1997), Laitner (2000), Caselli and Coleman (2001), Kongsamut et al. (2001), Gollin et al. (2002) and Foellmi and Zweimüeller (2008).

This first mechanism is consistent with Engel's law[2], which is considered a general law of consumption[3]. Luigi Pasinetti, one of the leading figures in the field of structural change, argues that regardless of the level of income per-capita or the price structure, the proportion of income spent by each consumer on any specific commodity varies from one commodity to another, and as income increases, the tendency is not to increase proportionately the consumption of already bought goods and services, but rather to buy new goods and services (Pasinetti, 1981, p. 77). Due to these characteristics the literature on Engel curves often assumes that they tend to follow a logistic path.

The second channel that explains the process of structural change in expenditure relies on changes

[1] In the literature, a sector is often equivalent to an industry. Thus, it is possible to say that the manufacturing sector is composed of several manufacturing industries.

[2] In his famous 1857 article, Ernest Engel produced empirical evidence showing that the poorer a family is, the larger the budget share it spends on nourishment. This empirical regularity is known as Engel's law. Ernest Engel's analysis initially suggested that as income rises, the proportion of income spent on food falls, even if actual expenditure on food rises. Moreover, he argued that such a change in the composition of demand implies that, as the economy grows and per capita income increases, new resources can be dedicated to the production of other goods unrelated to food (Engel, 1857, p. 50). The relation that describe how expenditure on a particular good or service depends on income is called Engel curve.

[3] Deaton and Muellbauer (1980) concluded that the vast majority of studies obtains the result that the expenditure share of a product changes systematically with income.

in relative prices. These changes in relative prices affect the expenditure shares whenever the elasticity of substitution across sectors is different from one. Relative prices change through two mechanisms: (1) by assuming differential productivity growth across sectors or; (2) by assuming changes in the relative prices of inputs if sectors vary in the intensity with which they use inputs and there are changes in the relative supply of factors (Herrendorf et al., 2014). The first mechanism goes back to Baumol (1967) and was recently formalized by Ngai and Pissarides (2007), which assert that structural change results from differences in the (exogenous) rates of total factor productivity across sectors. These differences cause changes in relative prices which induce the reallocation of labour across sectors. Thus, structural change takes place driven by changes in supply factors, consumption across sectors passively *follows* labour income. The second mechanism was stressed by Acemoglu and Guerrieri (2008) through the process of capital deepening. Despite their differences, these two mechanisms can account for structural change from a supply side perspective.

Most authors see the income and the relative price effects as competing explanations but there is no evidence in the literature that proofs that they cannot simultaneously determine and drive the process of structural change. Since both explanations describe the same phenomenon, their integration, despite being a natural step, is a theoretical challenge. Boppart (2014) provides empirical evidence that both drivers of structural change are relevant. By combining non-homothetic preferences and differential TFP growth Boppart (2014) is able to explain the process of structural change driven by income and the relative price effects simultaneously. One of the limitations of Boppart's model is the assumption of exogenous TFP growth rates.

Despite the recent contributions, many aspects regarding the relation between growth and structural change are still not fully explored. The process of structural change is a much more complex phenomenon than it seems at first sight. Given its complex nature, a methodology based on agent-based modelling seems to be more suitable to explore its dynamics. Agent based models that integrate growth and structural change are fairly recent in the literature, some examples are Lorentz and Savona (2008); Ciarli et al. (2010); Ciarli (2012); Lorentz et al. (2016); Ciarli and Valente (2016). Micro-macro agent-based models give us the possibility to establish a link between consumption behaviour, innovation and financing, and thus are suitable to explore the interactions between agents (in our case firms) and some emergent macroeconomic properties (in our case growth, structural change and financial crises).

In the present article we develop an agent-based model to explore the interaction of growth, consumption and innovation, where structural change is driven by income and the relative price effects simultaneously and productivity growth is determined endogenously at the firm level. The remaining of the article is organized as follows: the next section discusses the tendency of demand to saturate and its consequence to the process of growth. Section 3 briefly introduces some of the literature that relates finance and growth, and finance and innovation. Sections 4 and 5 present the model and the simulation results respectively. Section 6 presents our concluding remarks.

2. Growth and Demand Saturation

Demand is a key component in the explanation of the phenomenon of structural change. Two properties reflecting the consumer behaviour play a central role in this explanation: the first is the difference in income elasticities of goods which reflects the hierarchical preferences of consumers when allocating their income; the second is the existence of a saturation level in consumption. The income elasticity is crucial to understand the sectoral evolution and transition and the saturation of demand is central in accounting for the size of sectors or structural composition in the long run.

Demand saturation derives from the tendency for expenditure Engel curves to flatten out at high income levels. This tendency is frequently seen as evidence that major shifts in household expenditure take place as household income rises (Aoki and Yoshikawa, 2002). Moneta and Chai (2014) using data from the UK Family Expenditure Survey and non-parametric techniques, find evidence of the tendency for Engel curves to saturate, is indeed widespread across a wide range of goods and services.

The saturation of the Engel curves means that, demand grows fast initially but eventually slows down as households reach the saturation level of income. Consequently, production of a commodity or in a sector is bound to slow down. As a result of the slowdown in demand growth, resources will be shifted away from industries where demand has saturated towards newly emerged industries producing goods for which demand has not yet saturated (Moneta and Chai, 2014). Without the introduction of new products/sectors to elicit new growth in demand, the economy's growth rate would slow down, as posed by (Andersen, 2001). This result can be seen in the model developed in section 4, which shows that growth can stagnate even in the presence of growing productivity. This conclusion confronts that of some neoclassical endogenous growth models, for which the economy is able continue growing as long as there is productivity growth. We argue that a necessary condition in order to achieve long-run growth with full employment is a mechanism which allows the economy to escape from demand satiation (Witt, 2001).

If one agrees with Pasinetti's view that demand tends to saturate, then the logical question would be "How an economy can overcome demand saturation?". The answer can be found in the process of product innovation. Economic growth has been strongly influenced by the introduction of new products. It is a fact that the introduction of new consumer products is a necessary condition for economic progress in a market economy. If there were only the same unchanged final products available in the market, consumers would inevitably become satiated, leading to stagnated demand and growth. Thus, if one assumes non-linear Engel curves with income elasticities less than one for the aggregate of existing products, the consumption ratio of an economy is bound to fall continuously in the absence of new products, which means that, the rise in per-capita income due to technical progress on the production side is not accompanied by a similarly rise in demand, leading to under-consumption (Frey, 1969). One way to overcome this imbalance between productivity growth and demand growth is represented by the emergence of new sectors. Long-term economic development and growth depends on the ability of the economic system to create new goods and services leading to new sectors (Saviotti, 2001).

In the model developed in section 4, the number of goods or sectors is fixed and restricted to three and the innovation process only affects labour productivity. Despite these limitations, the model is able to generate interesting findings that corroborate some of the results found in the literature, as it illustrates the stagnation tendency of the economic system when the number of goods is constant, even in the presence of technological progress.

3. Growth, Cycle, Innovation and Financing

The interaction between economic growth, technological progress and firm financing has been largely studied in the field of economics, from both the theoretical and the empirical perspective. But the three subjects do not appear together. There is a large body of literature on growth and innovation and another on growth and finance, though separately. An integrated approach was recently presented by Higachi et al. (2013).

A vast literature suggests the existence of a strong relation between the financial sector and economic growth (Levine, 2005). Some authors including Goldsmith (1969), McKinnon (1973) and Shaw (1973), claim the existence of a strong link between the financial superstructure of a country and its real infrastructure. This relation, according to Goldsmith (1969, p. 400) "accelerates the economic growth and enrich the economic performance on an extension that facilitates the movements of funds for its best application, that is, to places on the economy where the funds will produce higher social return rates".

