Structural Change and Business Cycles : An Evolutionary Approach *

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Abstract

The aim of this paper is to account for both the short-run fluctuations and the very-long run transformations induced by technological change in analysing long-run growth patterns. The paper investigates the possible imprint left by short-run fluctuations on the long run dynamics by affecting the mechanisms underlying structural change. To fulfil this aim, we revert to a growth model with evolutionary micro-founded structural change. The model endogenies both technical change and changes in patterns of final and intermediate demand as affecting macro-economic growth, through the structural change of the economy. This work is in line with the attempts to embracing in a unifying framework both neo-Schumpeterian and Keynesian line of thoughts in explaining economic growth. This model directly extends the one presented in Lorentz and Savona (2008). The paper reverts to numerical simulations to investigate both the imprint of various business cycles scenarios on the structural change patterns and the effect of various structural change scenarios on the amplitude of business cycles. We carry out the numerical simulation on the basis of the actual I-O coefficients for Germany. These numerical simulations show us that one the one hand, the factor at the source of business cycles drastically affect the patterns of structural change. On the other hand, the mechanisms at the core of structural change, generates business cycles as a by-product.

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1 Introduction

Understanding the sources of economic growth is an age-old issue in economics. Technological change has long ago been recognised as playing a key role in the processes of economic growth, and long-run development. It is also widely accepted that technological change is resulting from economic activity (being the accumulation of capital and machinery, R&D activity and/or knowledge accumulation). Investments are the key to sustain the process of economic growth and the long-run development of economies. As a result of this process economies experience drastic transformations in their structure. One can logically wonder whether the crisis advanced economies have been experiencing recently have an effect on their ability to sustain technological change and the resulting structural transformations at the core of the process of economic growth. In other words, do short-run fluctuations affect structural change ?

The literature on short-run fluctuations is a well established body of the macro-economic literature.[1] Varieties of formal models analyse the emergence and/or persistence of short-run fluctuations. The literature mainly revolves around two major and opposite view on the sources of these fluctuations:

(i) In the case of the 'Real Business Cycle' (RBC) theory, the sources of business cycles are to be found in exogenous shocks. In this case, short-run fluctuations are responding to stochastic shocks on the supply-side of the economy, such as productivity or technological shocks (as in the seminal work by Kydland and Prescott (1982)) or due to the propagation of external shocks through international exchanges (Backus, Kehoe, and Kydland, 1994). The initial shock propagates within the economy, generating persistent fluctuations around the long run equilibrium path. Within this literature, and in particular in its empirical branch, the structure of the economy is considered as affecting the propagation of these shocks. When considered, structural change is then treated as an exogenous factor affecting business cycles. In overlooking the possible effect of short-run fluctuations on structural changes, these empirical works remain in line with one of the key assumption made by the RBC, that short-run fluctuations do not modify the long run growth path.

(ii) A second approach, in direct line with the Keynesian and New Keynesian literature, considers short-run fluctuations as inherent to the economic activity. These endogenous Business Cycles find their sources either in structural market imperfections and/or in the behaviour of economic agents. On the one hand, short-run fluctuation are inherent to the economy due to possible mismatch, in the short-run, between supply and demand at the aggregated level (Samuelson, 1939; Harrod, 1948) or distributional tensions due to rigidities in the labour market dynamics (Goodwin, 1951; Goodwin, 1967). On the other hand, these short-run fluctuations can also emerge from informational imperfections

[1] Given that our present paper focuses on the effect of short-run fluctuations on patterns of structural change, we choose not to discuss the Business Cycles literature in details. Standard canonical models in this literature can be found in most macro-economic textbooks.

and/or frictions in behavioural patterns, leading to an excessive reactivity of the credit market (Minsky, 1980; Minsky, 1982), the propagation of market instability (Greenwald and Stiglitz, 1993; Akerlof and Yellen, 1985) or even perturbations in the market structure (Dos Santos Ferreira and Dufourt, 2006).

The developments of the Business Cycles literature, especially in the second half of the 20th century occurred in parallel to the literature on long-run economic growth. The modern growth theory is largely dominate by the New Growth Theory (NGT) (Aghion and Howitt, 1998). Due to the underlying idea that short-run fluctuations are not a long-run concern, shared by both the NGT, and the RBC literature, little concern is drawn on the interactions between short-run fluctuations and long-run growth path. Very little can be found in the NGT on structural change either. On the other hand, structural change is one on the major concerns of the heterodox approaches to economic growth, these include among others the *'Unbalanced Growth'* approach (Baumol and Bowen, 1966; Baumol, 1967) , the Post-Keynesians (Kaldor, 1966; Pasinetti, 1981; Cornwall and Cornwall, 1994) , the Neo-Schumpeterians (Dosi, Fabiani, Aversi, and Meacci, 1994; Montobbio, 2002; Saviotti and Pyka, 2004; Saviotti and Pyka, 2008; Metcalfe, Ramlogan, and Foster, 2006), the Neo-Austrians (Amendola and Gaffard, 1998) or the *'Regulation School'*.[2] Despite some crucial differences among these bodies of literature, all these share the idea that the very process of long-run growth is closely related to drastic changes in the structure of economies. The sources of structural change are then to be found in the very sources of long-run economic growth: the uneven expansion of outlets and resources as well as in the differences in efficiency, or efficiency increase among the various activities composing the economies. In most of the cases structural change is driven by a combination of this set of elements. The mechanisms at the core of the process of structural change can be grouped into three main classes:

(i) Structural change can be driven by competition, through international trade and sectorial specialisation. Economies tend to specialise in the economic sectors for which they experience or gained competitive advantage. This argument is in line with the traditional Ricardian argument. This process can then become self-reinforcing in case of emerging or existing increasing returns.(Cimoli, 1988; Cimoli, 1994; Dosi, Fabiani, Aversi, and Meacci, 1994; Los and Verspagen, 2006; Cimoli and Porcile, 2010; Lorentz, Forthcoming).

(ii) Structural change can be driven by modifications in the production apparel. Transformations in the nature of production, or of the production process lead to a transformation of the employment and/or output structure of the economy. These can be driven by productivity differentials, fostering transformations in favour of the reduction of production costs (Baumol and Bowen, 1966; Baumol, 1967; Montobbio, 2002; Ngai and Pissarides, 2007), a macro-level division of labour à la Young (1928) leading to the emergence of new sector (Saviotti and Pyka, 2004; Saviotti and Pyka, 2008) or transformations in the

[2] Silva and Teixeira (2008) propose a bibliometric account of the literature on structural change, however, largely incomplete due to the limitations of such exercise.

technological and/or organisational structure of the production process (Amendola and Gaffard, 1998; Metcalfe, Ramlogan, and Foster, 2006).

(iii) Structural change can be driven by transformations in aggregate demand. The structure of final consumption bounds the extension of output. The structure of expenditures relies on the differences in income elasticities and the expansion of income, shaping the long run structure of the economies and their changes (Kaldor, 1966; Pasinetti, 1981; Verspagen, 1993; Cornwall and Cornwall, 1994; Lorentz, 2006; Föllmi and Zweinmüller, 2008). This approach is in direct line with the more empirical analysis bridging structural transformations and Engel curves (Fisher, 1935; Clark, 1940).

Only few heterodox models do consider explicitly structural transformations and short-run fluctuations. On the one hand, considering transformations in the technological structure of the economy, Silverberg and Lehnert (1993) generate both short-run fluctuations and long-waves in the economic activity. Amendola and Gaffard (1998) argue that short-run fluctuations emerge from the discontinuities generated by the transformation in the production structure of the economy and the resulting mismatch between supply and demand at the aggregate level. On the other hand, Witt and Brenner (2008) or Ciarli and Valente (2007), explicitly connect the emergence of short-run cycles to the structural transformations of the economy, without however explicitly endogenising the process of structural change itself. In all these cases, the authors overlook the effect of the short-run fluctuations on the process of structural change.

The target of this paper is to account for both sides of the coin: On the one hand, we aim at investigating the imprint left by short-run fluctuations on the long run mechanisms of structural change. On the other hand, we aim to account for the effect of changes in the structure of economies on the amplitude of the short-run fluctuations. We are convinced that all the elements required to fulfill this aim are already present in the heterodox literature. The present paper therefore tries to recombine them.

We propose a formal model of economic growth, where structural change, at the macro-level finds its source at the level of firms' dynamics. This model is extending the model presented in Lorentz and Savona (2008). The sectoral structure of the economy is a function of both intermediate demand, resulting from firms production technology, and the structure of consumer's demand. Firms production technology evolves due to technological changes allowed by firms investments. The firms' investments are constrained by their sales, themselves constrained by both a meso-level selection mechanism and the macro-level structure of aggregate demand (intermediate and finale). In this respect, the model relies on an evolutionary micro-foundations of structural change.

Final demand is a function of (i) the income redistributed to workers by firms through wages, and (ii) external demand. The income available for final consumption is constrained by the expansion of wages and employment. Following Goodwin (1951) and Goodwin (1967), business cycles are generated by short run fluctuations on the labour market. The dynamics of wages follow a Phillips' curve; wages grow as employment grows. Employment dynamics depends on the balance between the expansion of effective demand, and the corresponding increase of labour demand, and that of labour productivity at the firm level, reducing the labour required to produce. As detailed in the next section, the co-evolution of these two mechanisms are at the source of the short-run fluctuations in employment and wages at the sectoral level, spreading to fluctuations in GDP at the macro-level. The model, therefore also model endogenous fluctuations.

More generally, we model both long-run transformations in the structure of the economy as well as short-term fluctuations through the co-evolution of effective demand and technological change. In this respect the model is in direct line with the recent attempts to embrace both Neo-Schumpeterian and Post-Keynesian lines of though in analysing macroeconomic dynamics (Verspagen, 1993; Llerena and Lorentz, 2004; Verspagen, 2004; Los and Verspagen, 2006; Metcalfe, Ramlogan, and Foster, 2006; Lorentz and Savona, 2008; Dosi, Fagiolo, and Roventini, 2010; Ciarli, Lorentz, Savona, and Valente, 2010). It also completes the literature on economic growth in that it accounts within the same model for both the structural transformations and the short-run fluctuations and their co-evolution.

We revert to numerical simulations to investigate both the imprint of various business cycles scenarios on the structural change patterns and the effect of various structural change scenarios on the amplitude of business cycles. We carry out the numerical simulation on the basis of the actual I-O coefficients for Germany as used in Lorentz and Savona (2008).

The remainder of the paper is organised as follows: Section 2 presents the formal model. Section 3 reports and discusses the simulation procedure (Section 3.1) as well as the result obtained (Section 3.2). Section 4 concludes the paper.

2 A Model of Endogenous Structural Change

Formally, the paper relies on an agent-based model, structured as follows:

- An economy is composed of J sectors indexed $j \in [1; J]$.
- Each sector j counts I firms indexed $i \in [1; I]$.
- The index t accounts for the time period the variable is computed.

This section presents the components of the model starting with the macro-economic framework of the model (2.1), followed by the description of the micro-dynamics of firms (2.2).

2.1 Defining the Structure of the Economy: The macro-frame

Drawing on an I–O framework (Leontief (1951)), we decompose the sectoral output into three components: intermediate consumption, final domestic consumption and (net) foreign consumption. The aggregate output is therefore a function of the sectoral structure of the economy, which in turn is determined by the components of aggregate demand.

$$\begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{j,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} = \begin{pmatrix} I_{1,t} \\ \vdots \\ I_{j,t} \\ \vdots \\ I_{J,t} \end{pmatrix} + \begin{pmatrix} C_{1,t} \\ \vdots \\ C_{j,t} \\ \vdots \\ C_{J,t} \end{pmatrix} + \begin{pmatrix} X_{1,t} \\ \vdots \\ X_{j,t} \\ \vdots \\ X_{J,t} \end{pmatrix} - \begin{pmatrix} M_{1,t} \\ \vdots \\ M_{j,t} \\ \vdots \\ M_{J,t} \end{pmatrix} \tag{1}$$

Aggregate demand ($Y_{j,t}$) for each sector j is decomposed in three components: Intermediate consumption ($I_{j,t}$), final domestic consumption ($C_{j,t}$) and net exports ($X_{j,t} - M_{j,t}$).

2.1.1 Decomposing aggregate demand

Intermediate consumption for a given sector j corresponds to the aggregation of the demand of sector j products by firms in each $k \in [1, .., J]$ sectors used for production. This intermediate demand is a function of the level of production of the demanding firms and of their production technology[3]. Once aggregated the sectoral level of intermediate demand can be expressed as follows:

$$I_{j,t} = \sum_{k=1}^{J} Y^{D}_{j,k,t} = \sum_{k=1}^{J} a_{j,k,t} Y_{k,t} \tag{2}$$

where $Y^{D}_{j,k,t}$ represents the demand for sector j products by the sector k; $Y_{k,t}$ represents the level of production in sector k, and $a_{j,k,t}$, the aggregation of intermediate coefficients are computed as follows:

$$a_{j,k,t} = \sum_{i} z_{k,i,t} a_{j,k,i,t-1} \tag{3}$$

where $z_{k,i,t}$ represents the market share of firm i belonging to sector k; firms' market shares are defined by the equation 21 and $a_{j,k,i,t}$ represents the intermediate coefficient of firm i (belonging to sector k) for sector j products.

