Kaldor-Verdoorn Cumulative Growth and Micro-founded Technical Change: On the Cyclizing Role of Endogeneous Markups and Conflictual Wage-setting Dynamics.

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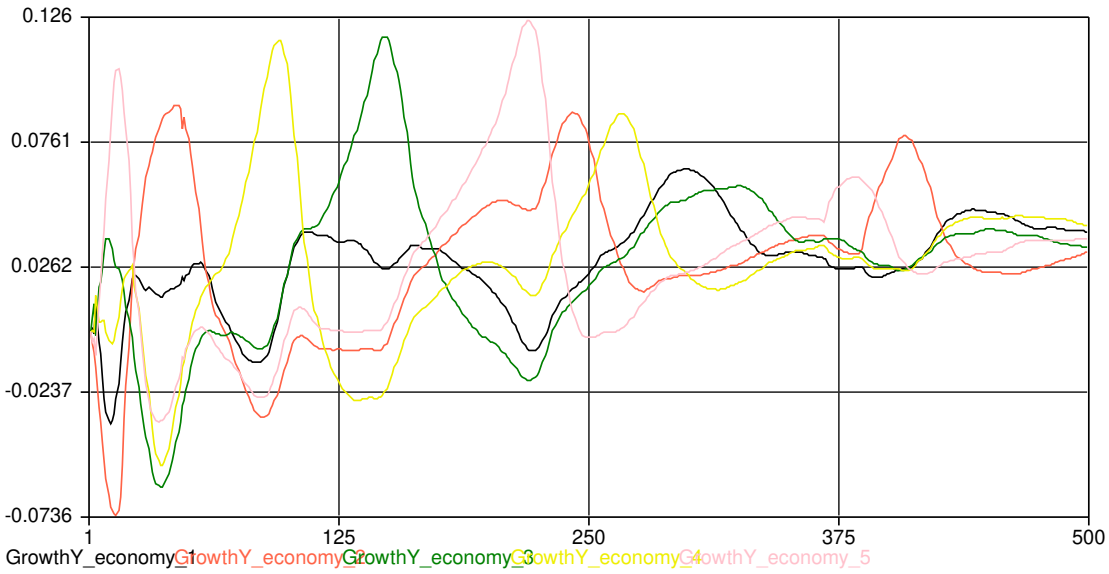

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1 Introduction: an ABM of micro-founded technological innovation and endogenous macroeconomic growth

The article of interest is **"Cumulative Causation And Evolutionary Micro-Founded Technical Change: On the Determinants of Growth Rate Differences"** by Llerena and Lorentz (2004). It aims to study a blind spot in mainstream theories of so-called "endogenous"[1] growth: the persistence of differences in per capita income and per capita income growth rates between countries, and the role of technical change in this, despite the results of Solow-Swan and Ramsey-Cass-Koopmans type models indicating that there must necessarily be convergence between poor and developed countries, due to higher marginal productivity of capital in poor countries with a lower capital stock - encouraging investment in these countries, until they reach the same level of marginal productivity as developed countries (due to the hypothesis of diminishing returns to scale).[2]

However, there is no sigma-convergence, i.e. convergence of per capita income levels, but even divergence, both in the long term (Pritchett, 1997) and in the short term (Jones, 2016). The results regarding beta-convergence, i.e. growth rates, are more nuanced: some studies seem to find a slight convergence, but after adjusting for factors such as human capital, this convergence seems to disappear (Maddison, 1987; Barro, 1991, Mankiw et al., 1992) - at the very least, there is divergence between clusters of countries. Some frivolous explanations based on errors as trivial as the confusion between real resources and financial flows in the accounting equation S = I + CA (CA for current account), like the Lucas paradox and Feldstein-Horioka puzzle, have tried to explain this by problems of international investment flows (c.f. Borio & Disyatat, BIS, (2015) for a debunkage), or others by the existence of a "rule of law" and the existence of property rights in the worthy neo-classical tradition of neo-institutionalism and law and economics (e.g. North, Demsetz (1967), Acemoglu et al. (2001)...).

Nevertheless, these reflections ignore a search for the structural economic mechanisms behind this difference in growth rates, and the role of the structure of the economy and its endogenous innovation dynamics. This article therefore seeks to study the various determinants of these differences, by constructing a theoretical model based both on macroeconomic dynamics based on cumulative causation, and on micro-founded and evolving technical progress, within a framework of an open economy and international competition. To this end, the authors construct an Agent-Based Model (ABM) in which the agents are the firms of different economies. ABMs are appropriate in this framework, as they allow for micro-founded modelling and emergence phenomena, learning, innovation and diffusion processes between heterogeneous and interacting agents, and allow for out-of-equilibrium dynamics (e.g., Caiani, Russo, Palestrini & Gallegati (2016) for a comprehensive introduction to ABM).

We refer to the article in question for a presentation of the formal structure and causal relations of the model - there is no added value in re-exposing it here. Nevertheless, it should

[1] i.e. growth being a source of growth, through an endogenous increase in productivity (e.g. Romer, 1986; learning-by-doing à la Arrow, investments à la Aghion and Howitt...). The simplest formal basis is: $\frac{\dot{a}}{a} = \alpha + \gamma * g$ where g is the GDP growth rate and a is productivity.

[2] Despite the demonstration of increasing returns, both from the presence of minimum fixed costs (Lipsey & Lancaster, 1956), and the situation in underdeveloped countries (Murfy, Shleiger & Vishny (1989); Krugman, (1995) - validating in passing the Big Push theory of Rosenstein-Rodan).

be pointed out that the ABM of interest draws on three traditions:

1. The Kaldorian approach to endogenous growth based on cumulative causation, through its three mechanisms which are a) aggregate demand driving growth and innovation, b) the Kaldor-Verdoorn law (Verdoorn 1949; Kaldor 1966, considering a causal link between economic growth and productivity growth through the presence of increasing returns) and c) Thirlwall's law (growth is driven by a country's relative ability to export and therefore by its degree of international competitiveness, Harrod's trade multiplier type) - these three phenomena being self-perpetuating, hence the cumulative nature (Kaldor (1981); Dixon & Thirlwall (1975); Verspagen (2002)). The problem with this approach is that innovation is not endogenous, and above all, that the Kaldor-Verndoorn mechanism is a "black box";

2. Evolutionary economics, particularly as applied to the theory of the firm and innovation, following on from the seminal work of Neslon & Winter (1982) and the neo-Schumpeterians (Andersen (2009) et Witt (2008) for a comprehensive presentation). This paradigm makes it possible to introduce heterogeneity and endogenise industrial dynamics by opening up the 'black box' of the Kaldor-Verdoorn law, as well as that of the innovation process and its diffusion (e.g. Dosi, 1982), making it possible to really model technological progress, its determinants (investments, profits for self-financing R&D), its diffusion and adoption, and its impact on growth[3], by micro-founding innovation and explaining the decisive role of firms in innovation and growth under macro-economic constraints of aggregate demand, competitiveness and profit (the only source of R&D financing here). The evolutionary approach offers real and explicit "microfoundations", not in the sense of Lucas (1977) and the New Classical Economics (c.f. Kirman (1992) for what the pseudo-microfounded representative agent really is as well as Haldane & Turrell (2018) demonstrating that NEC models are not robust to Lucas' (1976) critique);[4]