In addition to the relation between finance and growth, there is a specific and complementary literature that has analysed the interaction between finance and innovation. According to Arrow (1962a) and De la Fuente and Marin (1996), in an uncertain environment, as the one where innovation takes place, firms can benefit from a well developed financial market if they are able to obtain financing for their R&D activities. As the financial system becomes more and more efficient in allocating assets to research projects, by selecting the most profitable ones and by monitoring and sharing the risks, economic growth tend to rise. That is, the financial system has a positive impact on the growth rate by allocating credit among firms with the best profit prospects. According to the literature, financial mediation may provide a solution to the problem of adverse selection on the credit market[4].

The financial system can exert a positive or a negative effect on economic growth. As observed by Brown et al. (2009), if firms need financing for R&D and there is some constrains on the supply of financing, this could lead to significant negative macroeconomic consequences. An expansion in the supply of financing may lead to an increase in R&D and a contraction to a reduction in R&D.

4. The Agent-Based Model

In order to explore the dynamics of all these elements we developed an agent-based computational economic (ACE) model. The objective of our analysis is twofold. First, to explore the macroeconomic properties of growth and structural change that emerge from the interactions of heterogeneous firms with a financial sector. Second to show that when one assumes that demand has a tendency to saturate, then the introduction of new products and/or sectors that creates new demand, is a necessary condition to sustain the process of growth with full employment of factors in the long run.

The present model portrays an economy with three sectors each one producing one good. Each sector is populated by heterogeneous firms with the same strategies regarding pricing, resources allocated to R&D and sales expectation formation. Firms differ in terms of success in innovating. Due to differences in innovation success rate, firms have different cash-flows, price levels, demand and financing needs.

The financial sector provide credit to firms which, exposed to competition by innovation and pricing, lose sales and market share and accumulate negative profits. Firms with negative profits do not invest in innovation and might lose even more sales and market share. By financing their negative profits, these firms can continue investing in innovation and might be able to increase their sales and regain market share depending on the success of their innovations. When seen from this perspective, the financial sector is a factor that positively contributes to growth. However, as firms keep increasing their debts, the risk of default is increased. If banks realize that firms' accumulated debt has risen above a certain limit, they are forced to react by increasing the interest rate. Thus, an adaptive banking system creates the possibility of credit restriction through increases in the interest rate.

A higher interest rate might make the financial situation unsustainable for the least competitive and more indebted firms forcing them to exit the market. One the one hand this process might increase the overall efficiency and productivity of the economy, however, on the other hand, if too many firms go bankruptcy due to unsustainable debt, the economy might be pushed into a general crisis.

Regarding the sectoral dynamic aspects of the model, as in Boppart (2014), structural change is driven by income and relative price effects simultaneously, but differently from Boppart (2014) wherein the sectoral productivity rates are constant and exogenous, in the present model these rates are made endogenous and are determined by a complex technological competition, based on a higher level of interaction between firms.

4.1. Production, and Inventory at Level Firm

On the production side it is assumed a pure labour economy, whose production oscillations are determined by variations on the quantity of labour employed at each period. Since we are interested in describing the labour dynamics under structural change we do not include a capital

[4] Other works on this literature include Bencivenga and Smith (1991), Levine (1991), Boyd and Smith (1992) e Saint-Paul (1992).

market in the model. It is assumed the following production function from Leontief and Strout (1963), $Y = min\{BK; AL\}$. Firms production depend on the amount of labour employed and on the production technical coefficient $A_{z,i,t}$, which varies in time and among sectors z and firms i. A firm i will produce $X_{z,i,t}$ unities at time t by hiring $L_{z,i,t}$ unities of labour with productivity given by $A_{z,i,t}$, which increases according to a process described ahead in sub-section 4.3:

$$X_{z,i,t} = A_{z,i,t} L_{z,i,t} \tag{1}$$

The economy is divided into sectors $z \in \{1, 2, ..., Z\}$, where each sector produces one final good which satisfy one consumer need. The economy has a constant labour supply. In the simulation ahead, the number of sectors is constant and set to three as a reference to the common trichotomy of agriculture, manufacturing, and services, however, the analysis can be expanded to include any number of sectors. Each sector is populated by $i \in \{1, 2, ..., n\}$ firms. Firms determine their pricing and innovation strategies by interacting with each other within their respective sectors. The economy's aggregate production is given by:

$$X_t = \sum_z \sum_i X_{z,i,t} \tag{2}$$

In order to carry out their production plans, firms hire a given quantity of labour at time t, based on their labour demand in the previous period ($L_{z,i,t-1}$), on their expected demand ($C^{Exp}_{z,i,t}$), on their productivity ($A_{z,i,t}$), and on the previous period unemployment rate (μ_{t-1}) according to the following equation:

$$L_{z,i,t} = \xi L_{z,i,t-1} + (1 - \xi) \frac{C^{Exp}_{z,i,t}}{A^{\iota(1-\mu_{t-1})}_{z,i,t}} \tag{3}$$

where ξ is a fixed parameter equal to all firms in all sectors that shows how much of their labour demand firms adjust due to variations in their expected demand, labour productivity and the unemployment rate. The parameter ι is also fixed and equal to all firms in all sectors. Firms calculate their expected demand according to the following adjusting mechanism:

$$C^{Exp}_{z,i,t} = \eta C^{Exp}_{z,i,t-1} + (1 - \eta) C^{Eff}_{z,i,t-1} \tag{4}$$

where η is a fixed parameter common to all firms in all sectors. This mechanism ensures that differences between a firm's expected and effective demand are corrected as time passes. For instance, if effective demand is higher than expected, firms do not increase production immediately, but adjust their production in the next periods, according to the interaction between equations (4), (3) and (1). Thus, if the effective demand grows at time t, production increases at time $t + 1$. This mechanism allows for a non-instantaneous adjustment of the goods market, or between supply and demand. It is possible that while some firms accumulate unplanned inventory, others might face excess demand. However, firms are able to correct these unbalances from one period to another.

The demand for goods is given by $C_{z,t}$, and is initially determined at the aggregate sectoral level. Once the aggregate sectoral demand is computed according to sub-section 4.4 ahead, it is divided among the firms within their corresponding sectors according to their market shares ($ms_{z,i,t}$). A firm's market share may vary from one period to the next, depending on its competitiveness and its price.

Since firms calculate how much to produce based on sales expectation ($C^{Exp}_{z,i,t}$), given by equation (4), their production and effective demand might not be equal, what results on the formation of unplanned inventory or excess of demand. This unbalance affects the firm's profit in that period and might even have further negative consequences. If a firm realizes negative profits and does not have enough accumulated profit in equity, it will have to resort to the banking system to finance its losses.

Firms effective demand ($C^{Eff}_{z,i,t}$) is given by the following equation:

$$C^{Eff}_{z,i,t} = ms_{z,i,t} C_{z,t} \tag{5}$$

where $C_{z,t}$ (see sub-section 4.4 ahead) is the sectoral aggregate consumption and $ms_{z,i,t}$ is the firm's market share. A firm's market share depends on its own competitiveness $E_{z,i,t}$ and on the average competitiveness $\bar{E}_{z,t}$ of all the firms in the sector, according to equation (11). A firm's own competitiveness is equal to the inverse of its price $E_{z,i,t} = 1/P_{z,i,t}$, whereas the average competitiveness $\bar{E}_{z,t}$ is equal to the weighted average of the individual competitiveness within the sector, with the individual market share as the weighting factor (Dosi et al., 1994).