The vector I_t of intermediate consumption can therefore be represented as follows:

$$\mathbf{I_t} \equiv \begin{pmatrix} I_{1,t} \\ \vdots \\ I_{j,t} \\ \vdots \\ I_{J,t} \end{pmatrix} = \begin{pmatrix} a_{1,1,t} & \dots & a_{1,k,t} & \dots & a_{1,J,t} \\ \vdots & \ddots & & & \vdots \\ a_{j,1,t} & \dots & a_{j,k,t} & \dots & a_{j,J,t} \\ \vdots & & & \ddots & \vdots \\ a_{J,1,t} & \dots & a_{J,k,t} & \dots & a_{J,J,t} \end{pmatrix} \begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{k,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} \tag{4}$$

Final consumption corresponds to the component of aggregate demand emanating from households. We assume here that at each time period, households spend their entire income among the J sectors' products. Households' income corresponds to the total wage

[3]See equation 17

bill of the economy. The distribution of expenditure shares c_j remains fixed in time.[4] Final consumption for sector j ($C_{j,t}$) is a share c_j of the aggregate real income level deflated by the price index of the sector j. The level of final consumption addressed to each sector j can therefore be expressed as follows:

$$C_{j,t} = \frac{c_j}{p_{j,t-1}} \sum_{k=1}^{J} w_{k,t-1} L_{k,t} \tag{5}$$

where $p_{j,t-1}$ represents the price index of sector j[5], $L_{k,t}$ and $w_{k,t-1}$ correspond respectively to the sector k level of employment level and wage rate. Firms' level of employment is deduced from their sales level as a function of their of labour productivity. We can deduce the sectoral level of employment as follows:

$$L_{k,t} = \sum_i L_{k,i,t} = \sum_i \frac{Y_{k,i,t}}{A_{k,i,t-1}} = \sum_i \frac{z_{k,i,t} Y_{k,t}}{A_{k,i,t-1}} \tag{6}$$

The vector C_t of final consumption is therefore computed as follows:

$$\mathbf{C_t} \equiv \begin{pmatrix} C_{1,t} \\ \vdots \\ C_{j,t} \\ \vdots \\ C_{J,t} \end{pmatrix} = \begin{pmatrix} \frac{c_1 w_{1,t}}{p_{1,t-1}} \sum_i \frac{z_{1,i,t}}{A_{1,i,t}} & \cdots & \frac{c_1 w_{k,t}}{p_{1,t-1}} \sum_i \frac{z_{k,i,t}}{A_{k,i,t-1}} & \cdots & \frac{c_1 w_{J,t}}{p_{1,t-1}} \sum_i \frac{z_{J,i,t}}{A_{J,i,t-1}} \\ \vdots & \ddots & & & \vdots \\ \frac{c_j w_{1,t}}{p_{j,t-1}} \sum_i \frac{z_{1,i,t}}{A_{1,i,t}} & \cdots & \frac{c_j w_{k,t}}{p_{j,t-1}} \sum_i \frac{z_{k,i,t}}{A_{k,i,t-1}} & \cdots & \frac{c_j w_{J,t}}{p_{j,t-1}} \sum_i \frac{z_{J,i,t}}{A_{J,i,t-1}} \\ \vdots & & & \ddots & \vdots \\ \frac{c_J w_{1,t}}{p_{J,t-1}} \sum_i \frac{z_{1,i,t}}{A_{1,i,t}} & \cdots & \frac{c_J w_{k,t}}{p_{J,t-1}} \sum_i \frac{z_{k,i,t}}{A_{k,i,t-1}} & \cdots & \frac{c_J w_{J,t}}{p_{J,t-1}} \sum_i \frac{z_{J,i,t}}{A_{J,i,t-1}} \end{pmatrix} \begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{k,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} \tag{7}$$

The last component of aggregate demand corresponds to the net exports. The sectorial level of exports ($X_{j,t}$) are assumed to grow exogenously at a constant rate δ. We neutralise here the effect of changes in the export patterns (or specialisation patterns) as a source for structural change to focus the analysis on domestic sources of structural change.[6] For each sector j, the level of imports ($M_{j,t}$) corresponds to a share m_j of the total domestic demand ($I_{j,t} + C_{j,t}$). Sectoral net exports are defined as follows:

$$X_{j,t} - M_{j,t} = X_{j,0}(1+\delta)^t - m_j(I_{j,t} + C_{j,t}) \tag{8}$$

[4] Our aim in this paper is to focus on the transformation of the industrial structure of the economy as source of structural change, therefore overlooking final demand as a trigger for structural change. Preexisting papers have been investigating final consumption as the driving force of structural change. Among these, and in a similar vein than the present model, one might more particularly consider Verspagen (1993), Lorentz (2006), or Ciarli, Lorentz, Savona, and Valente (2010)

[5] The price index is computed as:

$$p_{j,t} = \sum_i p_{j,i,t} z_{j,i,t}$$

where $z_{j,i,t}$ represents the market share of firm i belonging to sector j.

[6] Note that we analyse the effect of international trade and sectoral specialisation on structural transformation and on the growth patterns of economies more specifically in Lorentz (Forthcoming).

while at the macro-level, net exports can be described as follows:

$$\mathbf{X_t} - \mathbf{M_t} \equiv \begin{pmatrix} X_{1,t} \\ \vdots \\ X_{j,t} \\ \vdots \\ X_{J,t} \end{pmatrix} - \begin{pmatrix} M_{1,t} \\ \vdots \\ M_{j,t} \\ \vdots \\ M_{J,t} \end{pmatrix} = \begin{pmatrix} X_{1,0} \\ \vdots \\ X_{j,0} \\ \vdots \\ X_{J,0} \end{pmatrix} (1+\delta)^t - m_j \begin{pmatrix} I_{1,t} + C_{1,t} \\ \vdots \\ I_{j,t} + C_{j,t} \\ \vdots \\ I_{J,t} + C_{J,t} \end{pmatrix} \tag{9}$$

2.1.2 Macro-identity and reduced form of the model

Introducing equation 4, 7 and 9 in equation 1, we obtain the following expression for the vector of sectoral demand:

$$\begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{j,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} = \begin{pmatrix} \alpha_{1,1,t} & \dots & \alpha_{1,k,t} & \dots & \alpha_{1,J,t} \\ \vdots & \ddots & & & \vdots \\ \alpha_{k,1,t} & \dots & \alpha_{j,k,t} & \dots & \alpha_{k,J,t} \\ \vdots & & & \ddots & \vdots \\ \alpha_{J,1,t} & \dots & \alpha_{1,k,t} & \dots & \alpha_{J,J,t} \end{pmatrix} \begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{k,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} + \begin{pmatrix} X_{1,0} \\ \vdots \\ X_{j,0} \\ \vdots \\ X_{J,0} \end{pmatrix} (1+\delta)^t \tag{10}$$

with

$$\alpha_{j,k,t} = (1 - m_j) \left(a_{j,k,t} + \frac{c_j}{p_{j,t-1}} w_{k,t-1} \sum_i \frac{z_{k,i,t}}{A_{k,i,t-1}} \right)$$

This expression leaves us with a vector of sectoral demand as a function of the sectoral production levels, the exogenous vector of external demand. In a traditional Keynesian fashion, we assume that the levels of production are constrained by effective demand in the short-run. Hence the vector of level of sectoral production has to match the vector of sectoral demand. We then obtain the reduced form of our model from this last equation, assuming the short-run macroeconomic identity holds:

$$\begin{pmatrix} Y_{1,t} \\ \vdots \\ Y_{j,t} \\ \vdots \\ Y_{J,t} \end{pmatrix} = \begin{pmatrix} 1-\alpha_{1,1,t} & \dots & -\alpha_{1,k,t} & \dots & -\alpha_{1,J,t} \\ \vdots & \ddots & & & \vdots \\ -\alpha_{k,1,t} & \dots & 1-\alpha_{j,k,t} & \dots & -\alpha_{k,J,t} \\ \vdots & & & \ddots & \vdots \\ -\alpha_{J,1,t} & \dots & -\alpha_{1,k,t} & \dots & 1-\alpha_{J,J,t} \end{pmatrix}^{-1} \begin{pmatrix} X_{1,0} \\ \vdots \\ X_{j,0} \\ \vdots \\ X_{J,0} \end{pmatrix} (1+\delta)^t \tag{11}$$

The vector of sectoral demand is obtained as a function of the parameters defining the structure of aggregate demand (given in the short–run but evolving over time) and of exports. The latter are evolving exogenously.

2.1.3 Wage Dynamics and short-run cycles

The labour market in our model is sectoraly segmented. The labour force and its corresponding wages as sector specific. The sector level labour market dynamics is represented by a modified Phillips Curve. The growth of wages applied by all firms in a given sector $k \in [1; ...; J]$ is correlated with the growth of employment in the sector:

$$w_{k,t} = w_{k,t-1}\left(1 + \gamma\left(\frac{L_{k,t}}{L_{k,t-1}} - 1\right)\right) \tag{12}$$

The parameter γ controls the sensitiveness of wages to these changes, and therefore illustrate to rigidities on the labour market. The level of employment in the sector k can be deduced from the level of output of the sector as described in equation 6. The sectoral level of output can be deduced from the short-run macro identity (equation 11). We can then directly link the wage dynamics to the sectoral demand dynamics:

$$w_{k,t} = w_{k,t-1}\left(1 + \gamma\left(\frac{Y_{k,t}}{Y_{k,t-1}} - \frac{A_{k,t}}{A_{k,t-1}}\right)\right) \tag{13}$$

where $A_{k,t}$ is an approximation of the sectoral labour productivity[7]

Similarly to Goodwin (1951) and Goodwin (1967), short run fluctuations are rooted in the labour market and emerge through the co-evolution of employment and wage dynamics. Our model, however, slightly departs from Goodwin's approach in that business cycles do not rely on the co-evolution of wages and profits shares but rather on the co-evolution of wages and effective demand affecting both employment and investment capacities. Formally, the whole short-run macro-dynamics can then be represented by the system composed by equations 13 and 11. Assuming for the moment that Input-Output coefficients remain fixed, the short-run dynamics of the system can be expressed as follows :

$$\frac{\Delta w_{k,t}}{w_{k,t-1}} = \gamma\frac{\Delta Y_{k,t}}{Y_{k,t-1}} - \gamma\frac{\Delta A_{k,t}}{A_{k,t-1}} \tag{14}$$

$$\frac{\Delta Y_{k,t}}{Y_{k,t-1}} = \left(\underbrace{\frac{\partial \Lambda^{-1}}{\partial w_{k,t}}}_{(i)} + \underbrace{\frac{\partial \Lambda^{-1}}{\partial p_{k,t}}\frac{\partial p_{k,t}}{\partial w_{k,t}}}_{(ii)} + \underbrace{\sum_{j \neq k}\frac{\partial \Lambda^{-1}}{\partial p_{j,t}}\frac{\partial p_{j,t}}{\partial w_{k,t}}}_{(iii)}\right)\frac{\Delta w_{k,t}}{w_{k,t-1}} + \delta \tag{15}$$

where Λ^{-1} represents the Leontief-inverse matrix described in equation 11. The component (i) depicts the effect on output linked to sector's own consumption, (ii) captures the effect linked to own sector's price changes triggered by wages changes, while (ii) captures the effect linked to changes in the other sectors' prices. The effects cannot be explicitly computed, however, (i) is likely to be positive, while (ii) and (iii) likely to be negative as:

(i) an increase in wage generates an increase in final consumption in all sectors, and therefore sector's own production via intermediate demand too.

[7] $A_{k,t}$ computed as the inverse of the average labour intensity among the firms in the sector k:

$$A_{k,t} = \left(\sum_i \frac{z_{k,i,t}}{A_{k,i,t-1}}\right)^{-1}$$

(ii) an increase in wage generates an increase in production costs, and therefore an increase in price reducing final consumption for the sector.

(iii) an increase in wage generates an increase in other sectors' costs and prices, reducing final consumption for these sectors and therefore intermediate demand for the sector with the initial increase in wages.

If these effects are not compensated by exports' exogenous growth, these dynamics are likely to lead to a decrease in output, and then in employment. The latter translates to a decrease in wages through the Phillips Curve. For given parameter values, we should therefore be able to observe cyclical motions in the short-run.

2.2 The Micro–Dynamics and the foundations of structural change

The changes in the structure of the model presented above find their sources in the dynamics occurring at the firm level. These micro-dynamics are at the core of the emergence and diffusion of technological changes. In our model, technological changes take two distinct forms: changes in the production structure (intermediate coefficients) and changes in labour productivity.