3. Finally, there is *"some Austrian flavour in"* the model, due to the presence of constraints imposed on firms' decision-making plans and sequences (in particular innovation and investment, dependent on profits), making it much more complicated for them to coordinate towards equilibria and optimal growth paths (in contrast, for example, to models such as Real Business Cycles). Indeed, the Austrian analysis of business cycles is based on the malinvestment decisions of agents (for specific reasons such as easy money) and their dependence on historical time (Hayek, 1929). Another link with the Austrian school, although not mentioned by the authors, is the presence of a heterogeneous structure of productive capital, with combinations of different generations of vintage capital with different productivities, at the heart of Hayek's work (1941), and the opposite of an "amourphous putty" (Batemarco, 1994**;** Harcourt, 2012) which will always be profitable as expected by

[3]It should be noted, however, that the ability of changes in the structure of production (e.g. as a result of technological change) to modify the growth steady state has also been theorised in the Post-Keynesian literature, see *inter alia* the work of Luigi Pasinetti (e.g. 1981). The contribution of evolutionary economics is to realistically disaggregate and refine innovation dynamics and their impacts.

[4]Couplings between aggregate macroeconomic models and evolutionary-type micro-foundations for technological innovation are beginning to spread (e.g. the E3EMES economy-environment-energy model from Cambridge Econometrics, now used by the European Commission in addition to the traditional DSGE and CGE).

the hypothesis of the fixed K/Y ratio.[5] Note that the evolutionary part is also naturally close to Austrian economics, which has drawn heavily on it in its analysis of institutions and the emergence and evolution of market norms and mechanisms (c.f. von Mises (1949); Hayek (1988)).

The authors then simulate 5 economies, each containing 20 firms with identical initial conditions and parameters before introducing heterogeneity, and look at the impact of 5 parameters on growth and its differential: 4 at the macro level (income elasticity to imports β and exports α, price elasticity ϕ, wage absorption of productivity increase γ) and 2 at the micro level: the level of technological opportunities for innovators ($\bar{\sigma}_j$), and the capacity of imitating firms to absorb innovation (χ_j). The results of the simulations reveal three regimes of growth rate divergence:

1. Differences in growth rates maintained, simply because of heterogeneity in income elasticities.

2. Differences in growth rates with transitory phases of divergence, due to heterogeneity in technological opportunities, the transitory nature of which depends on wage dynamics.

3. Destructive divergences causing lagging economies to stall in the face of technologically dominant economies, as a result of wages not fully absorbing the rise in productivity, leading to situations of domination.

It is within this framework that we propose to introduce a humble and unsteady extension.

2 Proposed extension: endogenising markup and wage negotiations in conflict dynamics

2.1 Rationales

Llorena and Lorentz (2004) put forward as *"one of the major features"* of their model the fact that *"unlike growth theories, it never assumes full employment, and never considers general equilibrium framework for analysing growth. It means that it never assumes the existence of a natural rate of growth along a given balanced growth path"* (p.1193).

Yet there is no labour market in their model. Firms are constrained only in terms of production costs and therefore wage costs, but not in terms of the quantity of labour available, which is always sufficient. Unemployment is therefore not explained, and is not even residual since the size or evolution of the labour force is not specified. Full employment is therefore not assumed, but this is because no mechanism deals with unemployment here.

There is therefore no impact of unemployment (and therefore of the wage bill) on aggregate domestic demand, even though the capacity to consume income is one of its main determinants, alongside investment in productive goods and exports. This is because *"In our model, the time*

[5] In fact, the question of heterogeneous "Putty-Clay" capital (i.e. that can be designed before construction to be used by a certain number of workers ex ante, but with a fixed labour-capital mix ex post) is also present in the Post-Keynesian literature (notably as a result of the Two Cambridge Controversy) and has also been theorised elsewhere than in Austrian theory (e.g. Johansen, 1959; Sraffa, 1960; Akerlof, 1967; Akerlof & Stiglitz, 1969; Hu, 1972; Giraud & Arran, 2022).

dimension allows aggregate supply to match entirely aggregate demand. We do not consider here explicitly the process of coordination of demand and supply in the market for goods".

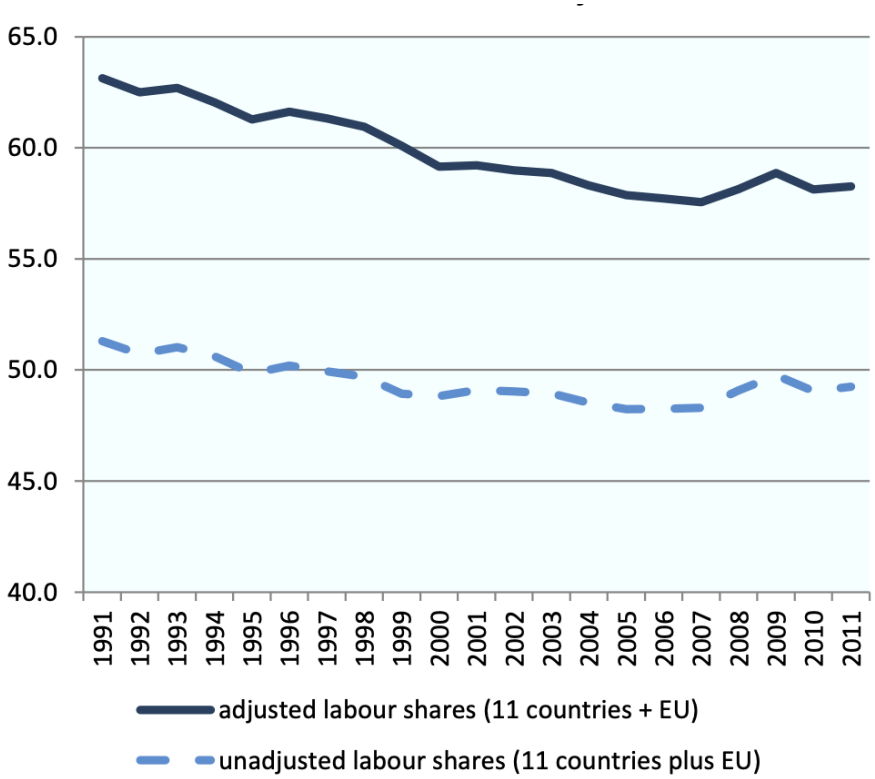
Moreover, since the work of Kalecki and Goodwin, we know the decisive role of the (conflictual, c.f. Marx, 1867) factorial distribution of incomes on economic activity: workers spend a larger share of their income, supporting aggregate demand, but it is capitalists who invest in R&D and in the accumulation of productive capital (depending on the share and/or rate of profit, which is more of a supply factor, or the rate of capacity utilisation, which is more of a demand factor and derives from workers' consumption). c.f. the Kuznets curve (1955). The work linking in a bidirectional manner (changes in) factor distribution and technological innovation/growth is widely studied (e.g. Pasinetti, 1962; Stigliz, 1969; Galbraith's many works).