Firms produce a quantity $X_{z,i,t}$ based on their sales expectations $C^{Exp}_{z,i,t}$. If production is higher than effective demand $C^{Eff}_{z,i,t}$, the difference will be accumulated in the form of inventory $X^S_{z,i,t}$. This can be summarized in equation (6).

$$X^S_{z,i,t} = \begin{cases} X_{z,i,t} + X^S_{z,i,t-1} - C^{Eff}_{z,i,t} & \text{if} \quad C^{Eff}_{z,i,t} < X_{z,i,t} + X^S_{z,i,t-1} \ , \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

If effective demand is higher than their production plus previous period inventory, then $X_{z,i,t}$ goes to zero.

4.2. Price, Mark-up, Income and Firms profit

Firms' effective demand depend on their market share and, therefore, on their prices and on their mark-ups. The firms' mark-up must be sufficiently high to cover their operational costs (basically wages), R&D and financial expenses. If a firm has a loss in a certain period, it has to finance it in the financial market by taking out a loan. Accumulated debt generates financial expenses that make its product more expensive. If an individual firm does not have any accumulated debt and does not take any financing in the current period, then it will set its price equal to its previous period's. Firms price formation is described by the following equation

$$P_{z,i,t} = (1 + mk_{z,i,t}) \frac{W_{z,i,t}}{C^{Exp}_{z,i,t}} \tag{7}$$

where $mk_{z,i,t} > 0$ is the firms mark-up rate. It is important to note that the pricing mechanism as specified in (7), does not mean that the only source of price change is the ratio between the firm's total labour cost ($W_{z,i,t}$) and its expected demand ($C^{Exp}_{z,i,t}$). When a firm successfully innovates, it reduces its price through two channels. The first is a direct channel that can seen in equation (7). A successful innovation increases productivity and reduces $W_{z,i,t}$, the firm's labour costs, which increases its profits. More profit means a reduction on accumulated debt ($D^S_{z,i,t}$), if it exists. A reduction in the firm's debt might affect its price again by reducing its mark-up ($mk_{z,i,t}$) (see equations 8 and 9), as the mark-up adjusting rate takes into account the firm's debt. This logical path, by which the technological progress may affect the firm's price, is not very obvious at first sight. Increases in productivity have positive effects on wages, firm's profits and on the firm's debt management.

The mark-up rate is fixed by firms through an adaptive and interactive behaviour. First, firms calculate how much they want to increase or decrease their mark-up rate by calculating a desirable mark-up adjusting rate ($mk^{des}_{z,i,t}$) based on two factors. The first factor is related to the firms' demand. If a firm's effective demand is recurrently higher (lower) than its production, the firm will want to increase (reduce) its mark-up rate. Second, if the firm has accumulated debt, it will want to increase its mark-up rate to raise more revenue to pay for the financial expenses ($DF_{z,i,t-1} = i_{t-1} D^S_{z,i,t-2}$). The desirable mark-up adjusting rate is calculated by the following additive equation:

$$mk^{des}_{z,i,t} = \frac{\check{mk}_1}{\left[1 + \lambda_1 \exp\left(\lambda_2 \left(\frac{C^{eff}_{z,i,t-1}}{X_{z,i,t-1}}\right)\right)\right]^{\lambda_3}} + \frac{\check{mk}_2}{\left[1 + \lambda_4 \exp\left(\lambda_5 (DF_{z,i,t-1} - f)\right)\right]^{\lambda_6}} \tag{8}$$

where $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \check{mk}_1, \check{mk}_2$ and f are parameters constant over time and equal to all firms in all sectors. The parameters $\check{mk}_1, \check{mk}_2$ represent the maximum increase in mark-up that each firm is able to apply. This values are exogenous and constant and are listed on table A.1. After having determined its desirable mark-up adjusting rate, each firm evaluates the feasibility of effectively implementing this adjustment onto its mark-up rate. In order to do that a firm compares its price with the average price of *four*[5] randomly selected firms. If its price is higher than the average price $(\bar{P}_{z,t})$, the firm reduces its desired mark-up rate by a factor $(1-\rho+mk^{des}_{z,i,t})$. If its price is lower than the average, the firm raises its mark-up rate by a factor $(1+\rho+mk^{des}_{z,i,t})$, where $0<\rho$. One of the main advantages of this approach is that it allows for the adjustment of firms mark-up to the market conditions as a whole. This mechanism also ensures that, although firms compete in prices, since they are always monitoring their competition, increases in productivity do not change prices too drastically. Formally the firms' mark-up is determined by the following equation:

$$mk_{z,i,t} = \begin{cases} (1-\rho+mk^{des}_{z,i,t})mk_{z,i,t-1} & \text{if} \quad P_{z,i,t-1} > \bar{P}_{z,t-1}, \\ (1+\rho+mk^{des}_{z,i,t})mk_{z,i,t-1} & \text{if} \quad P_{z,i,t-1} < \bar{P}_{z,t-1} \end{cases} \tag{9}$$

Once the firm has determined its mark-up rate and consequently its price, these variables will determine the firms market share $(ms_{z,i,t})$ in each period, and its effective demand $(C^{Eff}_{z,i,t})$, as it was described previously in equation (5). A firm's market share depends on its competitiveness, which is related to its price. We define competitiveness as being the inverse of the firm's price, as follows:

$$E_{z,i,t} = \frac{1}{P_{z,i,t}} \tag{10}$$

thus, the market share can be calculated by assuming that a firm owns a larger portion of the market, if its price is below the average market price, and a smaller portion if it is above the average price, as defined by the equation (11):

$$ms_{z,i,t} = \left[1+\beta\left(\frac{E_{z,i,t-1}}{\bar{E}_{z,t-1}}-1\right)\right]ms_{z,i,t-1} \qquad \textit{and} \qquad 0<\beta<1 \tag{11}$$

where β is a common parameter to all firms and measures the market share sensibility in relation to the competitiveness (price) degree. A larger β, means that a firm gains more market share if its price is below the market's average and vice-versa.

After defining its price and its market share, the firm is able to calculate its revenue, operational costs and its profit. The firm's total revenue is composed of operational revenue and financial revenue, which is interest income received on its accumulated profits remunerated at a percentage κ of the interest rate (i). Total costs are composed of the operational costs (wages), R&D expenses calculated as a percentage $(\varphi_{z,i})$ of accumulated profits at the beginning of period t and financial expenses on the accumulated debt. Hence, the firm's total profit at the end of period t is given by:

$$\Pi_{z,i,t} = (R^O_{z,i,t} + R^F_{z,i,t} - W_{z,i,t} - DF_{z,i,t} - RD_{z,i,t}) \tag{12}$$

In equation (12), $RD_{z,i,t} = \varphi_{z,i}\Pi^S_{z,i,t-1}$ is the share of accumulated profits that the firm allocates to R&D in each period. $R^O_{z,i,t}$ is the firm's operational revenue, $R^F_{z,i,t}$ is the financial revenue from accumulated profits at the beginning of period t, remunerated at a percentage κ of the interest rate (i), $W_{z,i,t}$ is the firm's total labour cost, which in this case is the firm's total variable cost, and $DF_{z,i,t} = i_t D^S_{z,i,t-1}$ is the firm's financial expenses, calculated by applying the interest rate i_t to the

[5]The exact number of firms is not crucial, one can assume any number or even that firms compare their prices with the market's average price. It is a matter of firms' market monitoring capacity.

firm's accumulated debt $D^S_{z,i,t-1}$. We assume that the parameter $\varphi_{z,i}$ is constant over time, this means that firms always allocate the same percentage of their profits to R&D, independently of the macroeconomic situation. A firm's total labour cost ($W_{z,i,t}$) depends on the nominal wage (V_t) and its labour demand ($L_{z,i,t}$):

$$W_{z,i,t} = V_{t-1}L_{z,i,t} \tag{13}$$

The Nominal wage (V_t) is calculated at the economy level by the following equation:

$$V_t = \begin{cases} \left[1 + \left(\frac{A_t}{A_{t-1}} - 1\right)\left(1 - \mu_{t-1}\right)^{\zeta}\right] V_{t-1} & if \quad \frac{A_t}{A_{t-1}} - 1 > 0, \\ V_{t-1} & otherwise \end{cases} \tag{14}$$

where A_t is the economy's average productivity rate at time t, ζ is a fixed parameter and μ_{t-1} is the economy's unemployment rate at time $t-1$.