Both technological changes emerge from firms R&D activity. Both are adopted by firms to increase their efficiency and survive market selection. Finally both diffuses in the economy through the process of selection and therefore leading to macro-level structural changes.

2.2.1 Production, pricing and market dynamics

At the micro–level firms' output is computed as a share ($z_{k,i,t}$) of sectoral demand as deduced from equation 11. We can deduce the level of production of firm i in sector k:

$$Y_{k,i,t} = z_{k,i,t} Y_{k,t} \tag{16}$$

To cover this demand a firm produces using a combination of product from all J sectors ($Y^D_{j,k,i,t}$) and labour ($L_{k,i,t}$). The production technology of a firm i active in sector k is defined as follows:

$$Y_{k,i,t} = min\left(\frac{1}{a_{1,k,i,t-1}} Y^D_{1,k,i,t}, ..., \frac{1}{a_{j,k,i,t-1}} Y^D_{k,k,i,t}, ..., \frac{1}{a_{J,k,i,t-1}} Y^D_{J,k,i,t}, A_{k,i,t-1} L_{k,i,t}\right) \tag{17}$$

The level of demand from firm i for sector j products is therefore defined as follows:

$$Y^D_{j,k,i,t} = a_{j,k,i,t-1} Y_{k,i,t} \tag{18}$$

The demand for labour expressed by firm i is defined as follows:

$$L_{k,i,t} = \frac{Y_{k,i,t}}{A_{k,i,t-1}} \tag{19}$$

where $A_{k,i,t-1}$ is the current labour productivity of the firm i, resulting from the adoption of past technological changes.

Firms set prices, applying a mark-up (μ) on their unitary production costs:

$$p_{k,i,t} = (1+\mu)\left(\sum_{j=1}^{J} a_{j,k,i,t-1}p_{j,t} + \frac{w_{k,t}}{A_{k,i,t-1}}\right) \tag{20}$$

where $p_{j,t}$ is the price index for sector j and $w_{k,t}$, the wage for applied in sector k, both defined in the section above.

The market share $z_{k,i,t}$ of firm i is computed using a replicator dynamics. This mechanism is used here as an abstract representation of the market selection process.[8] A firm exits[9] the market if its market share is below $\bar{z}$. Formally the market shares are defined as follows:

$$z_{k,i,t} = z_{k,i,t-1}\left(1+\phi\left(\frac{E_{k,i,t}}{E_{k,t}}-1\right)\right) \tag{21}$$

where $E_{k,i,t}$ and $E_{k,t}$ respectively, represent the level of competitiveness of firm i and the average competitiveness in sector k. Each firm's competitiveness level is defined as the inverse of the firm's price level

$$E_{k,i,t} = \frac{1}{p_{k,i,t}} \text{ and } E_{k,t} = z_{k,i,t-1}E_{k,i,t} \tag{22}$$

The profits resulting from firms activity can be deduced from the above equations ad be described as follows:

$$\pi_{k,i,t} = \mu\left(\sum_{j=1}^{J} a_{j,k,i,t-1}p_{j,k} + \frac{w_{k,t}}{A_{k,i,t-1}}\right) z_{ki,i,t}Y_{k,t} \tag{23}$$

The resources gathered by firms selling their production are then used to finance their R&D activity.

2.2.2 R&D and technological change

Technical change at the level of the firm consists in changes in labour productivity ($A_{k,i,t}$) and changes in the coefficient of intermediate demand ($a_{j,k,i,t}$). In line with most evolutionary models of industrial dynamics and/or economic growth, technological changes are a direct consequence of firms' R&D activity. This activity is highly uncertain. The probability of success is a function of the R&D efforts of the firms. For the sake of simplicity, we assume here that firms spend all their resources in R&D. The probability of success ($\mathcal{P}_{k,i,t}$) is defined as follows:

$$\mathcal{P}_{k,i,t} = 1 - e^{-\beta\left[\mu\left(\sum_j a_{j,k,t-1}p_{j,t} + \frac{w_{k,t}}{A_{k,i,t-1}}\right) z_{k,i,t}Y_{k,t}\right]} \tag{24}$$

[8]See Metcalfe (1998) for a discussion on the use of the replicator dynamics in economics.

[9]In this case, it is immediately replaced by a firm whose characteristics correspond to the average value of the sectoral characteristics. This assumption is required by the use of the replicator dynamics to represent market selection to limit the distortions in the dynamics linked to the exit and replacement of marginal firms.

If R&D is successful, the changes in both intermediate coefficients ($a_{j,k,i,t}$) and in labour productivity ($A_{k,i,t}$) are themselves resulting from a stochastic process.

The gains in labour productivity are drawn from a Normal distribution and directly incorporated in the production process. Formally, the resulting level of labour productivity can be described as follows:

$$A_{k,i,t} = A_{k,i,t-1} + \max\{0; \varepsilon_{k,i,t}\} \tag{25}$$

$$\varepsilon_{k,i,t} \sim N(0;\sigma) \tag{26}$$

where σ is fixed.

Similarly, changes in intermediate coefficients are drawn from a Normal distribution, but are only adopted by firms if they allow a reduction in production costs. Formally the potential set of new intermediate coefficients ($a'_{j,k,i,t}$) are computed as follows:

$$a'_{j,k,i,t} = a_{j,k,i,t-1} + \epsilon_{j,k,i,t} \tag{27}$$

$$\epsilon_{j,k,i,t} \sim N(0;\rho) \tag{28}$$

where ρ is given. The new set of coefficient ($a'_{1,k,i,t}, ..., a'_{j,k,i,t}, ..., a'_{J,k,i,t}$) as defined by this stochastic process, is introduced in the production function as $a_{1,k,i,t}, ..., a_{J,k,i,t}$ if the potential unitary cost is lower then the actual unitary cost:

$$(a_{1,k,i,t}, ..., a_{J,k,i,t}) = \begin{cases} (a'_{1,k,i,t}, ..., a'_{j,k,i,t}, ..., a'_{J,k,i,t}) & \text{If } \sum_{j=1}^{J} a'_{j,k,i,t} p_{j,t} < \sum_{j=1}^{J} a_{j,k,i,t-1} p_{j,t} \\ (a_{1,k,i,t-1}, ..., a_{j,k,i,t-1}, ..., a_{J,k,i,t-1}) & \text{Otherwise} \end{cases} \tag{29}$$

3 Simulation Results

3.1 Simulation Procedure

Given the agent-based nature of the model, as well as the intrinsically out-of-equilibrium focus of our evolutionary approach, we revert to numerical simulations to analyse the model developed above. To conduct these simulation we adopt the following procedure[10]:

- We consider a single economy, leaving external demand exogenous.
- The economy contains 13 sectors, corresponding to the 13 sectors used in Lorentz and Savona (2008) and reported for convenience in Table 1 in the Appendix.
- Each of the sectors contains 10 firms.[11]

[10] Numerical simulations are conducted using the *Laboratory for Simulation Development* available at http://www.labsimdev.org/, the code for this specific model can be obtained on request to the authors

[11] We limit here the number of firms to 10 to faster the computation of the multiple replications of the parameter settings. Increasing the number of firms in the model does not drastically change the outcome of the simulations.

- The results presented are the average outcome of a minimum of 20 replications of the simulation setting. Each simulation runs over 5000 steps.

In order to reduce the spectrum of the parameters to be analysed, we set the initial values of the parameters on the basis of the data used in Lorentz and Savona (2008). The simulations are carried out on the basis of the actual OECD I–O tables (1978–1995) for Germany to calibrate the initial time step for the following variables as well as the following parameters:

- Sectoral I–O coefficients ($a_{j,k,t-1}$). Table 2 in the Appendix reports the initial simulation step structure of the intermediate coefficients, as drawn from the German Input–Output tables for 1978.

- Sectoral exports ($X_{j,0}$). These figures are drawn from the I–O tables for Germany 1978, and reported in Table 3 in the Appendix.

- Sectoral shares of final consumption (c_j). These are computed as the ratio between the sector's consumption and total consumption using the 1978 German I–O table. The figures are reported in Table 3 in the Appendix.

- Sectoral shares of import (m_j). These are computed as the ratio between sector's foreign demand and sector's total demand (final and intermediate) using once again the 1978 German I–O table. Also these figures are detailed in Table 3 (Appendix).

We focus the analysis of the parameter space on the effect of the remaining four key parameters:

- γ: the parameter controlling the wage rigidity in the Phillips Curve.

- δ: the parameter controlling the exogenous growth rates of exports.

- β: the parameter controlling the probability of occurrence of technological shocks.

- σ: the variance in productivity gains.

We consider the effect of changes in these parameters' values pair-wise to isolate their effect according to three scenarios:

- γ vs. δ: the macro-determinants of short-run fluctuations. As shown in equation 14, these two parameters directly affect the amplitude of short run fluctuations. γ determines the reactivity of wages to changes in employment. The more rigid the wages the lowest the fluctuations on the labour market. δ determines the exogenous growth rate of exports. The higher the growth rates of exports the lower the effect of labour market fluctuations on GDP dynamics. These fluctuations should affect the ability of firms to invest in technological changes and generate structural change. This first scenario, therefore also allows us to stress the effect of business cycles on structural changes.

- β vs. σ: the micro-determinants of technological shocks. As shown in section 2.2, these two parameters affect respectively frequency of technological changes generating changes in both the I-O coefficients and that of labour productivity, and the amplitude of productivity gains resulting from these shocks. In other words the parameters directly affect the patterns of structural change. Productivity changes also affect employment dynamics, and are therefore likely to generate short run fluctuations, while structural changes are likely to modify the amplitude of the fluctuations as shown in equation 14. In other words, this second scenario also allow us to stress the effect of structural change on business cycles.

- γ vs. β: the interaction between wage cycles and technological shocks. This last scenario aims at analysing the cross effects between short-run fluctuations in the labour market and technological change in affecting both structural change and business cycles.

The remaining of the parameters concerns the initialisation of firms' dynamics. We assume here that all firms i in each sector j are set identically, in terms of their initial productivity levels ($A_{j,i,0} = 1; \forall i \in [1; I], \forall j \in [1; J]$), initial market shares ($z_{j,i,0} = 0.1$) and wages ($w_{j,0} = 1$). Initial prices are then deduced from the I–O coefficients given the initial productivity levels and the initial wages. The initial level of employment of firms is deduced from the sectors demand, computed used the OECD I–O tables for Germany (1978). All firms in a given sector j are therefore initially identical, and firms differ across sectors only in terms of their initial prices, employment and level of production.

In order to analyse the effect of these scenarios on structural change and business cycles, we revert to the following statistics. We measure the amplitude of business cycles using the coefficient of variation in GDP[12] over the 5000 simulation steps ($\mathcal{V}_T$), as depicted below:

$$\mathcal{V}_T = \frac{\sum_{t=1}^{T} \left(y_t - \sum_{t=1}^{T} \frac{y_t}{T} \right)^2}{\sum_{t=1}^{T} \frac{y_t}{T}} \tag{30}$$

with

$$y_t = \frac{\sum_j^J \frac{p_{j,t}}{p_t} Y_{j,t}}{\sum_j^J \frac{p_{j,t-1}}{p_{t-1}} Y_{j,t-1}} - 1 \tag{31}$$

A higher coefficient of variation corresponds to a larger amplitude of the short-run fluctuations. This measurement allows us to depict the variations in GDP, washing away the long run trend in GDP. Note that this measure might be problematic in the cases in which the average growth rate across time steps is close to zero.

In order to measure the amplitude of structural changes, we revert to the inverse Herfindahl indexes in respectively sectoral output ($\mathcal{H}_{O,t}$) and sectoral employment ($\mathcal{H}_{L,t}$)

[12] Note that we consider variations in Real GDP as depicted in equation 31, with p_t measuring the macro-level production price index

as follows:

$$\mathcal{H}_{O,t} = \left(\sum_{j=1}^{J} \left(\frac{Y_{j,t}}{\sum_j \frac{p_{j,t}}{p_t} Y_{j,t}} \right)^2 \right)^{-1} \tag{32}$$

$$\mathcal{H}_{L,t} = \left(\sum_{j=1}^{J} \left(\frac{L_{j,t}}{\sum_j L_{j,t}} \right)^2 \right)^{-1} \tag{33}$$

These indexes approximate the number of sectors concentrating the activity. Hence, if $\mathcal{H}_{O,t}$ or $\mathcal{H}_{L,t}$ tend to J, the economic activity respectively in terms of output or employment is equally spread among all sectors. As this indicator tends to 1, the economic activity tends to be concentrated in a limited number of sectors. Note that this measure do not inform us on the nature of structural changes: An economy might end with the same level of concentration but drastically changed the nature of its activities. To capture the sectoral composition of the economy we then revert to the distribution of sectors shares in output or employment.