Here, the model of interest here specifies that *"we assume here that the mark-up coefficients are fixed for each firms in a given economy. This insures that the share of profits in GDP is constant over time, which corresponds to one of Kaldor's stylised facts."*, in reference to Kaldor (1961).

Nonetheless, the factorial trend distribution of value between wages and profits, over and above its cyclical nature (c.f. Goodwin), has been changing structurally in recent decades, to the benefit of profits (for empirical work in a Goodwin-type macro modelling framework e.g. Grasselli & Maheshwari, 2018; McIsaac, 2021; Borio et al, 2023), with, for example, a fall of 0.3% per year in the wage share in the G20 countries since 1990 (IMF, 2007; European Commission, 2007; BIS, 2006; ILO, 2012)[6].

[6]This can be explained by the erosion of trade unions, deindustrialisation, offshoring and competition between workers in the globalisation of value chains, the unravelling of labour codes and employment protection, the flexibilisation of the labour market and the development of fixed-term contracts, 1 jobs since the late 1970s have profoundly damaged workers' wage bargaining power, to the point where the Phillips curve is empirically considered to be 'flattened' in most developed countries (Ratner & Sims, FED, 2022).

Figure 1: Adjusted and unadjusted labour shares in selected G20 countries



Note: Data of Australia, Canada, France, Germany, Italy, Japan, The Rep. of Korea, the Russian Federation, South Africa, United Kingdom and the United States. *Data Source:* ILO based on main National Accounts from UN DATA (www.data.un.org).

Similarly, assuming a constant ratio or one that changes only as a result of technological progress is equivalent to making the assumption that the factor distribution is determined solely by technological conditions.

So, at first sight, we might be tempted to modify the model to incorporate distributive conflict, worker/capitalist heterogeneity, different spending behaviours, a consumer goods sector and a capital goods sector, and a labour market, an explicit goods market with the possibility of disequilibrium between supply and demand through the independence of consumption and investment behaviour, using inventories to relax Say's law, and an investment function that can depend on both the rate of profit (supply) and the rate of utilisation of productive capacity (demand) of the Badhuri and Marglin (1990) type. This also makes it possible to make the wage share dependent on the socio-economic context and not on purely technical contingencies as in Cobb-Douglas technologies, where factors are remunerated at their marginal productivity.

However, 1) this would lead to an excessive modification of the model, the objective being to study the impact of a specific extension in relation to a given framework with properties that are already known, and 2) in reality there is no need for so many tricks to reveal conflict in the distribution of value and variation in the wage and profit shares: in my opinion, it is "sufficient" to endogenise the markup in the price dynamics, and the parameter for absorbing productivity growth (and therefore productivity)[7] by wage growth in the wage dynamics. And so to connect

[7]In neo-classical theory, γ is fixed and equal to 1, with wages absorbing all productivity gains, despite the widespread empirical decoupling in developed countries between wages and productivity, c. f. OECD (2018).

the two. Indeed, these two parameters are at the heart of one of the main mechanisms at the source of endogenous fluctuations and dynamics: the conflict in the factor distribution of value added[8]. This still requires the inclusion of an employment rate dynamics equation and a labour-work force (with an exogenous growth rate).

2.2 Endogenising markups and wage bargaining power

It can be assumed that firms seek to increase their profit margins (i.e. their markup)[9] at constant production costs (including wages) by raising their selling prices. Indeed, the price must cover unit labor and material costs, and generate a profit rate required by firms - in this case, to enable self-financed investment in innovation and productive capital, the only possibility of financing for firms, as external financing was not considered here. Production prices are generically cost-plus prices i.e. prices depend on some standardized unit cost to which is added a costing margin[10] under the constraint of the price elasticity of demand, a situation symptomatic of imperfect competition (Kalecki, 1943). Market power and imperfect competition are the "standard" case (Hall & Hitch, 1939; Lee & Irving-Lessmann, 1992; Hall, 2018 for recent empirical results for the US economy). Nevertheless, a static approach to imperfect competition generally prevails, as the Post-Keynesian tradition assumes a constant markup (price dynamics then being the convergence of observed prices through a lagged adjustment towards a long-run equilibrium price composed of a markup on production costs, see for example Godley and Lavoie, 2007, Section 8.3). Thus, in a situation of "imperfect competition", a markup necessarily emerges, all the more so with a selection process.

The endogenization of the markup is justified by the fact that it depends on a certain number of economic parameters and on a dynamic, negotiated and constrained optimization. It is true that the oligopolistic nature of the industry can theoretically manifest itself in rigidity between prices and production costs. Nevertheless, the assumption of markup fixity on production costs, according to which any increase in wages or fall in apparent labour productivity can only be inflationary (e.g. by Weintraub (1978) and Moore (1979)) is, from a strictly formal point of view, an isomorphism with the quantitative theory of money (Loranger & Halévi, 1986). This position does not take into account the current degree of monopolization of economies, particularly Western ones, strongly characterized by large surpluses of production capacity and underemployment of labor power (Kalecki, 1971).

Furthermore, if we follow Kalecki, the degree of monopoly, and therefore markup, depends

[8]Moreover, endogenizing markups reinforces the out-of-equilibrium character, as it reinforces the fact that prices are not set so as to insure the equality between supply and demand; instead they are perceived as reproduction prices, that is, prices that insure the reproduction of the system - this is confirmed here by the fact that profits are the only sources of financing investment and innovation for companies.