4.3. Technological Progress and Productivity

Once technical change is taken into account, technological improvements that raise labour productivity will affect firms' profitability and financial fragility, as they affect unit labour costs and, therefore, the firms' competitiveness. This interaction becomes more intense and complex when technological progress is endogenous. Technological progress, in this model, results from one of three different sources: from dynamic increasing returns to scale deriving from a 'learning by doing' cumulative process, from imitation and from innovation based on the firm's own R&D.

The first source, follows the concept of dynamic increasing returns to scale arising from 'learning by doing' as analysed by Arrow (1962b) and embedded in the Kaldor-Verdoorn Law. In this first channel, productivity grows as a function of the firm's own production expansion. This is represented in equation (15), where the technological learning rate depends linearly on the production growth rate:

$$\hat{A}^{LD}_{z,i,t} = \delta_1 \hat{X}_{z,i,t} \qquad \text{if} \qquad \hat{X}_{z,i,t} > 0 \tag{15}$$

and

$$A^{LD}_{z,i,t} = (1 + \hat{A}^{LD}_{z,i,t})A_{z,i,t-1} \tag{16}$$

where δ_1 is the Kaldor-Verdoorn coefficient, which represents the sensibility of labour's productivity growth relative the growth of production. This parameter is is exogenous and constant to all firms[6]. $\hat{A}^{LD}_{z,i,t}$ is the rate of technological learning from production and $\hat{X}_{z,i,t}$ is the production growth between periods $t-1$ and t. Additionally, $A_{z,i,t-1}$ is the firm's productivity at time $t-1$. The restriction $\hat{X}_{z,i,t} > 0$ implies that negative growth of production do not cause technological unlearning.

The second source of increase in labour productivity is imitation. This source of technological progress is stochastic, local and is available to all firms. The technology subjected to imitation has some tacit components, what means that the imitating firm is only capable of absorbing part of the productivity from its imitated counterpart. First, the imitating firm randomly selects three firms and compare their productivities before deciding which one it is going to imitate. The imitating firm chooses the technology of the firm with the highest productivity within the selected ones, formally we have:

$$A^{IM,max}_{z,i,t} = \max(A^{IM}_{1,z,t-1}, A^{IM}_{2,z,t-1}, A^{IM}_{3,z,t-1}) \tag{17}$$

Once the imitated firm is chosen, the next step is to define how much of that firm's productivity can be imitated. This depends on the technological distance between the imitating and the imitated

[6] A Kaldor-Verdoorn coefficient equal to zero would imply that no 'learning by doing' takes place. Although equation (15) applies the Kaldor-Verdoorn Law correlation at the microeconomic level, the aggregate relation is preserved.

firm, as shown by the following equation:

$$A^{IM}_{z,i,t} = A_{z,i,t-1} + \exp\left[-\ln\left(\frac{A^{IM,max}_{z,i,t-1}}{A_{z,i,t-1}}\right)\right]\delta_2(A^{IM,max}_{z,i,t-1} - A_{z,i,t-1}) \tag{18}$$

The functional form of equation (18) captures the technological gap effect. The wider the gap between the two firms the less the imitating firm is able to absorb from the imitated one's technology. Since the wider the gap the harder it is to make the technological transition or "jump". The exponent of the neperian term captures the technological gap, which follows an inverse exponential process. The parameter δ_2 determines how much of the productivity difference between the imitating and the imitated firm will be absorbed by the former.

The third source of technological change is the innovation based on the firms' own research. At the beginning of each period firms allocate a fraction $\varphi_{z,i}$ of their accumulated profits $\Pi^S_{z,i,t}$ to R&D. Even though innovation depends on R&D expenses, it is a highly uncertain process. Therefore, in the present model this process is set as a two stages stochastic event. In the first stage, there is the event "success or failure" in the discovery of a new technology, while in the second stage there is the event of increasing labour productivity, which follows an inverse exponential function as in Nelson and Winter (1982) and Valente and Andersen (2002).

In equation (20), the probability of innovation follows an exponential inverse process that depends on the relation of R&D expenses to total revenue and on cumulative effects of productivity $A^{IN}_{z,i,t-\tau}$. The relation of R&D expenses to total revenue ($RDR_{z,i,t-1}$) is given by,

$$RDR_{z,i,t-1} = \frac{RD_{z,i,t-1}}{RT_{z,i,t-1}} = \frac{\varphi_{z,i}\Pi^S_{z,i,t-2}}{(R^O_{z,i,t-1} + R^F_{z,i,t-1})} \tag{19}$$

Therefore, to capture the non-linearity of the labour productivity growth, in equation (21) we assume that the event "success" in innovate results from an inverse exponential distribution with mean $\ln(A_{z,i,t-\tau})$ and variance σ_2^2. This result is only implemented if the probability of innovation ($P^{IN}_{z,i,t}$) given by (20) is greater than or equal to a pseudo-random number generated by a uniform probability distribution function varying between 0 and 1:

$$P^{IN}_{z,i,t} = \frac{\gamma_0}{(1 + \gamma_1 \exp -\gamma_2 RDR_{z,i,t-1})^{\Omega_1}} + \frac{\gamma_0}{(1 + \gamma_3 \exp -\gamma_4 A^{IN}_{z,i,t-\tau})^{\Omega_2}} \tag{20}$$

where γ_0, γ_1, γ_2, γ_3, γ_4, Ω_1 and Ω_2 are parameters that adjust the sensibility of the probability of innovating to accumulated profits ($\Pi^S_{z,i,t}$) and to cumulative effects of productivity ($A^{IN}_{z,i,t-\tau}$). The value of the probability is $P^{IN}_{z,i,t} \in [0,1]$. The innovation's productivity is, therefore, calculated as:

$$A^{IN}_{z,i,t} = \begin{cases} \exp Norm(\ln A_{z,i,t-1}, \sigma_2^2) & \text{if} \quad P^{IN}_{z,i,t} \geq \text{RND(0,1)} \\ A_{z,i,t-1} & \text{if} \quad P^{IN}_{z,i,t} < \text{RND(0,1)} \end{cases} \tag{21}$$

The innovation process has a cumulative technological learning component, therefore its productivity depends on cumulative effects of past productivity. The firm may discover a technology that results in higher or lower labour productivity than the old one. If the newly discovered technology delivers a lower productivity than it will not be implemented and the firm will continue to use the old technology.