Finally, the major source of structural change in our model is the unevenness of technological change among sectors. In order to account for the sectoral differences in technological changes we revert to the coefficient of variation in sectors' labour productivity ($\mathcal{V}_{A,t}$) :

$$\mathcal{V}_{A,t} = \frac{\sum_{j=1}^{J} \left(A_{j,t} - \sum_{j=1}^{J} \frac{A_{j,t}}{J} \right)^2}{\sum_{j=1}^{J} \frac{A_{j,t}}{J}} \tag{34}$$

This indicator captures the degree of heterogeneity in labour productivity across sectors. As we assume that all firms in all sectors have the same initial labour productivity, as $\mathcal{V}_{A,t}$ departs from 0, technological change occurs. The higher $\mathcal{V}_{A,t}$ the more uneven these technological changes.

The next section presents and analyse the effect of the three scenarios described above on structural change and business cycles at the light of these statistics.

3.2 Preliminary Results

This section reports and discuss the results obtained through the numerical simulations conducted as described above.

3.2.1 γ vs. δ: the macro-determinants of short-run fluctuations

The first set of simulations focuses on the analysis of the effect of the macro-level parameters affecting short-run fluctuations. We first present and discuss their effect of the amplitude of the business-cycles. We then extend the analysis to the patterns of structural changes emerging from the simulations. We aim in this paragraph to put into light the mechanisms through which business cycles might affect the process of structural change.

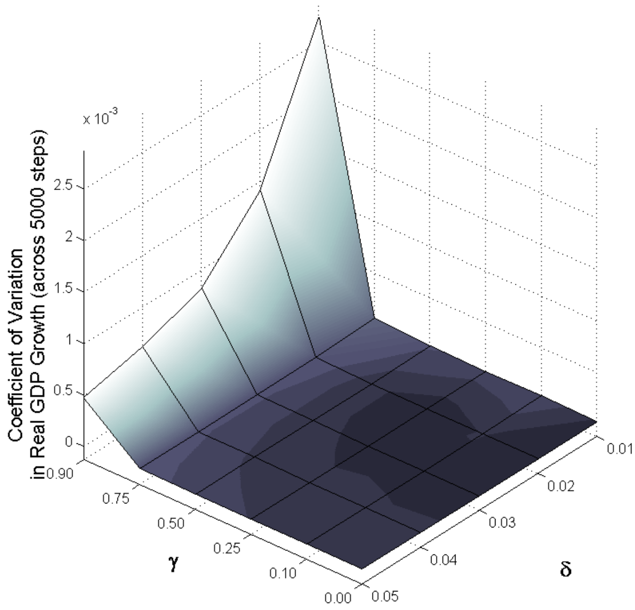


Figure 1: Coefficient of Variation in Real GDP growth rates over 5000 steps $\mathcal{V}_T$; δ vs. γ

Figure 1 presents the values of $\mathcal{V}_T$, used to measure the amplitude of short-run fluctuations, with changes in the parameters δ and γ.[13] As expected above, higher values of γ generate larger fluctuations in GDP growth. The more flexible wages are the higher the amplitude of the short-run cycles. The effect of δ is slightly more subtle: for larger values of γ, a higher δ limits the fluctuations in GDP, while for lower values of γ, higher δ increase the amplitude of the cycles. As expected business cycles generated by wages fluctuations due to a larger wage flexibility are slightly limited by higher growth rates of exports. Fluctuations in internal demand due to the dynamics of the labour market are partially compensated by the external component of final demand. When wages are more rigid, higher growth rates of exports slightly increase the amplitude of short-run fluctuations. The sources of these cycles are no more to be found on the labour market, but at the firm level. With rigid wages, the main source of increase in demand are exports. Higher growth rates of exports deliver more resources for firms to generate productivity gains, and therefore price changes, and fluctuations in the internal demand. In this case short-run fluctuations are generated by the technological shocks occurring at the level of firms, and the productivity shocks they induce. As wage flexibility increases, the effect of technological shocks is absorbed by wage fluctuations, and the effect of effective demand fluctuations should then dominate.

Figure 2 reports the effect on output concentration $\mathcal{H}_{O,t}$ induced by changes in the

[13] Note that we exclude from the figure the case in which $\delta = 0,00$. The complete picture can be found in Figure 15, in Appendix.

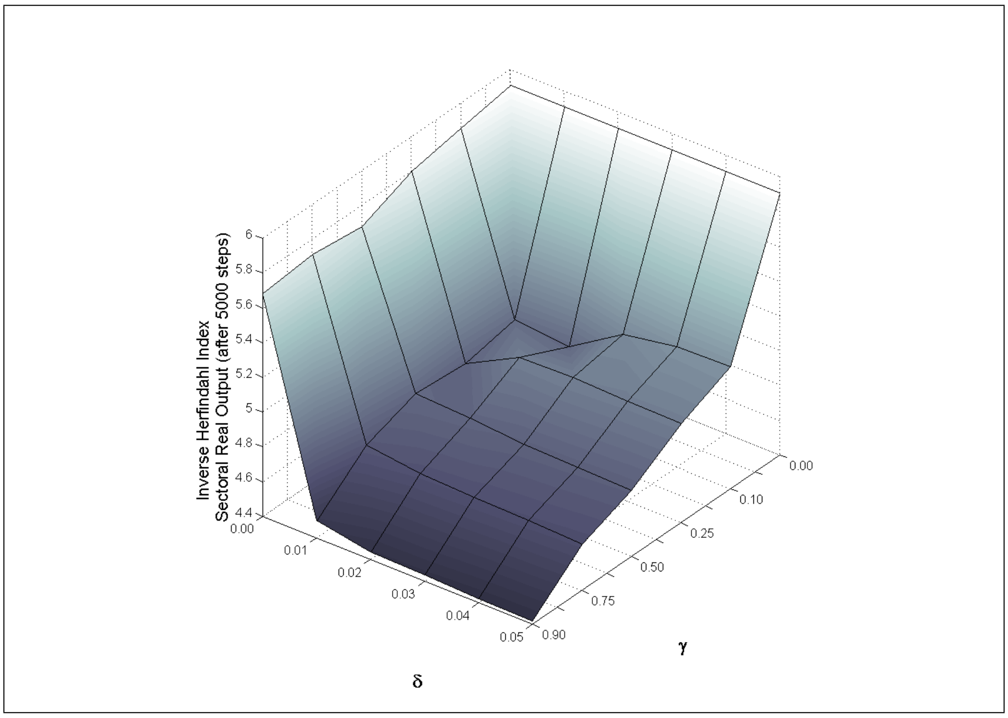
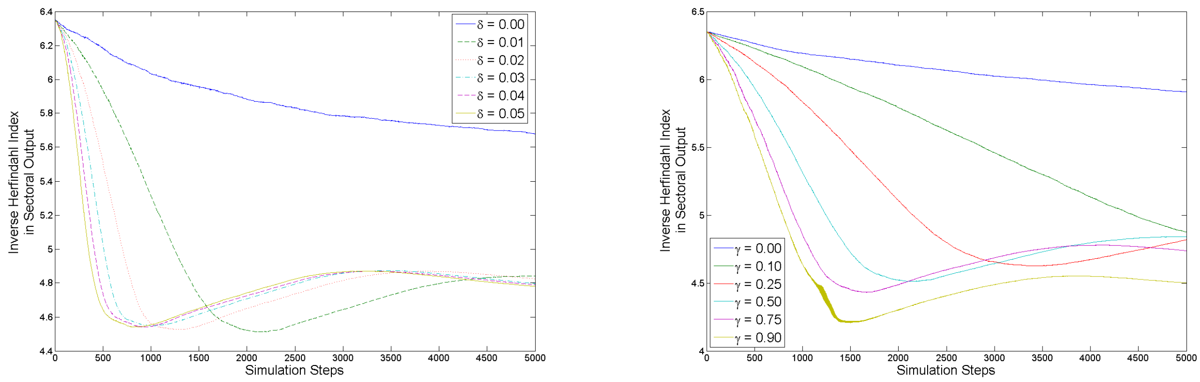


Figure 2: Concentration in Real Output $\mathcal{H}_{O,t}$; γ vs. δ (t=5000)

parameters δ and γ. This figure presents the degree of concentration of the activity after 5000 steps. Both parameters have a clear impact: the higher γ, the lower $\mathcal{H}_{O,t}$; similarly the higher δ, the lower $\mathcal{H}_{O,t}$. In all cases the concentration is much higher then the initial level (around 6.3). In other words, some structural change has occurred leading to a more concentrated activity. Both parameters affect the amplitude of this structural change. However, the effect of γ on $\mathcal{H}_{O,t}$ seems to overtake the effect of δ. Hence, while considering the effect of our macro-determinants of short-run fluctuations on the pattern of structural change, wage flexibility seem to drastically shape the pattern, while exports growth appears to catalyse this effect.

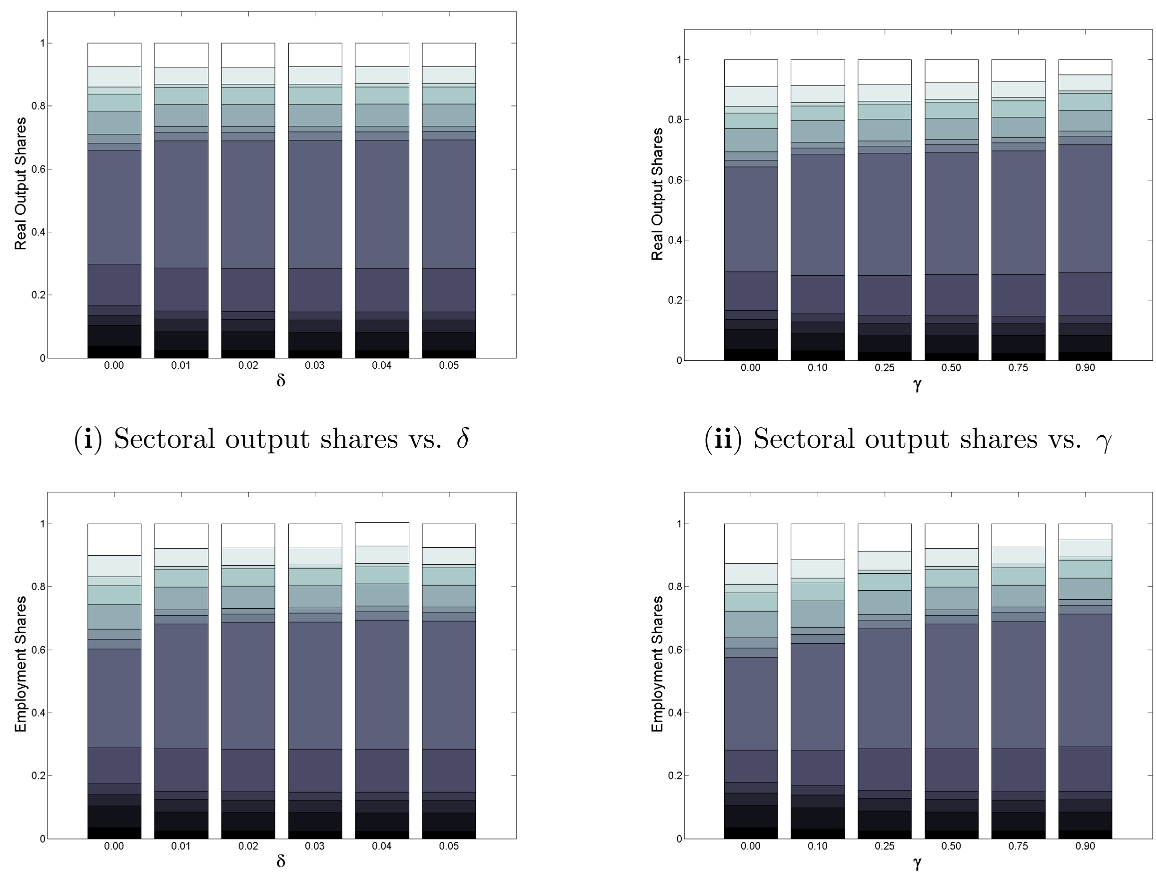
Figure 3 reports the dynamics of output concentration $\mathcal{H}_{O,t}$ along the 5000 simulation steps for different values of the parameters δ and γ. Increasing γ affects both the degree of concentration and its speed: The more rigid the wages the slower and the lower structural change. In other words, rigid wages seem to act like a break on the process of structural change. On the other hand, higher δ faster the process of structural change, but only marginally shape the degree of concentration. Similar patterns emerge considering the effect of γ and δ on the employment concentration, as depicted in Figures 16 and 17 in Appendix.