[9]Hypothesis supported by empirical literature on the evolution of corporate strategy towards the maximization of EBIT margin rates and therefore profit (to the detriment of investment and R&D, c.f. Stockhammer, 2014; Durand & Gueuder (2018); Stockhammer)

[10]There are different methods for calculating the profit margin depending on the sector: mark-up procedure (p = (1+ rate of margin) * average unit cost); normal cost procedure (p = (1+ net profit margin) * normal cost at standard production level); target rate of return procedure (same as normal costing but the value of the net mark-up at (target rate of return * technology ratio) / (standard utilisation rate - target rate of return * technology ratio); (production price: p = wage rate * labour per unit of output + uniform profit rate * p * number of machines per unit of output)... Here, we consider the unit cost of production (and not the marginal price).

on both goods market conditions (i.e. industrial structure and concentration) and labor market conditions (in particular, workers' bargaining power). It is a dynamic phenomenon of negotiation and arbitration, with the constraint of inter-sector competitiveness: *"High markups in existence will encourage strong trade unions to bargain for higher wages since they know that firms can 'afford' to pay them. If their demands are granted but... [the markup is] not changed, prices also increase. This would lead to a new round of demand for higher wages and the process would go on with price levels rising. But surely an industry will not like such a process making its products more and more expensive and thus less competitive with the products of others industries. To sum up, trade-union power restrains the markups."* (Kalecki, 1971, p.161)

This is a single-sector model, but the inter-sector character is equivalent here to the framework of an open economy and international competition, with the degree of imperfect competition also given by the price elasticities of imports and exports (equivalent to the price elasticities of other sectors). Thus, the size of the markup is variable and dynamic, and it depends not only on factors relating to product markets such as the number of firms and the elasticity of demand, but also on the bargaining strength of trade unions against owners within firms (Dutt, 2012).

So there are several possibilities open to us. If we had the time (*sigh...*), we could construct a Nash bargaining-type process between firms and workers to optimally identify the markup and nominal wage, à la Sen and Dutt (1995). For example, Mehrling (1988) integrates a differential game into a Goodwin model, Lancaster's class struggle model, which gives different hierarchical and codetermined equilibria according to the degree of organization and capacity for influence of the social classes "for themselves" (capitalists and proletarians).

Nevertheless, Nash bargaining-style optimization is based on very strong assumptions of rationality, inconsistent and incompatible with Simon's hypothesis (1979) of bounded rationality, which denies that firms set prices in an attempt to maximize profits, but instead follow simple rules of thumb, or routines (c.f. Nelson & Winter 1982; Mazzoleni & Nelson, 2013). Similarly, the variability of markup in relation to a stable institutional situation should not be overestimated: *" . . custom and competition are predominant among the determinants of the mark-up for profit. . whatever competitive factors affect the determination of the mark-up, the role of custom and convention is significant enough to place the motivation of the price administrators outside the simple description of maximizing profits..."* (Lee, 1994, p. 325-326)[11].

We can therefore create a simpler endogenisation. We choose the following approach: the markup depends on 1) the degree of market imperfection and industrial concentration, 2) the price elasticity of demand (the lower the elasticity, the less demand will react to a price change, reinforcing the ability of firms to raise prices without lowering revenues), and 3) wage bargaining power, which includes union strength. Indeed, the struggle of workers and unions to maintain and increase their purchasing power involves not only raising nominal wages, but also limiting price rises, and hence markups. Moreover, Llerena and Lorentz's ABM already has a parameter

[11]Similarly, we could construct an evolutionary dynamic not only of innovation but of prices. In Seppecher et al. (2017) which constructs a stock-flow consistent ABM with an evolutionary pricing, the firms update their markup levels and leverage targets using an evolutionary algorithm along the lines of Alchian (1950). In the simplest version of this evolutionary learning process, two operators are essential: an exploration process that constantly introduces new, potentially more profitable strategies into the population of existing strategies, and an exploitation process that propagates the profitable strategies among the population of firms. Nevertheless, in Lorena and Lorentz (2004), evolutionary dynamics already exist for market shares.

that can be used as a proxy: γ, which weights the effect of labour productivity growth on wage dynamics (i.e. the degree of wage absorption of productivity growth), which enters the wage determination equation; and the parameter ϕ, which measures demand rigidity to price (competitiveness) change, which enters the determination of the market share of each firm.

We can go even further: wage bargaining power, which includes union strength, is contingent on labour market tensions and the unemployment rate (Woodford 2003; Gali & Gertler, 1999; Borio et al., 2023), an idea already present in Marx (1867, chap.25) under the concept of the "reserve army of labour". We can therefore endogenize this parameter, through a linearized short-term Phillips curve.

In so doing, wage dynamics also evolves: the degree to which productivity increases are absorbed by wages γ is endogenized by the Phillips curve, and can also be increased by a degree of monetary illusion (wage negotiations take into account not only the employment rate but also inflation), and of course the Phillips curve directly in relation to the unemployment rate.

3 Formalisation of the model extension:

***NB**: I have reproduced the entry/exit mechanism for firms (cf Firm_Exist_Entry) - to be precise, the technological variables assumed to be set to the economy average for the new firms are $A_{firm}, E_{firm}, p_{firm}$, and K_{firm}. The average values of these technological variables are calculated before any firm exits and then used to initialize the new firms that enter the market*[12]*. In addition, slight modifications have been made to the reproduction of the code, e.g. replacing the uniform draw with a Bernoulli draw for the R&D outcome, following Lorentz (2018) - there are also problems with the modification of the firm exit mechanisms. I also have had to add non-division-by-zero conditions to several equations due to the collapse of variables in certain agents/economies.*

We will assume that the labour force available in the economy, $L_{s,t}$, grows exogenously at a common fixed rate, n, such that $L_{s,t} = L_{s,t-1}(1+n)$ and that the labour supply always corresponds to this labour force (there is no reservation wage, as people need to eat).

The demand for labour by firm i is derived from the production function :

$$L^D_{i,j,t} = \frac{Y_{i,j,t}}{A_{i,j,t-1}}$$

The aggregate demand for labour in the j economy is therefore :

$$L^D_{j,t} = \sum_i L^D_{i,j,t}$$

The constraint $L^D_{j,t} \leq L_{j,t}$ is assumed to be never binding, due to the continued existence of incompressible frictional unemployment (in 3 and 5%) and mass unemployment in developed countries as well as a heavy informal economy in developing countries, allowing the hypothesis of a rationing of labour supply to be ruled out. Thus, the employment rate is defined as the

[12]Actually, the idea that new firms replace obsolete firms without changing the total number of firms in the market significantly is quite accurate empirically (e.g. Bartelsman et al., 2003).

ratio between the number of employed workers $L^D_{s,t}$ which always correspond to the demand for labor from firms, and the labor force $L_{j,t}$:

$$l_{j,t} = \frac{L^D_{j,t}}{L_{j,t}}$$

We can thus construct the employment rate equation as an increasing function of the GDP, a decreasing function of the labour productivity, and a decreasing function of the labour force growth - note that the last two components of the equation correspond to Okun's law, and that this equation resembles the differential employment rate equation à la Goodwin, showing a prey-predatory dynamics between employment rate and labour productivity.

$$l_{j,t} = \frac{Y_{j,t}/A_{j,t}}{L_{j,t-1}(1+n)}$$

Let's write it in terms of growth rate :

$$l_{j,t} = l_{j,t-1}\left(1 + \frac{\Delta Y_{j,t}}{Y_{j,t-1}}\right)\left(1 - \frac{\Delta A_{j,t}}{A_{j,t-1}}\right)\left(\frac{1}{1+n}\right)$$

In the following, what we call $l_{j,t}$ will correspond to the logistic function $f(l_{j,t})$ in order to restrict the values of the employment rate to the closed interval $[\ 0, 1]$. Otherwise the model takes on infinite values, making the simulations uninteresting. $f(x)$ corresponding to $\frac{1}{1+e^{-x}}$.