We have described three sources of technical progress that firms can resort to in order to increase their labour productivities. It can be thought that each source correspond to a different technology that delivers a different level of productivity. The firm will compare these three technologies: the one deriving from 'learning by doing', the one deriving from imitation and the one deriving from innovation based on the firm's own research. Then, the firm will choose the technology that delivers the highest labour productivity among these three options. This is formalised by equation (22):

$$A_{z,i,t} = \max(A^{LD}_{z,i,t}, A^{IM}_{z,i,t}, A^{IN}_{z,i,t}) \tag{22}$$

The firm will only implement the new technology if it delivers a productivity higher than the productivity at $t-1$, otherwise the firm do not innovate and maintains the previous period's level of productivity $A_{z,i,t-1}$.

4.4. Aggregate Consumption at Sectoral Structure

Consumption is determined at the aggregated sectoral level and faces a saturation limit. In the present model, each sector $z \in \{1, 2, 3, ...Z\}$ has a different hierarchical logistic consumption function. Aggregate sectoral consumption is computed by equation (23) and is asymmetrically affected by two components: wage and interest rate. Wage has a positive impact on consumption while the interest rate has a negative impact. The share α of the consumption that is determined by wages W depends on a minimum and a maximum level of consumption C_z^{min} and C_z^{max} respectively, which are exogenous and constant. The maximum consumption level C_z^{max} is the saturation limit which, in this model, is different for each of the three sectors. The share of the consumption that depends on the interest rate $(1-\alpha)$ depends on wages W_{t-1} from the previous period and on the difference between the interest rate adjusted by mark-up charged by the banks i_{t-1}, which we will call the lending interest rate, and the deposit interest rate i_t^*, which is the rate of interest that banks pay on deposits by firms. The deposit interest rate can be a fixed parameter or a variable, in this model it is assumed to be a fixed parameter.

$$C_{z,t} = \alpha C_{z,t}(W_{t-1}) + (1-\alpha) C_{z,t}(W_{t-1}, i_t) \tag{23a}$$

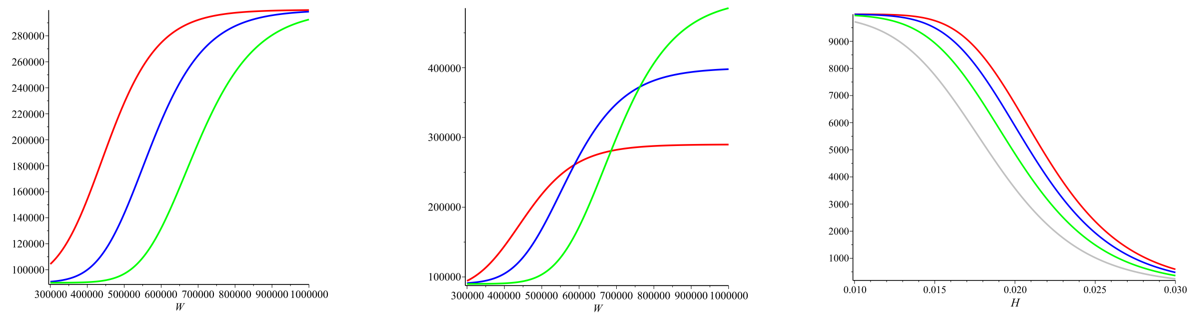
$$C_{z,t}(W_{t-1}) = C_z^{min} + \frac{(C_z^{max} - C_z^{min})}{\left[1 + q_z^1 \exp(-\frac{W_{t-1}}{g_z^1})\right]^{\psi_z^1}} \tag{23b}$$

$$C_{z,t}(W_{t-1}, i_t) = C_{z,t}(W_{t-1}) \left[1 - \frac{1}{[1 + q_z^2 \exp(-g_z^2(i_{t-1} - i_t^*))]^{\psi_z^2}}\right] \tag{23c}$$

The parameters q_z^1, g_z^1, ψ_z^1, q_z^2, g_z^2 and ψ_z^2 are exogenous and adjust the shape of the demand curve and the speed of saturation. Some of these parameters are equal to all sectors and some are different, their values are in table (A.1). The minimum level of consumption C_z^{min} is the same for all three sectors.

The behaviour of the consumption function can be illustrated in figure (1). Figures (1a) and (1b) show how sectoral consumption evolves according to income growth (W). In figure (1a) all the sectors have the same saturation limit, while in figure (1b) they have different limits. Figure (1c) illustrates how sectoral consumption evolves with respect to the interest rate. As the interest rate rises, consumption declines.

Figure 1: Consumption evolution to Income (W) and Interest Rate (H)



(a) (b) (c)

Sectors differ in their income elasticities of demand and in their productivities. Sectoral productivity is calculated by the average of that sector firms' productivities weighted by their market share. In the model, firms in sector 1 have the lowest variance of innovation, thus productivity in sector 1 is the lowest. Firms in sector 2 have an intermediate value and firms in sector 3 have the highest variance of innovation, making then the most productive ones, and thus sector 3 the most productive sector. Sectoral demand evolves in a hierarchical way. Demand in sector 1 starts to growth before the other two sectors, only after a certain level of income has been reached that demand in the other two sectors start to grow at a significant rate.

4.5. The Financing of the Firm and the Banking Sector

In the present model, firms not only produce goods and invest in R&D but also interact with the banking system, financing their losses by taking out loans to finance their negative cash flows (negative profits). The loan operation lasts only one period and, if the firm does not obtain enough profit to pay the interest on the debt and/or to write it off, a new loan is taken out in the next period and the process goes on until the firm is able to eliminate its debt. If a firm accumulates more debt than a certain multiple of its total revenue, the firm goes bankruptcy and exit the market. In our simulation, this multiple is ten.

Equations (24) to (27) formalise the mechanism through which the banking system finances the firms. The banking system or the financial sector is represented in a simple and straightforward manner. It can be understood as a pool of representative banks or as one bank that receives demand deposits and grant loans to firms. The deposit interest rate (i^*) is the rate banks pay firms on their accumulated profits invested in the financial system. In the present model, the deposit interest rate is assumed to be constant and exogenous. The lending interest rate (i_t) is the rate charged by banks for loans to firms. The difference between the two rates ($i_t - i^*$) is the net interest spread. This mechanism assumes an endogenous money supply in the sense of Kaldor (1982, 1985) and Moore (1988). This approach to the money supply is also known as the "horizontalist approach", according to which banks are passive and adjust the quantity of money to a given interest rate, money has an infinity elasticity of supply. Therefore, credit is restricted by means of price (the interest rate) not quantity.

The supply of credit is endogenous and determined by the firm's demand for credit. The firm's demand for credit is equal to its losses or negative profits $D_{z,i,t} = \Pi^{-}_{z,i,t}$. A firm's negative profit needs to be covered by bank loans. Since all the firm's losses automatically become debt, the firm's accumulated debt $D^{S}_{z,i,t-1}$ is equal to its accumulated negative profit. The economy's aggregate demand for credit (also the economy's total debt) in period t is calculated by the sum of all the individual firms' demand for credit, formally given by:

$$D_t = \sum_{z} \sum_{i} \Pi^{-}_{t} \tag{24}$$

The lending interest rate for the loan operations is calculated by applying a mark-up (h_t) over the deposit interest rate, according to the following equation:

$$i_t = (1 + h_t) i^* \tag{25}$$

Banks set the lending interest rate (i_t) based on their evaluation of the economy's degree of indebtedness. Once set, it is applied to all firms, independently of their individual degree of indebtedness. The banks' mark-up (h_t) is adjustable and might change from one period to the next depending on a loan payment default indicator (d_t), which is ratio of the economy's total debt to its total accumulated profits,

$$d_t = \frac{\sum_z \sum_i \Pi^{-}_{t}}{\sum_z \sum_i \Pi^{S}_{t}} \tag{26}$$

The risk adjusted banking mark-up is given by:

$$h_t = \frac{h^{max}}{[1 + \theta_1 \exp \theta_2 d_{t-1}]^{\theta_3}} \tag{27}$$

where h^{max} is the maximum mark-up set by the banks and $\theta_1, \theta_2, \theta_3$ are parameters that control the sensibility of the mark-up to the degree of risk perceived by the banking system at each period. It is assumed that h^{max} is exogenously fixed. An increase in the default rate at any period raises the expected default rate for the next period. Banks react by increasing their risk adjusted mark-up for the next period. Empirical evidence for this behaviour can be found in Angbazo (1997), Saunders and Schumacher (2000) and Brock and Rojas-Suarez (2000).