Figure 4 presents the sectoral composition of the economy after 5000 steps for the various values of the parameters γ and δ. This figure informs us on the nature of the structural changes underlying the changes in both output and employment concentration. As for our concentration indexes, changes in the value of γ gradually affect the structure



(**a**) $\mathcal{H}_{O,t}$ modifying δ (**b**) $\mathcal{H}_{O,t}$ modifying γ

Figure 3: Inverse Herfindahl Index in Output $\mathcal{H}_{O,t}$; δ and γ



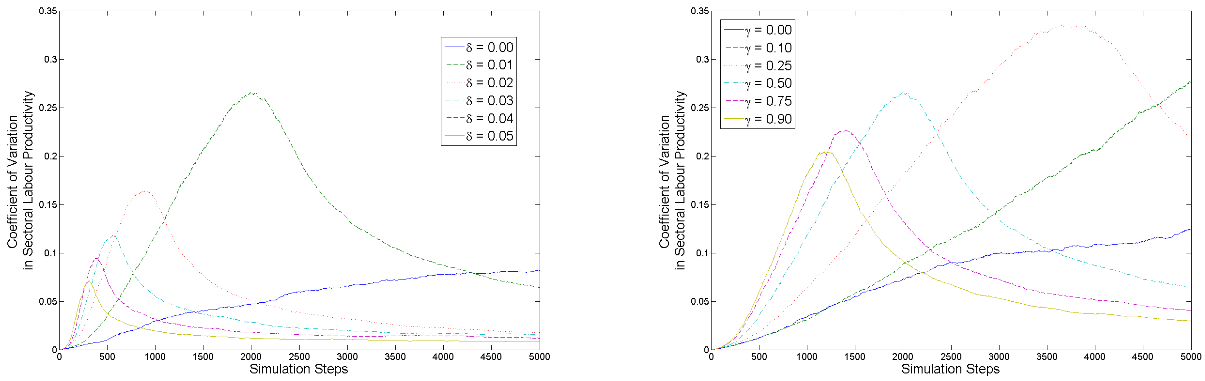
(**i**) Sectoral output shares vs. δ (**ii**) Sectoral output shares vs. γ

(**iii**) Sectoral employment shares vs. δ (**iv**) Sectoral employment shares vs. γ

Figure 4: Sectoral composition of the economy ; δ and γ (t=5000)

of the economy after 5000 steps, while for δ, the effect is closer to that of a switch. :ost of the observed changes appear switching from $\delta = 0.00$ to $\delta > 0.00$. Moreover, having a closer look at the sectoral structure, we observe that in its nature, the process of structural change always lead to a comparable structure: The same sectors concentrate more output and employment, regardless the values of both γ and δ. These parameters do not intrinsically shape the process of structural change, but rather accelerate it and/or allow it completion. In other words, export growth and wage flexibility do not change the direction of the process of structural change but its speed as well as the degree at which it occurs.

The actual sources of structural change, as considered in the model are productivity differences among sectors. The relative productivity affects relative prices. These affect the level of final demand through domestic consumption on the one hand. Relative prices also affect the direction of structural change, through intermediate demand. Firms modify their production technology to reduce their costs. They favour sectors with lower prices, and therefore higher productivity. The whole process of structural change feeds on productivity differences across sectors.



(**a**) $\mathcal{V}_{A,t}$ modifying δ (**b**) $\mathcal{V}_{A,t}$ modifying γ

Figure 5: Coefficient of variation in sectors' labour productivity $\mathcal{V}_{A,t}$; δ and γ

Figure 5 presents the patterns of productivity differential among sectors over the 5000 steps for the various values of the parameters γ and δ. Even though, we initially set firms labour productivity at the same level for all the sector, differences emerge in the course of the simulation. The productivity differences among sector find their sources in the differences in sectors demand. Firms in sectors with a higher demand, also experience a higher probability to experience technological change (see equation 24). The sectors with the highest initial demand turn out to be the ones favoured by the process of structural change (Figure 4). In other words the whole process of structural change relies on a Kaldor-Verdoorn type of process: the growth of output positively increase productivity. Or more specifically in our model, output differentials linked to the initial structure of aggregate demand induce productivity differences, reinforcing the structural change favouring output differentials, and uneven productivity gains. Both wage flexibility and exports growth then accelerate this process: higher growth of exports favours output of all sectors, due to the structure of the intermediate demand, this higher growth is unevenly spread among sectors fostering productivity differentials. Wage flexibility, on the other hand, allows for higher wages, in the sectors already favoured by the process of structural change and therefore foster domestic demand, as well as higher profits, both favouring productivity gains. This effect is however limited to phase of wage increases. Numerical simulations we conducted show that the productivity gains concentrate on the periods experiencing positive growth in wages. Phases of declining wage rates are characterised by a stagnation in productivity.

To summarise this first set of results, on the one hand, wage flexibility positively affect both business cycles and structural change by favouring the emergence of technological change and productivity gains. On the other, exports growth favours both the speed of structural change, providing firms necessary resources to sustain productivity gains and limits the effect of wages fluctuations on business cycles, compensating at the effect of wage drops in the declining side of the cycles.

3.2.2 β vs. σ: the micro-determinants of technological shocks

The second set of simulations focuses on the description of the effects of the micro-level parameters shaping the process of technological changes at the source of structural change. We first present and analyse the effect of these parameters on the amplitude of business cycles. In a second step we present the effect of these parameters on the patterns of structural change. We aim with this second set of simulations to show the influence of the micro-sources of structural change on short-run fluctuations.

Figure 6 presents the values of $\mathcal{V}_T$, measuring the amplitude of short-run fluctuations with changes in the parameters β and σ. As illustrated by Figure 6, both parameters positively affect the amplitude of the business cycles. A closer look at the simulation results, however, shows us drastic differences: the effect of σ is clearly dominates that of β. Increasing the amplitude of the technological shocks (in terms of productivity gains) drastically increase the amplitude of business cycles. On the other hand, increasing β seem only to amplify the effect of σ. For low values of σ, on the one hand increasing β has little to no effect on business cycles. For high values of σ, on the other hand, increasing β increases the amplitude of short-run fluctuations. The parameter β affects the probability of success of firms' R&D activity. In other words, β controls the frequency of appearance of technological shocks, both in terms of productivity gains and changes in intermediate coefficients.

These different impacts can be explained as follows:

- σ directly affects the gains in labour productivity of the firms. These productivity gains have two distinct impacts on the short run fluctuations: First, for a given level of sectoral demand, productivity gains decrease employment, and therefore wages, reducing domestic demand. Second, with a time delay, productivity gains reduce

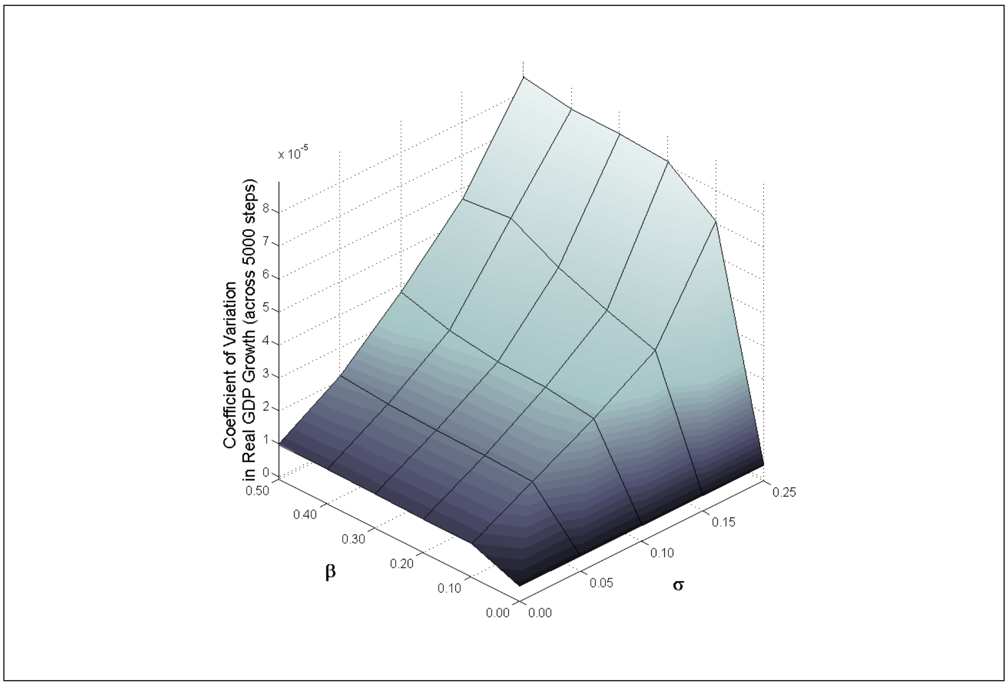


Figure 6: Coefficient of Variation in Real GDP growth rates over 5000 steps $\mathcal{V}_T$; β vs. σ

prices, and therefore increase demand. Increasing the amplitude of productivity shocks therefore amplifies the fluctuations on the labour market, at the source of business cycles.

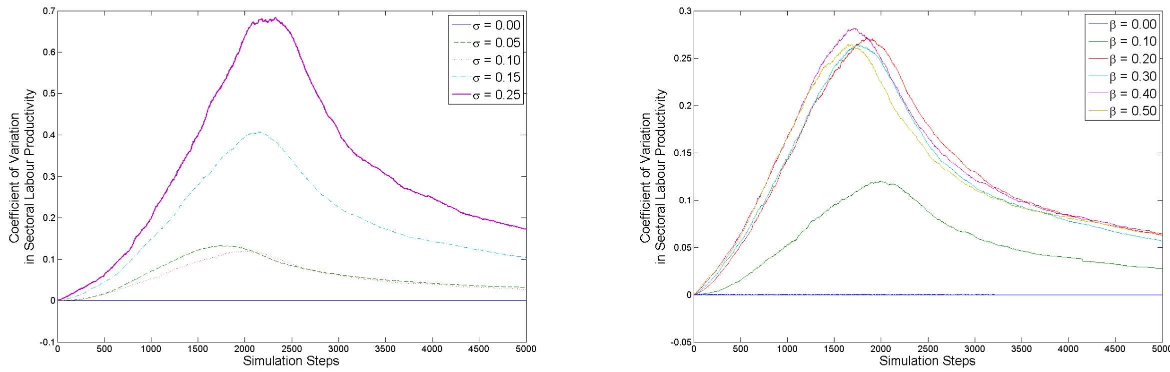
- β affects the frequency of technological shocks. This has two distinct impact on the short-run fluctuations. First, it accelerates the changes in intermediate coefficients. These changes, modify the structure of intermediate demand. This process tend to favour the absorption of short-run fluctuations. Second, only for higher potential productivity gains, increasing the frequency of the shock favours the emergence of large productivity gains, amplifying the effect of higher values of σ on the labour market as described above.

This is confirmed by Figure 7, presenting the dynamics of labour productivity differentials among sectors for the different values of σ and β. Changes in σ clearly influence the amplitude and persistence of productivity differentials. Changes in β on the other hand, mainly affect the speed at which these differentials emerge and are gradually absorbed. These patterns should then reflect on structural change.

Figure 8 presents the concentration in output after 5000 steps $\mathcal{H}_{O,t}$ with changes in the parameters β and σ.[14] Figure 9 reports the concentration in employment after 5000 steps $\mathcal{H}_{L,t}$.[15] As expected, both parameter have an impact on the concentration of the activity, both in terms of output and of employment. However, the nature of the effect on

[14]Note that the figure is truncated as we exclude the case in which $\beta = 0,00$. The complete picture can be found in Figure 18, in Appendix.

[15]The figure is also truncated and the complete picture can be found in Figure 19, in Appendix.