Wage dynamics still includes average labour productivity growth, but now also the inflation rate in a logic of preserving purchasing power (as the price of consumer goods and that of capital is not differentiated, there is no notion of consumer price and we just take the change in the average price $\overline{p}_{j,t}$), with workers taking this observed rate into account in their negotiations. In addition, a short-term Phillips curve is also added, to take into account the effect of unemployment and tensions on the labour market on wage bargaining power.

$$w_{j,t} = w_{j,t-1}\left(1 + \gamma\frac{\Delta A_{j,t}}{A_{j,t-1}}\right)\left(1 + \zeta\frac{\Delta \overline{p}_{j,t}}{\overline{p}_{j,t-1}}\right)(1 + \kappa(l_{j,t}))$$

With constant ζ, between 0 and 1, representing the degree of monetary illusion ($\zeta = 1$ means that workers are fully integrating inflation into their negotiations). Let's precise here that, and it will be the same for the markup extension *infra*, I consider that factors have interactive effects. For example, the impact of productivity on wages might be different at different levels of employment. Thus, I use the multiplicative approach instead of the additive approach in the specification of the different change rates' components (i.e $x(1+\alpha)(1+\beta)$ instead of $x(1+\alpha+\beta)$). . As for the short-term Phillips curve, it is some increasing real-valued linear function[13] :

$$\kappa(l_{j,t}) = \nu_{0,j} + \nu_{1,j} * l_{j,t}$$

[13]Goodwin had estimated the Phillips curved as a linear function to simplify the model and saying that this would not change the relationship (Goodwin 1967, 54), but non-linear specifications do exist. E.g. Desai et. al. (2003, 7) propose the following form : $\kappa(L^D_{j,t}) = \nu_0 + (\lambda - L^D_{j,t})^{-\delta}$ with λ the boundary of the workers' share and δ an auxiliary variable. More trivially, a good approximation would be the function $\nu_0 + \frac{\eta}{1-L^D_{j,t}}$ to avoid explosive dynamics, and anything in the form of a logistic function (e.g. à la Verhulst). We have tried the specification $\frac{\nu_1}{1+\nu_0}$ with $\nu_0 = 0.5$ and $\nu_1 = 0.8$ and we obtained results similar to the linear form.

$\nu_{0,j}$ is a negative constant (to allow a negative wage growth rate even for a non-zero employment rate, but that can represent the base rate of wage growth independent of the employment rate too, like the union minimal power and State collective conventions and regulations on wage progression and indexation), and $\nu_{1,j} > 0$ the sensitivity of wage growth to changes in the employment rate.

To refine the model in terms of agents' behavioural equations, we could consider that workers consider variations in the above variables of interest through their moving averages (or even a linear combination of moving averages of inflation and unemployment) in order to smooth fluctuations and take an interest in trends and not in noise or cyclical fluctuations, with adaptive type expectations (while prioritising recent changes). Nevertheless, we keep our calculations light, and we can consider that a significant reactivity to variations, even of a cyclical or stochastic type, is not unrealistic (particularly in terms of response to a variation in inflation, for example).

We can now also endogenise the markup, which therefore depends on 1) the degree of market imperfection and industrial concentration, the proxy for which is the economy's $z_{j,t}$ market share, 2) the elasticity of demand in relation to price (the lower the elasticity, the less demand will react to a variation in price, reinforcing the ability of firms to raise their prices without lowering their revenues. If the elasticity is infinite, then we have perfect competition). We have such an elasticity in the seminal model, which is common to all economies and is ϕ. Finally, the markup also depends on 3) wage bargaining power, which includes union strength. The struggle of workers and trade unions to maintain and increase their purchasing power involves not only raising nominal wages but also limiting price rises, and hence markups. A proxy for this phenomenon already exists in the seminal model: the γ parameter for the absorption of productivity growth by wages. It can be seen as firms adjust their markup based on how sensitive wages are to productivity changes. If wages are highly responsive to productivity (γ is high), firms might increase their markup to maintain profit margins. By connecting it, the proposed markup equation is:

$$\mu_{j,t} = \mu_{j,t-1}\left(1 + \xi(\frac{1}{1+\phi} - \gamma + z_{j,t-1})\right)$$

Dividing by $1 + \phi$ instead of subtracting ϕ prevents the markup from becoming negative, and ξ is a parameter that determines the speed of adjustment of the markup to changes in the other variables.

However, as the γ has itself been endogenised, wage bargaining power, the ability of wages to absorb productivity gains, and union strength, are themselves contingent on the unemployment rate and therefore a Phillips mechanism. It assumes that the same factors affecting wage growth through the Phillips curve also affect the pass-through of productivity to wages. γ could therefore be written as:

$$\gamma_{j,t} = \gamma_{t-1}(1 + \theta(\nu_{0,j} + \nu_{1,j} * l_{j,t}))$$

But $\gamma_{j,t}$, even endogenised, must lie in the closed interval $[\,0, 1]$. Let's use a logistic function to "squash" the output of the Phillips curve into that range, $g(x)$:

$$g(x) = \frac{1}{1 + e^{-x}}$$

Thus:

$$\gamma_{j,t} = g(\theta(\nu_{0,j} + \nu_{1,j} * l_{j,t}))$$

We are considering here a markup common to an economy, in a context of competitiveness and international competition with other economies. Labour market conditions have an impact on all firms in a country (all the more so in a mono-sector framework). The role of each agent's technology still exists in the pricing equation of firms through the agent's wage/productivity term $w_{j,t-1}/A_{i,j,t-1}$, alongside the common markup. Moreover, the imperfect nature of competition at the national level allows the markup to be diffused even for less innovative firms, with custom and social norms also playing a role in the diffusion and determination of the markup (Alchian, 1950; Lee, 1994).