The present model, although having a relatively simple general structure, being comprised an aggregated demand function, of a number of heterogeneous firms grouped into sectors and a representative financial sector, is capable of producing interesting emergent macroeconomic dynamics due to its evolutionary behaviour and complex interactions.

5. Simulation and Results

In order to evaluate this complex system of sectoral growth and dynamics, we conducted a simulation and assessed the evolution of three sectors[7]. Sectors differ in some of their demand curve parameters that control for the shape and speed of saturation of demand, on the saturation limit or maximum consumption of each sector C_z^{max} and on the variance of innovation σ_2^2, that controls the possible impact of an innovation on the firms productivity in that sector. Sector 1 has the lowest variance of innovation, sector 2 has an intermediate value and sector 3 has the highest variance of innovation. Their variance of innovation are reported in table (A.1).

Each sector is composed of 100 firms at the beginning of the simulation. The simulation is run through 500 periods. The banking system provides financing to all the firms in all three sectors. The firms ability to finance themselves derives from their profitability, which in turn depends on their success on innovate or on imitate their competitors. The deposit interest rate i is fixed at 1%. The economy and sectors' initial conditions are so that, each sector starts with effective demand set at 100.000 units, at a price of 1.00. Sectors 1, 2 and 3 have their saturation limits set at 300.000, 400.000 and 500.000 units respectively. All firms in all sectors start with market shares of 1%, which then evolve as firms adjust their mark-ups according to equation (9). Firms' market shares change by a percentage β of the difference between their prices and the sector's average price. In this simulation β is set at 0.1 for all three sectors. All the firms start with accumulated profits of 1.000, in order to allow them to survive for a longer time in the beginning. Lastly the banks' mark-up is set initially at 1%.

Figure (2) shows, as expected, that the sectoral consumption evolution follows a logistic form. This is due to the functional form chosen for the demand curve. The different shapes of the sectoral demand curves represent the different income elasticities of demand of each sector. Sectoral consumption and production fluctuate very closely but are not equal. This is because firms accumulate (decrease) inventory when their expected demand is higher (lower) than their effective demand. As we can see in figures (4), (5) and (6) these two variables tend to move closely together due to the adaptive characteristics of the model's equations. During the period of rapid expansion of consumption, effective demand grows faster than expected demand for all sectors. After consumption reaches the saturation point the two variables match.

[7]The simulation was computed with the Laboratory for Simulation and Development (LSD) software, version 7.0, developed by Valente (2008). The model's code can be made available upon request.

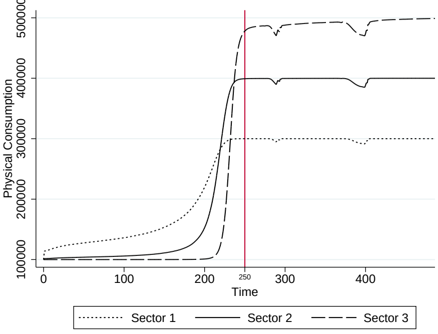


Figure 2: Sectoral Consumption

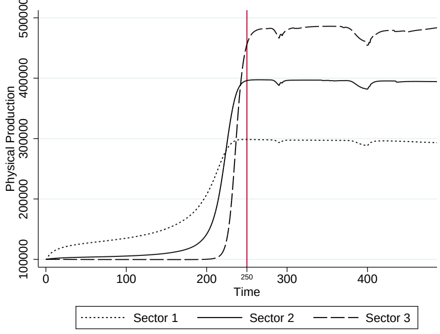


Figure 3: Sectoral Production

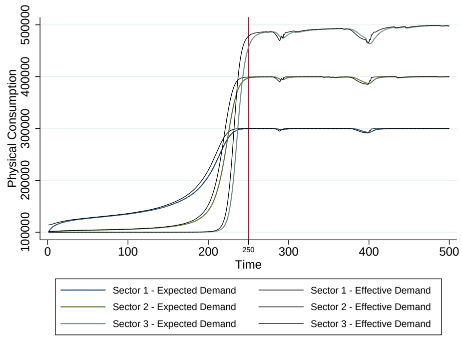


Figure 4: Expected and Effective Demand

The simulation resulted in two financial crises, a smaller one starting around period 280 and a bigger one starting around period 374. These crises can be seen in figures (2) and (3) in terms of fall in consumption and production, and in figures (9) and (10) in financial terms. A financial crisis is characterised here by an increase in the lending interest rate charged by banks. When the lending interest rate rises, consumption in all sectors falls as it is affected by the lending interest rate according to equation (23) and consequently production also falls. Moreover, a higher lending interest rate put indebted firms in a more difficult situation.

At the beginning of the crises effective demand declines faster then expected demand. When the economy starts to recovery, effective demand grows faster than expected demand. This can be seen in figures (5) and (6), which depicts the effects of the financial crises on effective and expected demand in sector 3. This property is the result of the adaptive expectational characteristic of the model and shows that when consumption changes in either direction, firms take time to adjust to the new scenario. In both crises, as the lending interest rate starts to fall, effective demand starts to increase and eventually returns to its previous saturation level. The same pattern can be observed in sectors 1 and 2.

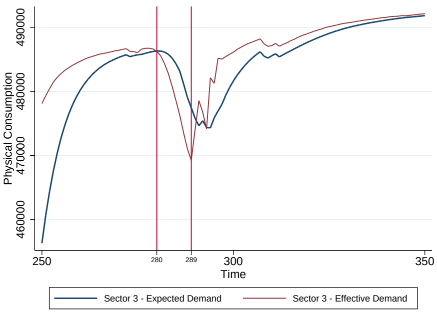


Figure 5: Sector 3 - Effective v.s Expected Demand Crises 1

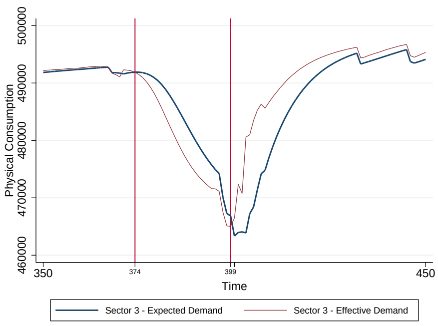


Figure 6: Sector 3 - Effective v.s Expected Demand Crises 2

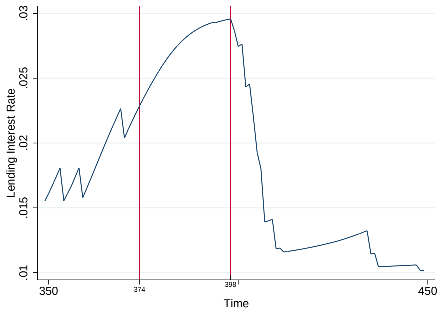


Figure 7: Lending Interest Rate During Second Crisis

Apparently, financial crises as the ones observed in our simulation tend to happen after sectoral demand has reached saturation. One explanation is that, after demand saturates, production stagnates and technological progress based on "learning by doing" is reduced, thus firms start to compete more based on innovation through R&D, leading to a greater inequality among firms in terms of productivity. With greater competition less productive firms tend to present higher rates of accumulated debt which increases the economy's overall indebtedness and risk of default, the Bank's risk rate. The financial system reacts by increasing the lending interest rate as we can see in figures (8), (9) and (10), this action makes the situation even more difficult for already indebted firms and have a negative impact on consumption and on production.