(**a**) $\mathcal{V}_{A,t}$ modifying σ (**b**) $\mathcal{V}_{A,t}$ modifying β

Figure 7: Coefficient of variation in sectors' labour productivity $\mathcal{V}_{A,t}$; σ and γ

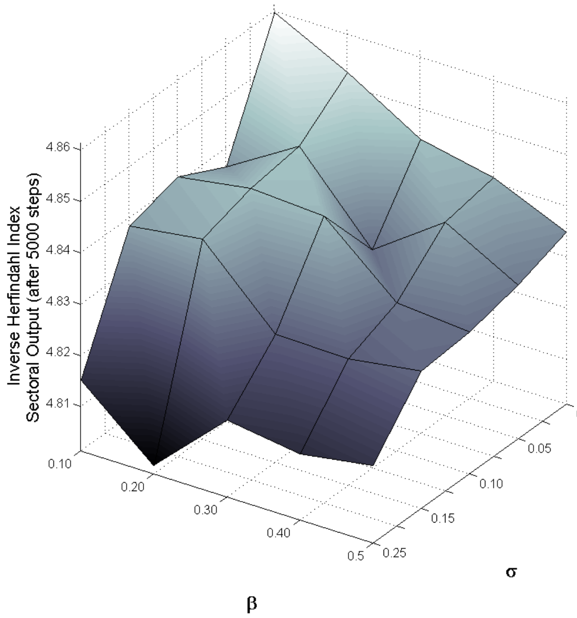


Figure 8: Concentration in Real Output $\mathcal{H}_{O,t}$; σ vs. β (t=5000)

the structure of output and of employment quite departs with changes in the parameter values. The higher β, the larger the concentration both in output (Figure 8) and in employment (Figure 9). In other words, the more frequent the technological shocks, the further goes the process of structural change. This result is foreseeable, as technological shocks are at the source of structural change in our model. The results obtained with changes in σ are less trivial. On the one hand, the higher σ, the larger the concentration of output. This can be explained by productivity differentials favouring structural change, though the process of cost reduction triggering changes in intermediate coefficients. On

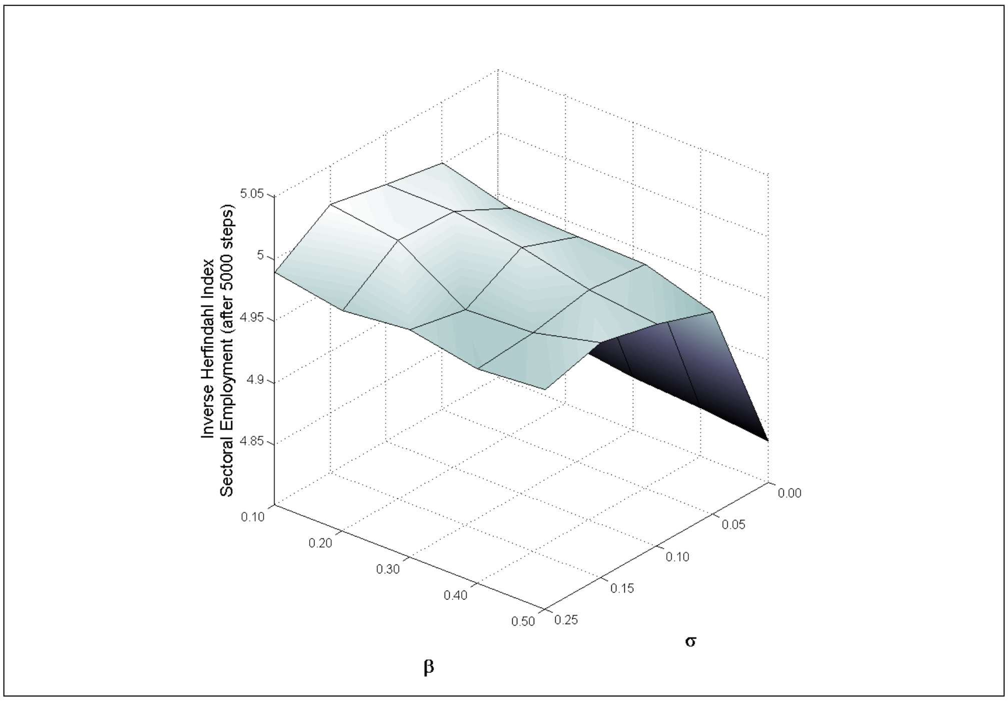
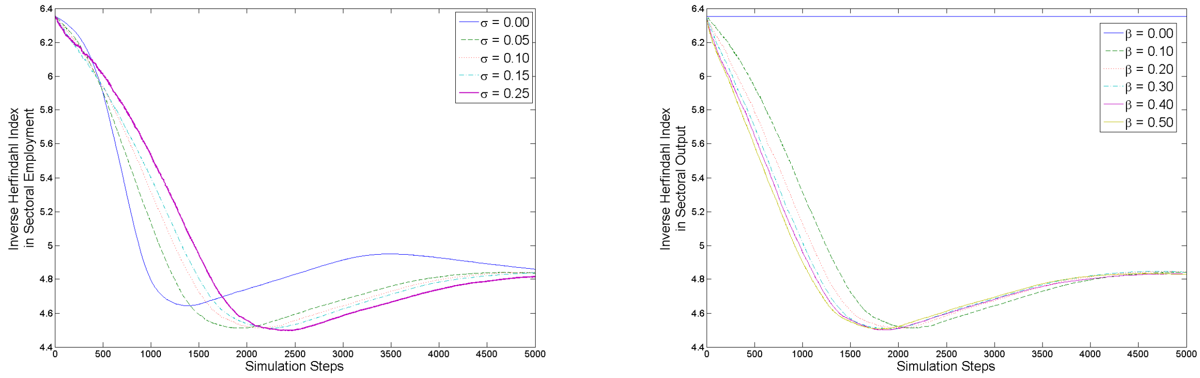


Figure 9: Employment concentration $\mathcal{H}_{L,t}$; σ vs. β (t=5000)

the other hand, the higher σ, the lower the concentration of employment. A quick look at the dynamics of employment concentration (Figure 11), confirms that the process of concentration is not inverted though, but seems slightly limited with higher values of σ. In other words, increasing the amplitude of the potential productivity gains, might slightly limit the concentration of employment. This result can be explained by the fact that the productivity gains directly impact employment. With larger σ, productivity gains compensate the expansion of demand so that the most productive sectors actually loose employment shares (see Figure 20 in Appendix). The patterns of structural change is then so that the structure of employment departs from the structure of output.

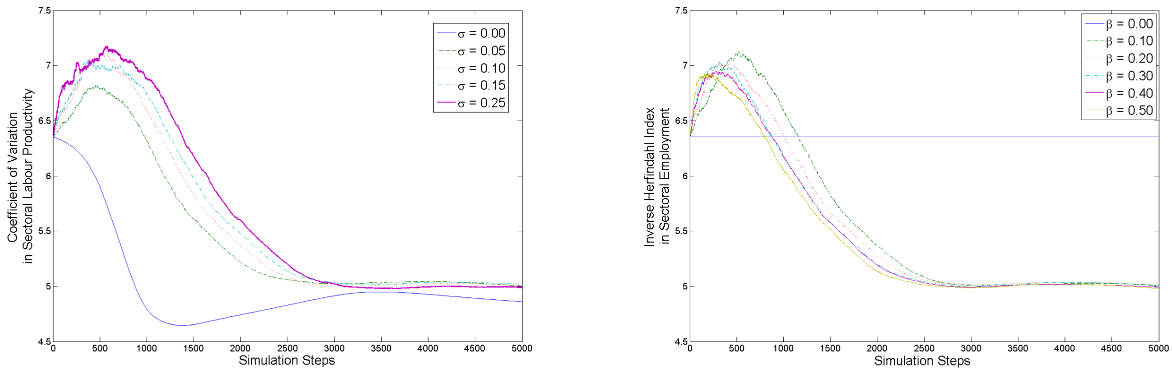
The range of these effects remains however quite marginal, when considering the whole picture (Figure 18 and Figure 19 in Appendix). The technological factors seem then to act more like switches: As long as $\beta > 0,00$, structural change occurs and the differences in the concentration levels in both output and employment only marginally differ. Figures 10 and 11 respectively present the evolution of the concentration patterns of output $\mathcal{H}_{O,t}$ and of employment $\mathcal{H}_{L,t}$ along the 5000 simulation steps for different values of the parameters β and σ.

In both cases, changing values of β only affects the speed of concentration in output and employment, for all values of $\beta > 0.00$. Favouring the frequency of technological shocks does not affect the nature of structural change. The direction of structural change is defined by a Kaldor-Verdoorn like mechanism generating productivity differentials linked to the differences in sectoral demand. As long as β remains null, the entire process of structural change is neutralised. For all other values of β this process simply accelerates.



(**a**) $\mathcal{H}_{O,t}$ modifying σ (**b**) $\mathcal{H}_{O,t}$ modifying β

Figure 10: Inverse Herfindahl Index in Output with $\mathcal{H}_{O,t}$; σ and β



(**a**) $\mathcal{H}_{L,t}$ modifying σ (**b**) $\mathcal{H}_{L,t}$ modifying β

Figure 11: Inverse Herfindahl Index in Employment $\mathcal{H}_{L,t}$; σ and β

On the other hand, changing values of σ affects both the speed and the degree of concentration of employment. For higher values of σ, concentration in employment is slower, and in the end of the process, employment appears slightly less concentrated. In other words, the process of structural change is so that, the structure of employment departs from the structure of output for higher values of σ. This result can be explained as follows: In most of the cases considered in our simulations, productivity gains emerge from the demand differentials among sectors, reinforcing the latter affecting relative prices. In these cases, output shares drive employment shares and the structure of employment is symmetric to the structure of output. For higher values of σ, the productivity gains overcome the expansion of demand. The growth of productivity is higher then the growth of output for the sectors favoured by the process of structural change. These sectors gains in output shares but lose in terms of employment shares. Employment appears less concentrated than output at the end of the simulation runs.

To summarise this second set of results, on the one hand, both technological factors affects positively the amplitude of business cycles. Their impact on structural change implies more subtle effects: enhancing the frequency of technological change mainly accelerate the process of structural change, while enhancing productivity gains might lead to patterns of structural change where the structure of output departs from the structure of employment.

3.2.3 γ vs. β: the interaction between flexibility and technological change

The first two sets of simulation, analysed separately selected macro-parameters from micro-parameters. This third set of simulation proposes to analyse the effect of wage flexibility (at the macro-level) together with that of the frequency of technological change (at the micro-level). We aim, with this last set of simulation, to weight the importance of both macro- and micro-factors.

Figure 12 presents the values of $\mathcal{V}_T$ with changes in the parameters β and γ.[16] Figure 13 reports the level of output $\mathcal{H}_{O,t}$ and employment $\mathcal{H}_{L,t}$ after the 5000 simulation steps for different values of the parameters β and γ. In both cases, the two parameters have a positive impact, these for the reasons exposed and discussed in the section above:

- β favours the emergence of technological shocks at the source of structural change that also generate short-run fluctuations in GDP, through both the labour market dynamics (via productivity gains) and through the structure of aggregate demand (via changes in intermediate coefficients).
- γ favours fluctuations on the labour market that spread to GDP dynamics through changes in both final demand (see equation 14) and intermediate demand (through relative prices), those affecting in return employment and labour market fluctuations. Wage flexibility also positively affects structural change, as wage gains increase the resources for firms to generate technological changes, through domestic consumption.

Interestingly, the effect of wage flexibility seems to dominate that of the frequency of technological shocks both for the amplitude of business cycles and the range of structural change. In other words, gains in the resources allowed by wage increases overtake the effect of increasing the probability of success of the R&D activities of firms in generating productivity gains and structural transformations. This can be explained by the fact that as long as technological shocks are possible ($\beta > 0$), structural change takes place. Increasing the frequency of the shocks simply accelerates the process. Moreover, the frequency of the shocks might influence the frequency of the fluctuations but not their intensity. On the other hand, the degree of flexibility of wages affects directly the reactivity of the labour market and hence shapes short-run fluctuations. At the same time, the growth of wages affects the resources of firms to generate technological changes generating

[16] Note that for the sake of readability, we exclude from the figure the case in which $\gamma = 0,90$. The complete picture can be found in Figure 21, in Appendix.

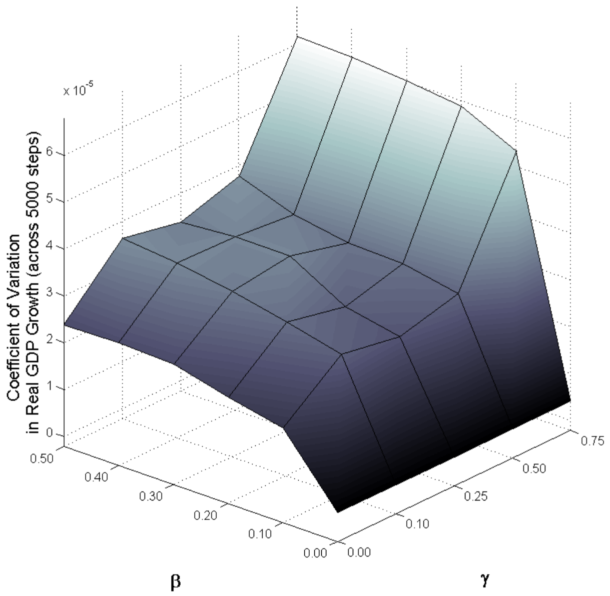
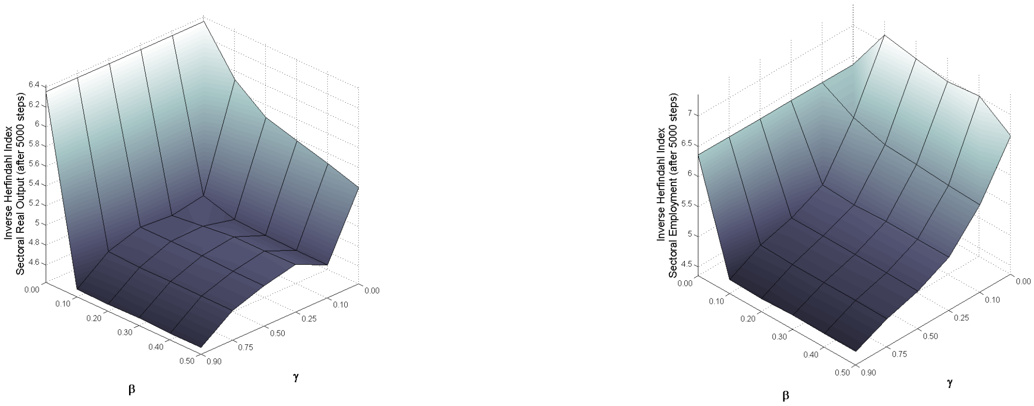


Figure 12: Coefficient of Variation in Real GDP growth rates over 5000 steps β vs. γ



(**a**) $\mathcal{H}_{O,t}$ γ vs. β

(**b**) $\mathcal{H}_{L,t}$ γ vs. β

Figure 13: Concentration in Output $\mathcal{H}_{O,t}$ and Employment $\mathcal{H}_{L,t}$; γ vs. β (t=5000)

structural change. The lack of these resources in some cases even prevents the completion of the process of structural change.