The table below summarises the structure of the model by its different categories of variables and parameters (macro and micro):

Table n°1: Table of the extended model					
Agents (i)	Micro variables	Micro parameters	Macro parameters	Macro variables	Decision rules
Firm i (of economy j)	$\mathrm{z}_{i,j,t}, Y_{i,j,t}, p_{i,j,t}$, $\mathrm{E}_{i,j,t}, A_{i,j,t}, L_{i,j,t}$, $\mathrm{a}_{i,j,t}, \Pi_{i,j,t}, R_{i,j,t}$, $\mathrm{I}_{i,j,t}, \sigma_{i,j,t}$(innovator/imitator), $\epsilon_{i,j,t}, \mu_{j,t}$	$\rho_{i,j}, \iota_{i,j}$	$\alpha_j, \beta_j, \xi, \zeta$ $\overline{\sigma}_j, \chi_j, \phi, \nu_{0,j}$, $\nu_{1,j}, n, \theta$	$\mathrm{Y}_{j,t}, M_{j,t}, X_{j,t}$, $\mathrm{z}_{j,t}, Y_{w,t}, E_{j,t}$, $\mathrm{w}_{j,t}, e_{j,t}, A_{j,t}$ $l_{j,t}$, $\gamma_{j,t}$	$\mathrm{I}_{i,jt}, R_{i,j,t}$
Firm from RoW			λ^{RoW}	Y_t^{RoW}	

4 Simulation and analysis

4.1 Calibration and initialisation

For parameter calibration and variable initialisation, we used the values chosen by Llerena and Lorentz (2004) for the parameters and variables taken from their model.

About the new parameters and variables:

- For the baseline scenario, all the economies have the same parameters for their Phillips curves (we will then differentiate them in intervals that preserve the calculability of the simulation, c.f. **Table 2** *infra*). The parameters of the linearised short-term Phillips curve are taken from the empirical estimation work carried out by Giraud, Bovari and McIsaac (2018) for the construction of their Goodwin-Keen IAM (AFD), an estimation mobilising data from the World Bank and the Penn World Table (on share of labor compensation in GDP), on a panel of representative developed and developing countries, over a period from 1991 to 2014.[14]. The constant $\nu_{0,j}$ is estimated at -0.292 , and the slope $\nu_{1,j}$ at 0.469.

- The ζ parameter for the reaction to inflation in wage bargaining is set at 0.2. It is not close to 1 because we must not confuse the absence of monetary illusion in the analysis by agents with their ability to negotiate better nominal wages as a result. The current inflationary situation in the West is a good illustration of this: workers are fully aware of the inflation affecting them, but in France, for example, despite the rise in nominal wages, real wages continue to fall (Souffron & Kleman, 2023; INSEE, 2023; Baudry et al., 2023).

- The markup, although endogenous, needs to be initialised. As the markup is calculated as a change relative to its previous period, the first $\mu_{j,t-1}$ is calibrated at 0.6

- For the initialization of the average price of each economy $\overline{p}_{j,t}$ (necessary because of the use of a rate of change), we normalize the $\overline{p}_{j,t-1}$ to 1, as all firm prices are equal to 1 in the first period.

- For the exogenous growth rate of the labour force n, we take the world growth rate for 2021 (World Bank, 2021), of 1.9%.

- As this work has to be concise, we will not study the impact of adjustment times and viscosities, so we set θ and ξ continuously equal to 1, for all economies.

- Finally, for the starting employment rate (here, the ratio of workers to the labour force, $l_{j,0}$), the starting value is 80%. This is lower than the world average and that of the OECD, but it is representative of the full-time equivalent employment rate, an important indicator of wage negotiation capacity: a low unemployment rate will have little impact on negotiations if employment is primarily precarious and artificial (multiplication of part-time jobs in the UK, '€1 jobs' in Germany, unemployment halo, etc.). Moreover, the dynamics are

[14]The list of selected countries includes: Argentina, Australia, Austria, Belgium, Canada, Chile, China, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Malaysia, Mexico, Netherlands, Norway, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, Thailand, Turkey, the United Kingdom, and the United States.

robust to very different starting employment rates (e.g. 20% for all economies), suggesting that the model is not over-sensitive to the initial conditions.

The table below summarises these new calibrations and initialisations[15]:

Table n°2: Calibration of the new parameters (compared to the seminal model)					
	Economy 1	Economy 2	Economy 3	Economy 4	Economy 5
$\nu_{0,j}$	- 0.292	- 0.292	- 0.292	- 0.292	- 0.292
$\nu_{1,j}$	0.469	0.469	0.469	0.469	0.469
$\nu_{1,j}$	1	1	1	1	1
$\nu_{1,j}$	0.469	0.602	0.734	0.867	1
ζ	0.2	0.2	0.2	0.2	0.2
$\mu_{j,t-1}$	0.6	0.6	0.6	0.6	0.6
$\overline{p}_{j,t-1}$	1	1	1	1	1
n	0.019	0.019	0.019	0.019	0.019
$l_{j,0}$	0.8	0.8	0.8	0.8	0.8
ξ	1	1	1	1	1
θ	1	1	1	1	1

And this table below summarises the calibration for the standard model :

Table n°3: Calibration of the seminal model					
	Economy 1	Economy 2	Economy 3	Economy 4	Economy 5
α_j	0.375	0.375	0.375	0.375	0.375
β_j	0.5	0.5	0.52	0.5	0.5
$\overline{\sigma}_j$	0.1	0.1	0.1	0.1	0.1
$\overline{\sigma}_j$	0.075	0.0875	0.1	0.1125	0.125
μ_j	0.6	0.6	0.6	0.6	0.6
χ_j	0.5	0.5	0.5	0.5	0.5
ϕ	1	1	1	1	1
γ	1	1	1	1	1

4.2 Results and interpretation

Ideally, a General Sensitivity Analysis should be carried out to identify which role a given parameter plays, and to identify the threshold values for which the qualitative properties of the model change (principle of Bifurcation Theory), or even Monte Carlo simulations. Actually, LMM/LSD is not really convenient for this. We will therefore do it manually.

We carry out four rounds of simulations (in addition to the comparison with the seminal model of Llerena and Lorentz, 2004): one round with the same Phillips curve parameter for all economies, $nu_{1,j}$ estimated at 0.469. A second round with this same parameter raised to 1, implying much greater capacity for wage bargaining and absorption of productivity gains by wages. A third round with a different and progressive value for each economy, from 0.469 to 1 (c.f. **Table 2**). Finally, a fourth and final round introduces heterogeneity into the level

[15] With a step of 0.13275 for $\nu_{1,j}$ for the simulation where it is different for each economy.