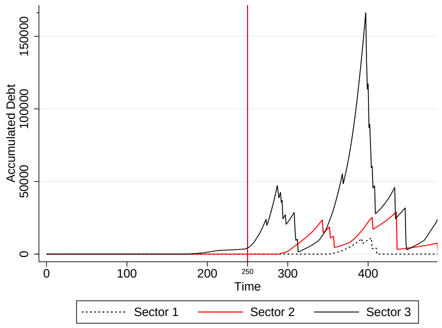


Figure 8: Sectoral Accumulated Debt

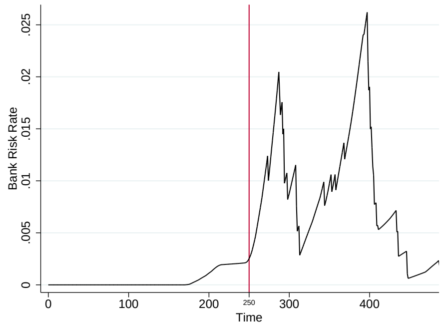


Figure 9: Loan Payment Default Indicator (Bank's Risk Rate)

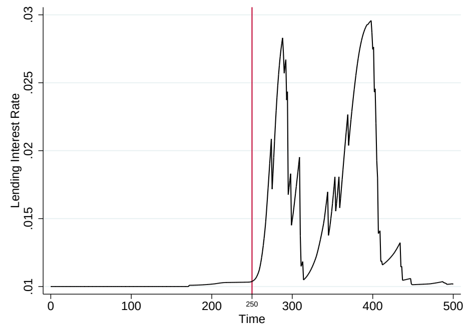


Figure 10: Interest rate Adjusted by Mark-up of the Banks (Lending Interest Rate)

The model also generates a process of structural change which derives from demand and supply factors simultaneously, as sectors differ in their income elasticities of demand and in their productivity rates. The sectoral employment evolution is related to the evolution of demand, but is also affected by the evolution of the sectoral productivity. When we look at employment in absolute terms, the three sectors seem to behave in similar ways. However, when we analyse the evolution of each sector's share of the economy's total employment we can observe an intense structural change until around period 250, after which, due to saturation in demand, structural change is significantly reduced as we can see in figure (13).

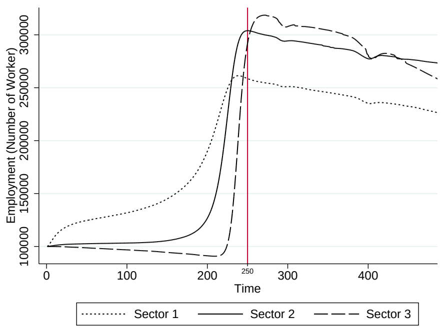


Figure 11: Sectoral Employment

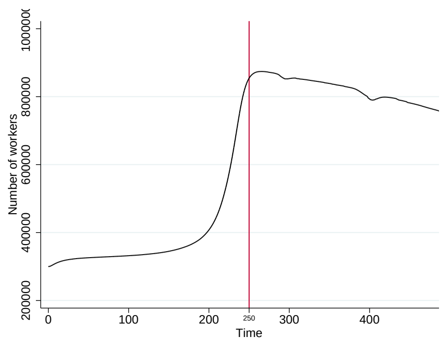


Figure 12: Economy's Total Employment

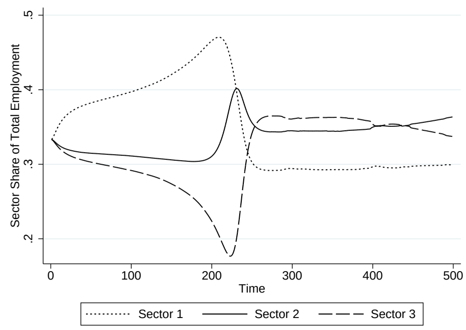


Figure 13: Sector Labour Share

After demand reaches saturation, employment in each sector starts to decline as firms continue to increase their productivities and need less workers to produce the same amount of goods. The speed of employment decline in each sector is different depending on the rate of increase of their productivities, which is determined at the firm level. Sector 3 with the fastest increase in productivity due to its high rate of innovation has the fastest decline in employment as it can be seen in figure (11). Moreover, productivity increases are reflected in lower prices. As it can be seen in figures (14) and (15) sectors with higher average productivity present lower increases in price. Sector 1, for instance, where increases in average productivity are the smallest, experiences the largest increase in price.

Some variables in the model are determined by the dynamics of the economy as a whole, such as nominal and real wages. They are affected by increases in the economy's average productivity rate, which in turn is affected by the level of innovation and competition among firms in all three sectors and by the unemployment rate. As we can see in figure (16), these variables initially increase due to increased demand and later, after demand saturates, they continue to rise due to higher wages resulting from increased labour productivity.

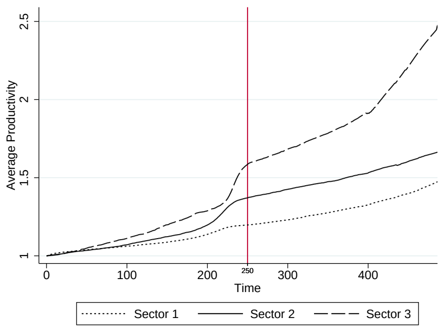


Figure 14: Average Productivity

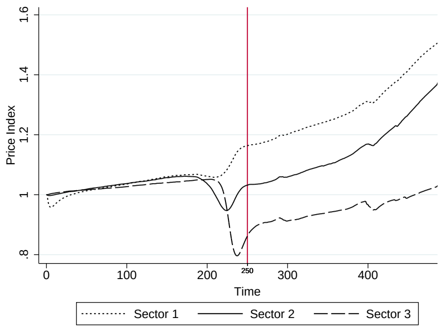


Figure 15: Sectoral Price Index

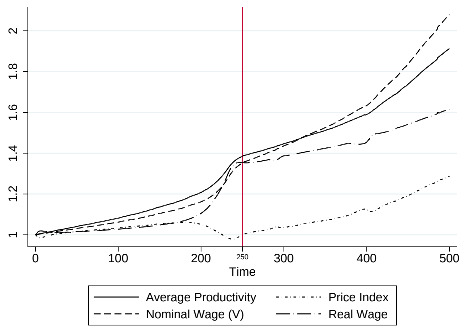


Figure 16: Variables at Economy level

At a microeconomic level, the interactions among the firms produce complex behaviour of system. Firms in sector 3 have a higher variance of innovation. Consequently, they innovate more based on R&D, but they also demand accumulate more debt. One of the consequences is that, starting with a hundred firms in each sector, at the end of the simulation sectors 1 had 97 firms, sector 2 had 93 and sector 3 had 73 firms. Sector 3 lost more firms then the other two. This pattern is also recurrent in simulations with other micro calibrations. The most innovative sector tend to lose more firms then the other sectors.