Finally, Figure 14 confronts for the three simulation sets, the amplitude of short-run fluctuations as measured by $\mathcal{V}_T$ to the degree of concentration of output $\mathcal{H}_{O,t}$. Through the three simulation scenarios analyse above, we observed that the factors generating structural change also generate business cycles. Reversely the factors amplifying short-run fluctuations also allow and foster structural changes. This leads us to consider a

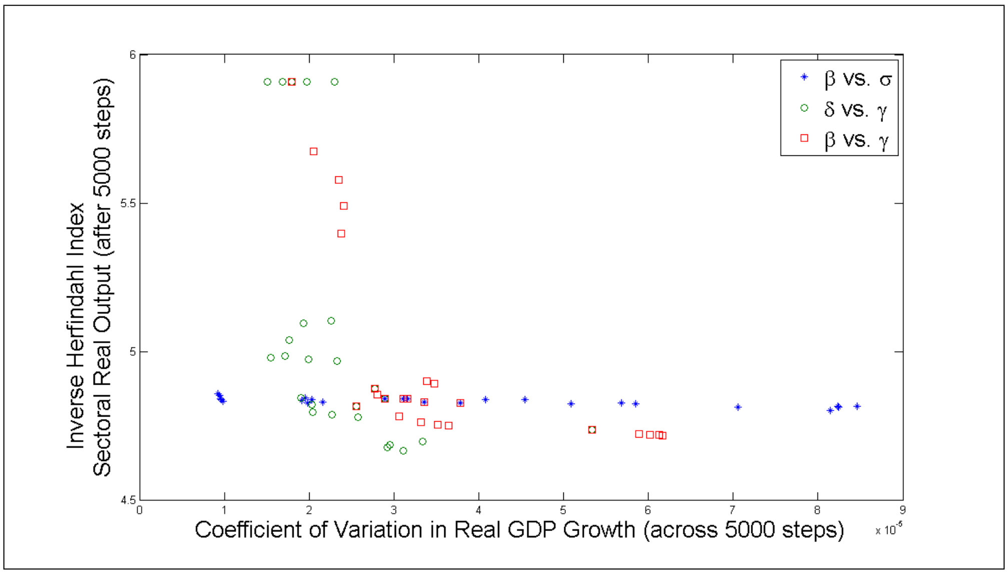


Figure 14: Coefficient of Variation in Real GDP growth rates over 5000 steps $\mathcal{V}_T$ vs. Concentration in Real Output $\mathcal{H}_{O,t}$

possible positive co-evolution of short-run fluctuations and long run transformations of the economies. This is confirmed by Figure 14 that shows for all three parameter sets an apparent negative (in various ranges) correlation between the coefficient of variation in GDP and the inverse Herfindahl index.

4 Final remarks

We aim, along this paper, to investigate the interactions between the short-run fluctuations in the growth pattern and the very-long run transformations induced by technological change. We propose a growth model with evolutionary micro-founded structural change. The model endogenies both technical change and changes in patterns of final and intermediate demand as affecting macro-economic growth, through the structural change of the economy. These mechanisms also reflect on the labour market dynamics generating short-run fluctuations, these spread to the growth pattern of the economy and influence the process of structural change. This work is in line with the attempts to embracing in a unifying framework both neo-Schumpeterian and Keynesian line of thoughts in explaining economic growth.

We carry out numerical simulations on the basis of the actual I-O coefficients for Germany to investigate both the imprint of various business cycles scenarios on the structural change patterns and the effect of various structural change scenarios on the amplitude of business cycles. Numerical simulations show us that the factor at the source of business cycles drastically affect the patterns of structural change. Hence, increasing wage flexibility and/or increasing the growth rates of exports, not only affect the amplitude of business cycles, but also affect the process of structural change. These factors influence the availability of resources for firms to generate technological changes at the core of structural change. On the other hand, the mechanisms shaping technological changes at the micro-level, not only allow for the process of structural change to occur, but also generate or sustain short-run fluctuations. Hence the process of structural change necessarily generates short-run fluctuations as a by-product.

These results however overlook the detrimental aspects of the cycles. Through all the simulations, technological changes and structural changes mainly occur in the growing phases of the cycles. Increasing wage flexibility favours these processes allowing for wages to grow faster. The declining phases are compensated partially by the exogenous growth rates of exports. Moreover, in the declining phase of the cycles, the process of structural change is simply put on hold due to the lack of technological change. The model still overlooks two crucial mechanisms:

- The growth rate of exports cannot be fully disconnected from internal fluctuations on the labour market. The model in his current form cannot account for the effect of wage rigidities on competitiveness, policy used in a large extend by Germany, among others, during the last decade to sustain its external demand.

- The declining phases of business cycles do not only put the process of structural change on hold. Due to the lack of resources for investments, firms should experience a decline in their productivity, and therefore in their competitiveness, due to the obsolescence of their production technologies. The model in its current form can not yet account for this mechanism.

We aim, in our future research agenda, at including for these two mechanisms in our analysis, allowing for a more complete picture of the effect of short-run fluctuations on the long-run processes of structural transformations.

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Appendix

Table 1: Sectors Included in the analysis

ISIC Rev.3	**Acronym**	**Industry**
1-14	AGRI	Agriculture, hunting, forestry, fishing, mining, and quarrying
15-16	FOOD	Food products, beverage and tabacco
17-19	TEXTILE	Textiles, textile products, leather and footwear
20-22	WOOD	Wood, wood products, cork, pulp, paper, paper products, printing and publishing
23-26	CHEM	Chemical, rubber, plastic, fuel products, and other non-metallic mineral products
27-35	MACHINERY	Basic and fabricated metal prod., machinery and equipments
36-37	MANEC	Manufacturing n.e.c.
40-45	ELEC	Electricity, Gas, Water and Construction
50-55	TRADE	Wholesale and retail trade; Hotels and restaurants
60-64	TRACOM	Transports, storage and communications
65-67	FINANCE	Financial Intermediation
70-74	KIBS	Real estate; Renting of machinery and equipment; computer and related; R&D; business services**
75-99	SOCIAL	Community; social; personal and other government services

**Business services (74) includes: Legal and Accounting; Engineering; Technical Consultancy; Marketing; Training; Cleaning; Security

Source: Lorentz and Savona (2008)

Table 2: Initial I–O coefficients (Germany 1978)

	AGRI	FOOD	TEXTILE	WOOD	CHEM	MACHINERY	MANEC	ELEC	TRADE	TRACOM	FINANCE	KIBS	SOCIAL
AGRI	0.16157	0.30250	0.03098	0.03728	0.09699	0.01651	0.00096	0.05997	0.01367	0.00022	0.00078	0.00940	0.00316
FOOD	0.08889	0.21821	0.00028	0.00039	0.00501	0.00052	0.00054	0.00028	0.05911	0.00636	0.00152	0.00989	0.01127
TEXTILE	0.00154	0.00074	0.32907	0.01668	0.00365	0.00210	0.00558	0.00174	0.00298	0.00209	0.00158	0.00272	0.00311
WOOD	0.00956	0.01792	0.00723	0.24626	0.01663	0.00907	0.02665	0.03156	0.02798	0.01101	0.01742	0.00856	0.04735
CHEM	0.07711	0.03023	0.07225	0.08083	0.30363	0.04622	0.06617	0.14025	0.02236	0.05728	0.00493	0.01865	0.01683
MACHINERY	0.05907	0.00934	0.01398	0.02796	0.02574	0.39281	0.24025	0.06671	0.01303	0.04702	0.01043	0.01469	0.01679
MANEC	0.00331	0.00999	0.00689	0.01628	0.00807	0.01221	0.03808	0.01543	0.00299	0.00289	0.00218	0.00187	0.00087
ELEC	0.04959	0.01182	0.01588	0.02187	0.03627	0.01703	0.01456	0.04710	0.02241	0.02219	0.01027	0.05487	0.00372
TRADE	0.02703	0.03541	0.05260	0.05086	0.03959	0.04836	0.05346	0.03270	0.05125	0.04373	0.01476	0.01319	0.00900
TRACOM	0.02351	0.02725	0.01842	0.03524	0.03109	0.01945	0.02294	0.02553	0.03468	0.10062	0.02985	0.00850	0.00941
FINANCE	0.02761	0.01138	0.02065	0.02163	0.01560	0.01923	0.02374	0.02835	0.03831	0.04751	0.02313	0.04680	0.01007
KIBS	0.01751	0.02474	0.03949	0.03580	0.04762	0.03701	0.04228	0.03706	0.10449	0.02585	0.14282	0.06973	0.01763
SOCIAL	0.00882	0.00211	0.00278	0.00272	0.00241	0.00239	0.00311	0.00127	0.00688	0.00214	0.00898	0.01306	0.00971

Source: OECD Input Output Tables, and Lorentz and Savona (2008)

Table 3: Initial values for selected coefficients (Germany 1978)

	Exports $X_{j,0}$	Consumption shares c_j	Import shares m_j
AGRI	9768.69818	0.00801	0.39532
FOOD	14510.06581	0.04785	0.11404
TEXTILE	16484.99734	0.01964	0.35369
WOOD	10152.96088	0.00863	0.13128
CHEM	65014.43969	0.02415	0.21723
MACHINERY	204944.78578	0.03033	0.17266
MANEC	12873.43864	0.00520	0.22848
ELEC	3117.50666	0.01261	0.00509
TRADE	13869.20244	0.06247	0.01892
TRACOM	23830.67028	0.01489	0.08088
FINANCE	366.39001	0.00828	0.00449
KIBS	7777.17059	0.0541	0.03043
SOCIAL	3263.04137	0.09851	0.01350

Source: OECD Input Output Tables, and Lorentz and Savona (2008)

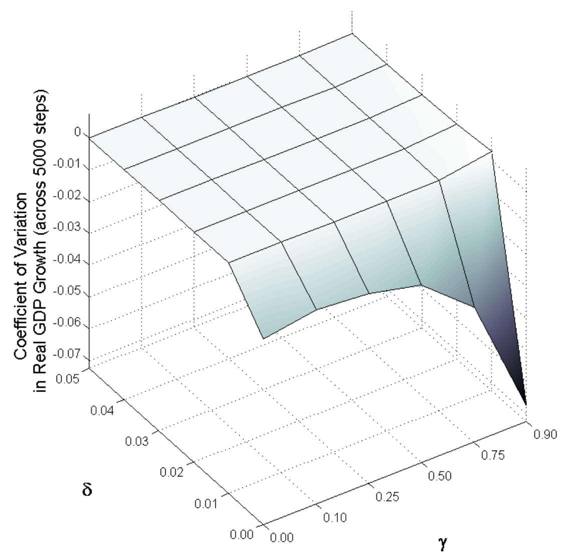


Figure 15: Coefficient of Variation in Real GDP growth rates over 5000 steps $\mathcal{V}_T$; δ vs. γ: The higher γ, the higher the amplitude of the fluctuations in GDP. Increasing δ limits the effect of γ. This figure includes the case in which $\delta = 0.00$. In this case the coefficient of variation is explosive as the average GDP growth over the 5000 steps is negative and tends to zero.