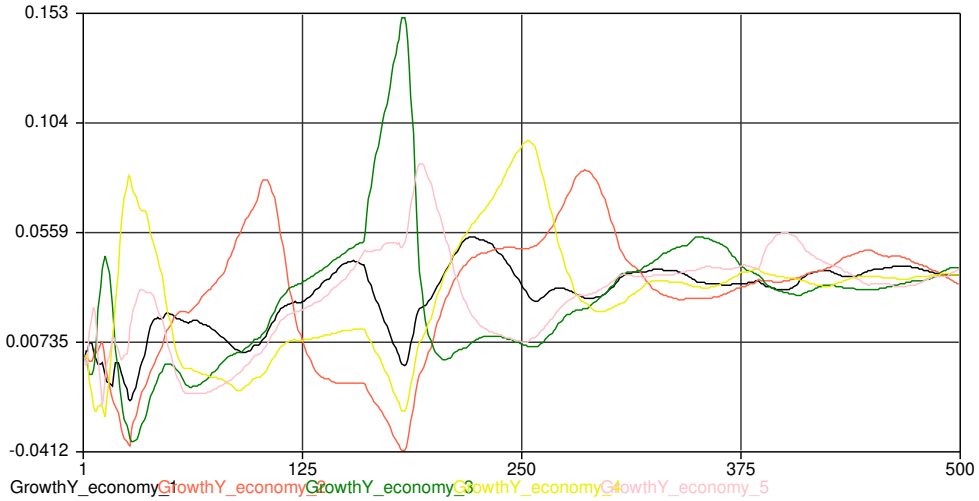


Figure 1: Output Growth with $\nu_{1,j} = 0.469$

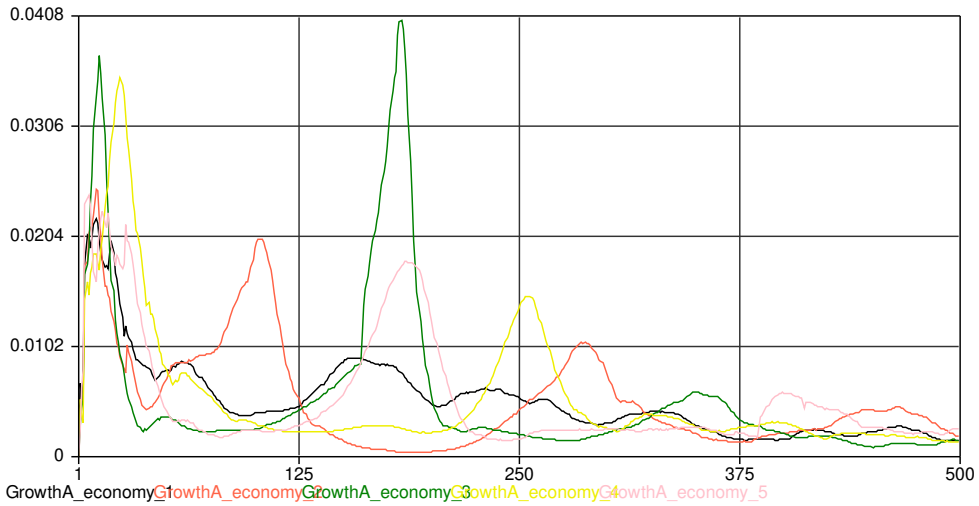


Figure 2: Productivity Growth with $\nu_{1,j} = 0.469$

of technological opportunities for the innovators $\overline{\sigma}_j$ to study the role of the degree of wage absorption of productivity gains and wage bargaining in amplifying or attenuating differences in innovation.

The first possible observation in comparison with the seminal model following the introduction of an endogenised markup through a realistic Phillips curve which is also included in the wage dynamics, and with a specified labour market, is the very realistic presence of fluctuations in the growth of all the economies (Fig. 1), as well as, to a lesser extent, in that of productivity (Fig. 2).

The high endogeneity of the extended model means that growth is cyclical and non-linear, and economies only converge towards the same growth rate in the long term. So, *things happen*, before reaching any kind of "steady state".

Furthermore, we note that the endogenisation of the markup at the level of each economy in relation to its labour market, bargaining capacities, market shares (market concentration)

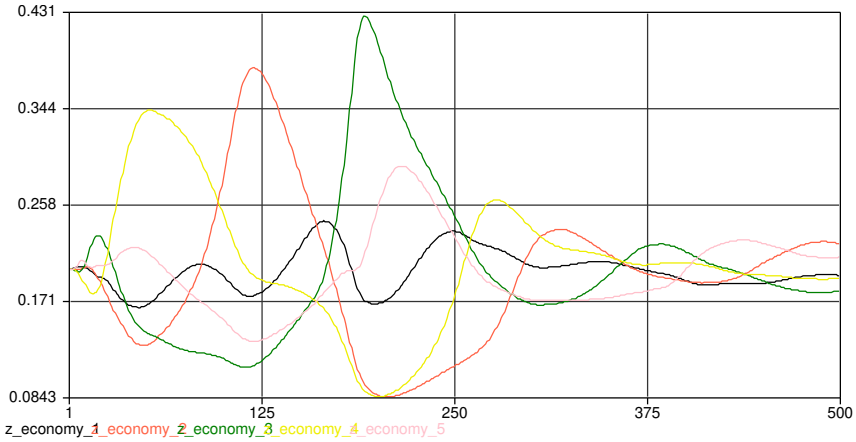


Figure 3: Economies' market shares with $\nu_{1,j} = 1$

Figure 4: Markups change with $\nu_{1,j} = 0.469$

and the price elasticity of demand, drastically opposes the naturally monopolistic character which generally emerges from selection mechanisms based on replicators. In fact, market shares also follow a cyclical pattern (Fig. 3), and no economy seems to 'dominate' the others: the economies with the highest market shares are also those with the lowest. The amplitude is in both directions, when the most stable economies have smaller fluctuations - these observations also apply to output growth rates, where no one strictly dominates the others and where the amplitude can be large (and even negative with recession periods).

Markups thus fluctuate slightly within fairly realistic ranges, appearing to converge in the long term too, and increasing slightly in the long term, in line with trends in market shares (Fig. 4). Finally, employment rates also fluctuate and are cyclical, before converging (Fig. 5).

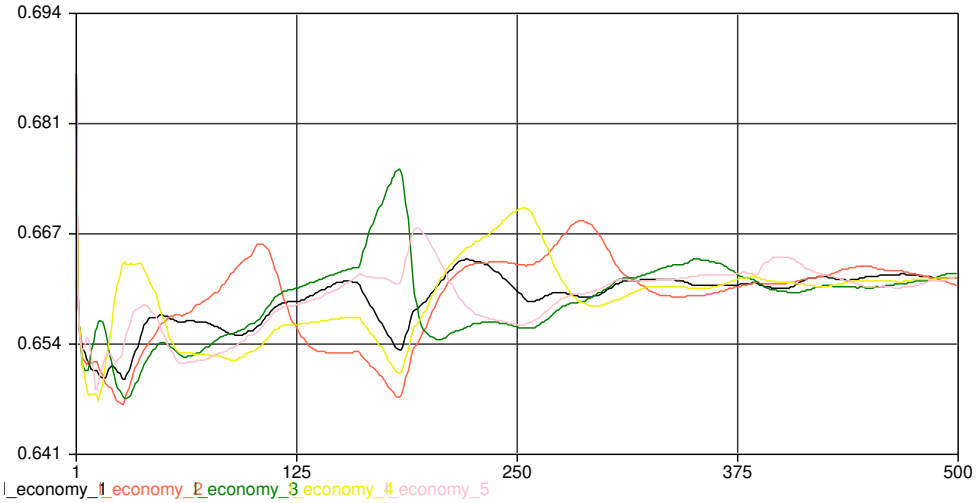


Figure 5: Employment rate with $\nu_{1,j} = 0.469$

For the second round of simulation, a much higher value was chosen for the $\nu_{1,j}$ parameter of the Phillips curve, 1, which is not very realistic given the flattening of the real curve, but is interesting for seeing the effects of a high common capacity for wage bargaining and absorption of productivity gains. Although output growth, productivity growth and market share initially fluctuate sharply, the economies also converge in the long term, without any dominance or stalling (Figs. 6, 7 and 8). Moreover, markups and employment rates are evolving considerably, although asymptotically increasing (Figs. 9 and 10). It would seem that a strong capacity for wage bargaining and wage absorption of productivity gains, as well as endogenous markups, slow down the cumulative divergences that may be linked to innovation, which are eventually absorbed. This is equivalent to a high γ in the seminal model.