Regarding the firms' technological strategy, they have three options of technology available at each period: a technology deriving from 'learning by doing', one from imitation and one from innovation based on the firm's own R&D. The third option might not be available to all firms at all times because some firms may not have accumulated profits to invest in R&D. Firms evaluate the productivity of each of the three technologies and choose, each period, the one that provides the highest productivity. Then, they compare the productivity of the new technology with the productivity of the technology used in the previous period. If the new technology delivers a higher productivity, firms switch to the new technology, if not, they continue to use the old one and productivity remains at the same level as the previous period.

Technical progress based on 'learning by doing' tend to be intense among firms in periods of rapid expansion of production. As demands reaches saturation, increases in productivity due to 'learning by doing' are significantly reduced. Table (A.2) shows the total number of each type of innovation in each sector considering all periods. The total of 50000 is the product of 500 periods in the simulation times 100 firms in each sector. Throughout the simulation some firms leave the market, so they appear in the table as empty cases due to firm disappearance. No innovation means that the firm kept the same technology and thus the same level of productivity of the previous period.

In sector 3, when innovations occur they have a greater impact on productivity, this means that it will take longer for a new technology to be able to deliver an even higher productivity, that is why sector 3 has the most cases of "no innovation". Thus, innovation based on R&D, for instance, in sector 3 are less frequent but have a greater impact on labour productivity then in the other two sectors. This is a direct result of the higher variance of innovation σ_2^2 of sector 3. In terms of sectoral average productivity sector 3 is far the most productive, as we could see in figure (14).

6. Concluding Remark

In the present model the macroeconomic and sectoral dynamics emerge from a cumulative process based on the interactions of heterogeneous agents. Economic growth, business cycles and structural change are emergent phenomena of complex, interactive and evolutionary behaviour of heterogeneous agents. The model showed the possibility to reproduce complex macroeconomic patterns of growth, structural change and business cycles from microeconomic dynamics.

The model replicates the dynamics of structural change where production factors (labour) is reallocated across the three sectors. In our model, the process of structural change is driven by demand and supply factors simultaneously, as sectors differ in their income elasticities of demand and in their productivity rates, determined at the firm level. Our analysis only develops one aspect of technological progress, the innovation of process. One of our findings is that when demand saturation is assumed to exist, one of the consequences of continuous increase in productivity, in an economy with no creation of new products/sectors, is a decline in employment in the log run. One way to escape this situation and increase employment, is to introduce new products/sectors that create new demand and sustain growth. Our analysis corroborates Saviotti (2001)' findings that long-term economic development and growth depends on the ability of the economic system to create new goods and services leading to new sectors .

The study of the evolution of demand , structural change and the emergence of new sectors which creates new demand, is crucial if one wants to comprehensively understand the process of long-run economic growth. In order to understand the interactions between sectoral dynamics and growth, one should account for the increase/decrease in the number of sector/products in the economy. Moreover, the emergence of new sectors, demand saturation and technological progress are elements that must be analysed simultaneously. We believe that agent-based computational economic (ACE) models offer a more flexible framework to deal with these issues.

By adding a financial dimension to the analysis of growth and structural change we created a channel through which microeconomic dynamics at the firm level could explain the emergence of crises in technologically developed economies. The negative impact of firms' bankruptcy, resulting from the intense technological competition, spreads out to the whole system affecting sectors with different intensities due to their heterogeneous demand. Financial crises are endogenous properties of a market economy and can emerge even when firms follow general innovation and pricing strategies. This conclusion is not a novelty and was already described in Minsky (1982). In principle, there is no behavioural assumption in the micro-foundations and nothing in the agents strategic behaviour that could lead to a financial crisis. Notwithstanding, crises do appear and are the result of the complex aspect of the model and of the real economy.

Our model can be extended in several directions. Three extensions are most promising. First, while our model assumes a fixed number of goods/sectors, the introduction of a process of product creation would enrich the analysis by creating the possibility for the labour displaced by increases in productivity be absorbed by the new sectors. Second, while our analysis has assumed a sectoral aggregated demand, the introduction of more consumer heterogeneity is potentially interesting, as the existence of rich and poor households with different consumption bundles would open up a new channel by which income inequality could affect growth and structural change. Third, hierarchic preferences and product specialization in a world economy where rich countries would specialize in new goods with a high income elasticity and poor countries would produce old goods with a low elasticity.

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Appendix A.

Table A.1: List of Parameters

Description	Par.	Equa.	Sect.1	Sect.2	Sect.3
Same values for all Sectors					
Desirable Mark-up Parameter	λ_1	8	8	8	8
Desirable Mark-up Parameter	λ_2	8	-40	-40	-40
Desirable Mark-up Parameter	λ_3	8	3	3	3
Desirable Mark-up Parameter	λ_4	8	0.01	0.01	0.01
Desirable Mark-up Parameter	λ_5	8	-0.2	-0.2	-0.2
Desirable Mark-up Parameter	λ_6	8	0.5	0.5	0.5
Desirable Mark-up Parameter	$\check{mk}_1$	8	0.03	0.03	0.03
Desirable Mark-up Parameter	$\check{mk}_2$	8	-0.03	-0.03	-0.03
Desirable Mark-up Parameter	f	8	80	80	80
Firms Mark-up adjustment Par.	ρ	9	0.03	0.03	0.03
Firm's Market-share Gain	β	11	0.1	0.1	0.1
Percentage of Remuneration of i	κ	12	0.8	0.8	0.8
% Profit Devoted to R&D	φ	12	0.1	0.1	0.1
Labour Demand Adjustment	ξ	3	0.8	0.8	0.8
Labour Demand Adjustment Parameter	ι	3	0.5	0.5	0.5
Expected Demand Parameter	η	4	0.8	0.8	0.8
Nominal Wage Adjustment Parameter	ζ	14	0.6	0.6	0.6
Share of Demand Derived from Wages	α	23	0.9	0.9	0.9
Demand Curve Parameter	q_z^2	23	100	100	100
Demand Curve Parameter	g_z^2	23	300	300	300
Kaldor-Verdoorn Coefficient	δ_1	15	0.1	0.1	0.1
Imitation Productivity Absorption	δ_2	18	0.9	0.9	0.9
Probability of Innovating Parameter	γ_0	20	0.075	0.075	0.075
Probability of Innovating Parameter	γ_1	20	20	20	20
Probability of Innovating Parameter	γ_2	20	200	200	200
Probability of Innovating Parameter	γ_3	20	5	5	5
Probability of Innovating Parameter	γ_4	20	0.15	0.15	0.15
Probability of Innovating Parameter	Ω_1	20	2	2	2
Probability of Innovating Parameter	Ω_2	20	2	2	2
Deposit Interest Rate	i^*	25	0.01	0.01	0.01
Bank's maximum mark-up	h^{max}	27	2	2	2
Bank's Mark-up Parameter	θ_1	27	5	5	5
Bank's Mark-up Parameter	θ_2	27	-250	-250	-250
Bank's Mark-up Parameter	θ_3	27	3	3	3
Sector specific values					
Demand Curve Parameter	q_z^1	23	80	70	120
Demand Curve Parameter	g_z^1	23	1.25e-5	1e-5	8e-6
Demand Curve Parameter	ψ_z^1	23	2.5	3.5	4.5
Demand Curve Parameter	ψ_z^2	23	5.0	4.0	3.0
Variance of Innovation	σ_2^2	21	0.008	0.015	0.023

Table A.2: Firms Innovation Strategies

Number of Cases	Sector 1	Sector 2	Sector 3
No innovation	17112	16193	24033
Learning by Doing	30892	31327	20968
Imitation	900	976	980
Innovation based on R&D	802	817	785
Empty cases due to firm disappearance	294	687	3234
Total	50000	50000	50000