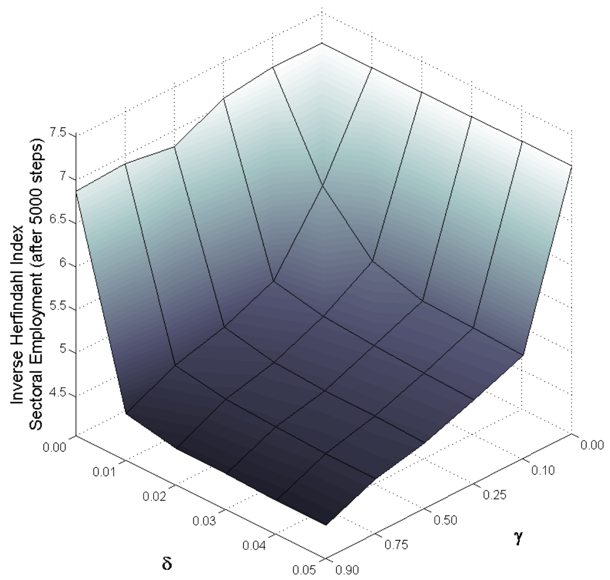
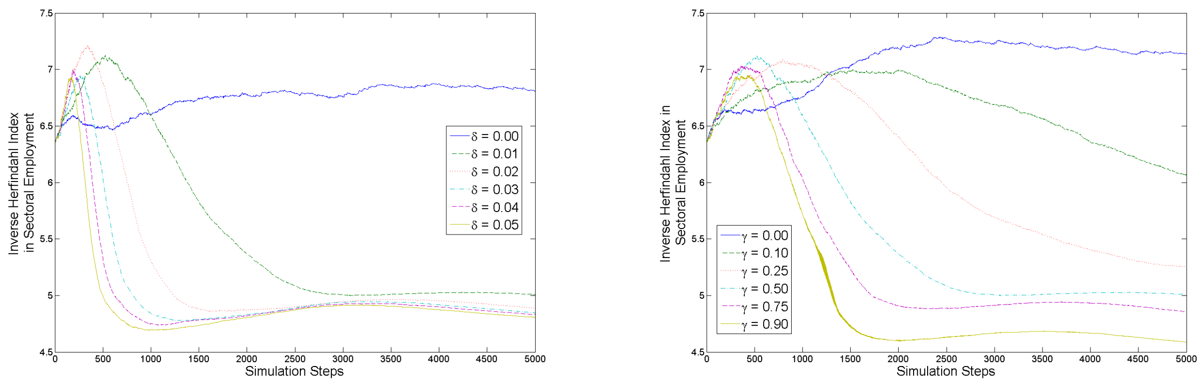


Figure 16: Employment concentration $\mathcal{H}_{L,t}$; γ vs. δ (t=5000): The higher γ the more concentrated is employment. The higher δ the more concentrated is employment. The effect of γ dominates the effect of δ except for lower values of γ.



(**a**) $\mathcal{H}_{L,t}$ modifying δ (**b**) $\mathcal{H}_{L,t}$ modifying γ

Figure 17: Inverse Herfindahl Index in Employment $\mathcal{H}_{L,t}$; δ and γ: The higher δ, the faster employment concentrates, with time the effect of higher values of δ reduces, leaving few differences in the concentration index at the end of the simulations. The higher γ, the faster employment concentrates. The degree at which employment concentrates is also drastically affected by the value of γ.

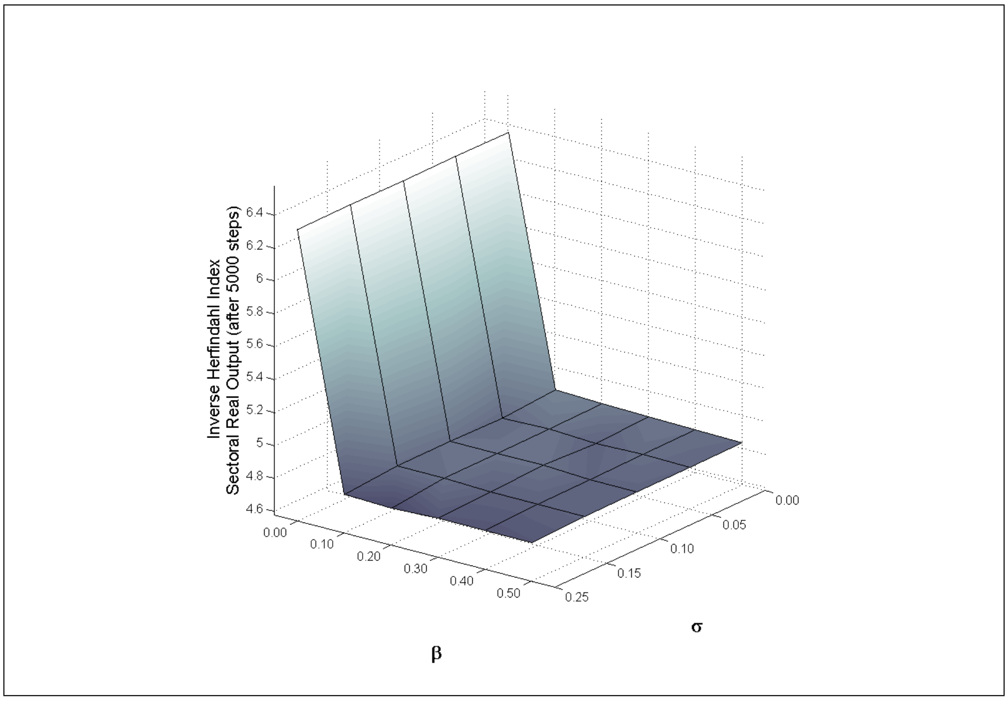


Figure 18: Concentration in Real Output $\mathcal{H}_{O,t}$; σ vs. β (t=5000): This figure includes the case in which $\beta = 0.00$. Structural change does not occur and the concentration in output remains unchanged.

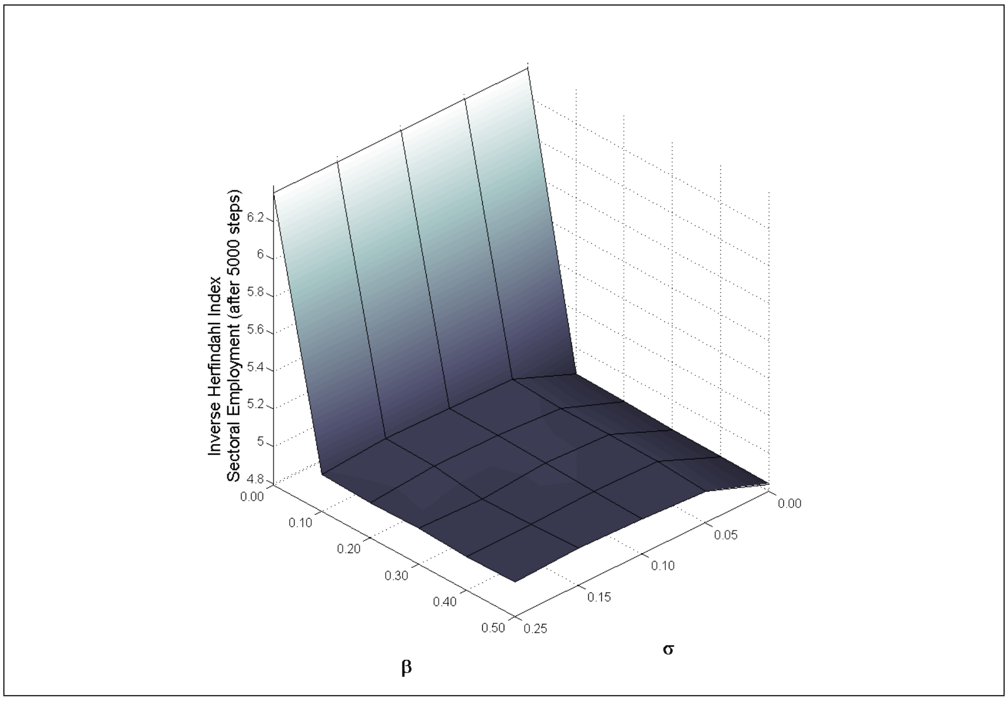
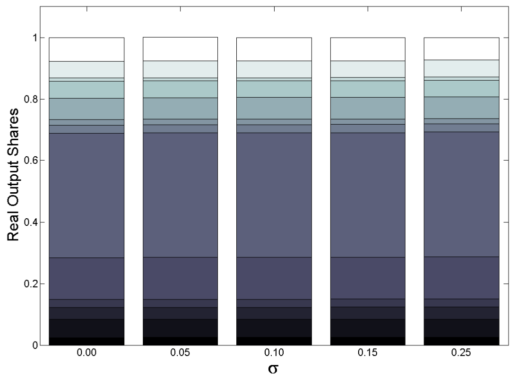
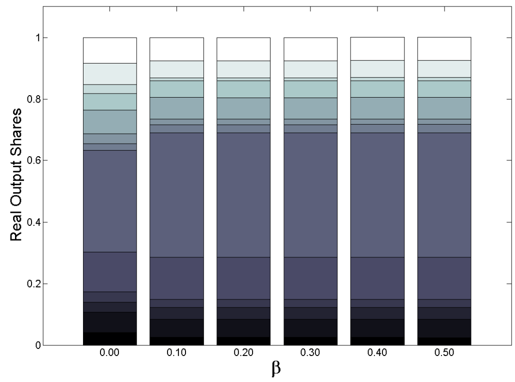


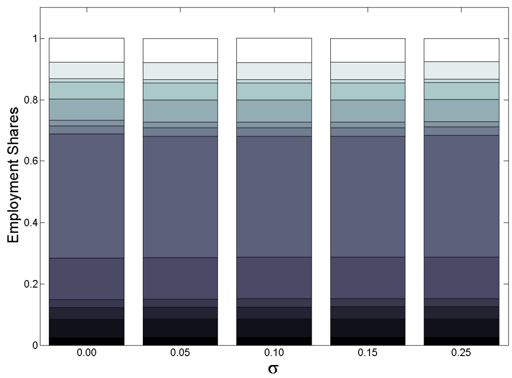
Figure 19: Employment concentration $\mathcal{H}_{L,t}$; σ vs. β (t=5000): This figure includes the case in which $\delta = 0.00$. Structural change does not occur and the concentration in employment remains unchanged.



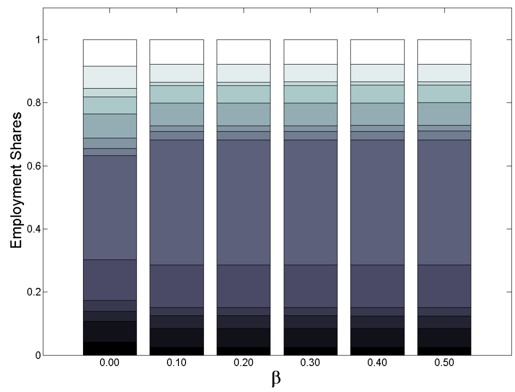
(**i**) Sectoral output shares vs. σ



(**ii**) Sectoral output shares vs. β



(**iii**) Sectoral employment shares vs. σ



(**iv**) Sectoral employment shares vs. β

Figure 20: Sectoral composition of the economy ; β and σ (t=5000): As long as technical change can occur ($\beta > 0$), little to no effect can be observed on the structure of the economy due to changes in β. With higher values in σ, the sectors concentrating the largest share of output loose shares in employment.

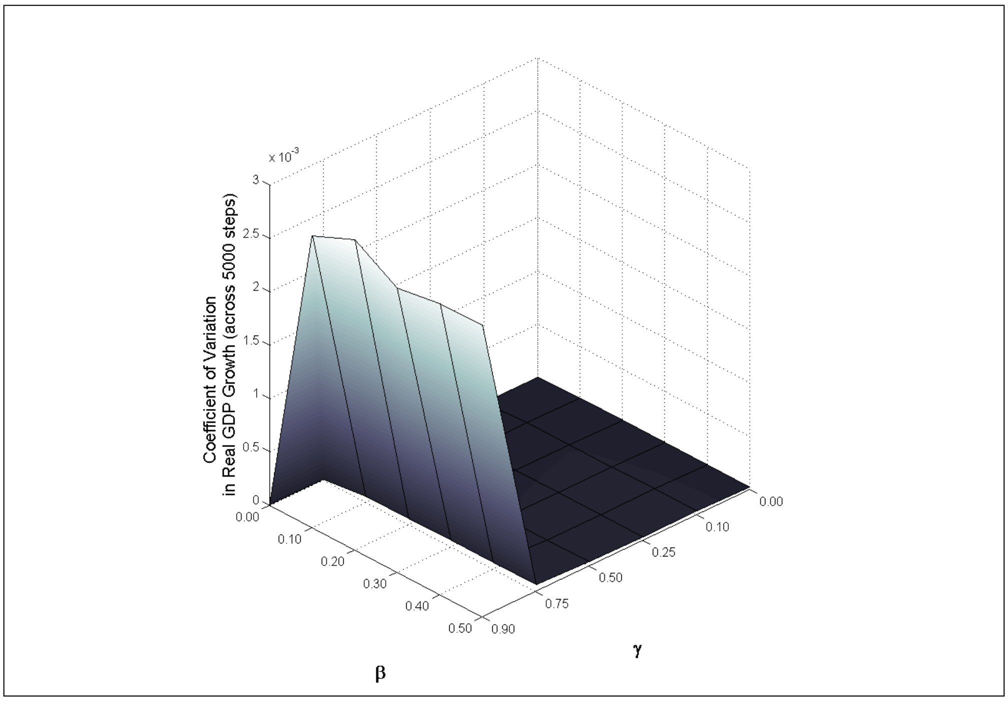


Figure 21: Coefficient of Variation in Real GDP growth rates over 5000 steps β vs. γ: This figure includes the case in which $\gamma = 0.90$.