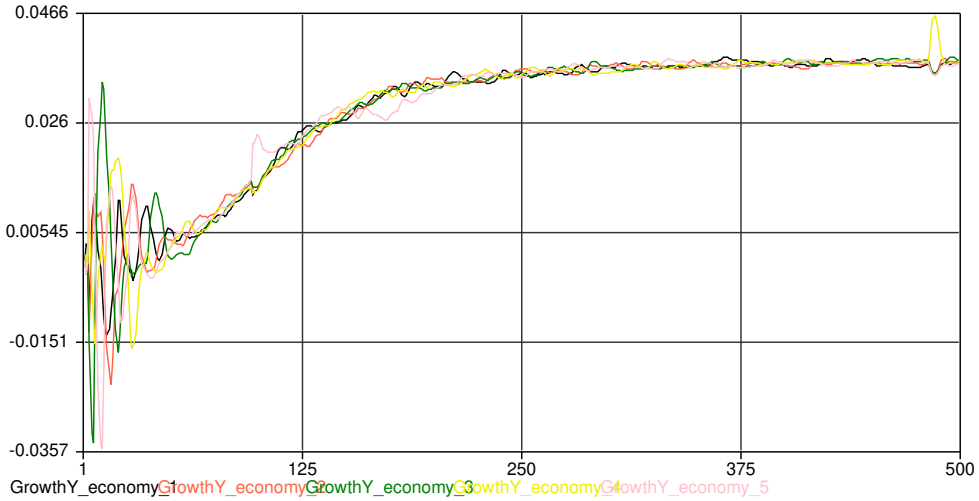


Figure 6: Output Growth with $\nu_{1,j} = 1$

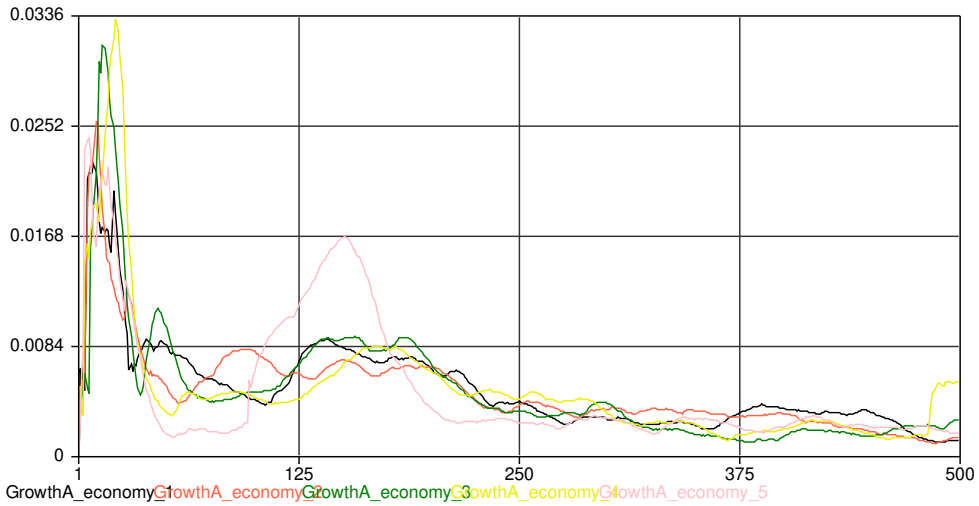


Figure 7: Productivity Growth with $\nu_{1,j} = 1$

Finally, for the third round of simulation, heterogeneity is introduced into the $\ni_{1,j}$ parameter of the Phillips curve, with 5 values ranging from 0.469 to 1 (c.f. **Table 2**), in ascending order economy 1, 2, 3, 4 and 5 (Fig. 11). The results are very clear: heterogeneity in bargaining and wage absorption of productivity gains leads to strong cumulative divergences in output growth and productivity (Figs. 12 and 13). Economies with low bargaining/absorption capacities (economies 1 and 2) largely dominate the others in both the short and long term, and obtain much lower markups (Fig. 14) because of their competitiveness (market shares) and low union/wage pressure.) These results seem consistent with the mechanisms described and are of the same order (simulations available on request) if heterogeneity is also introduced into the level of technological opportunities for the innovators $\overline{\sigma}_j$.

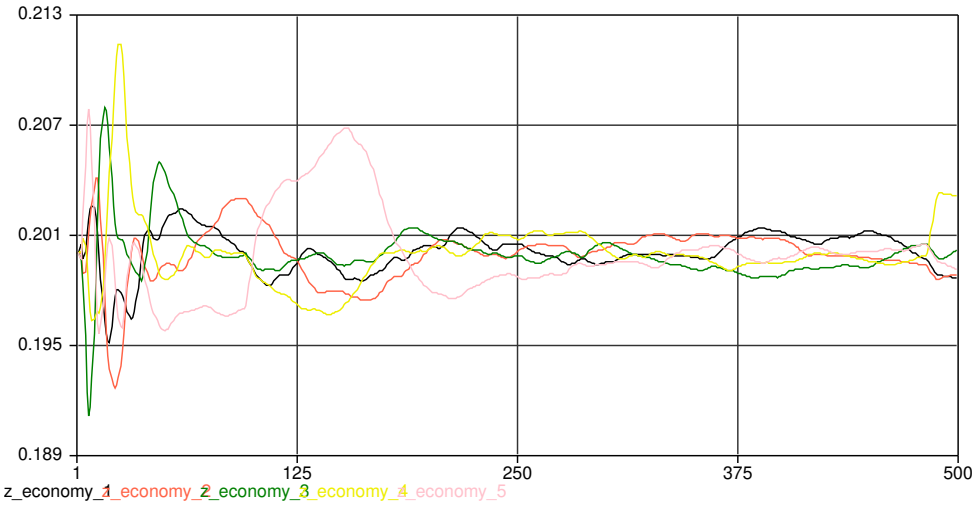


Figure 8: Economies's market shares with $\nu_{1,j} = 1$

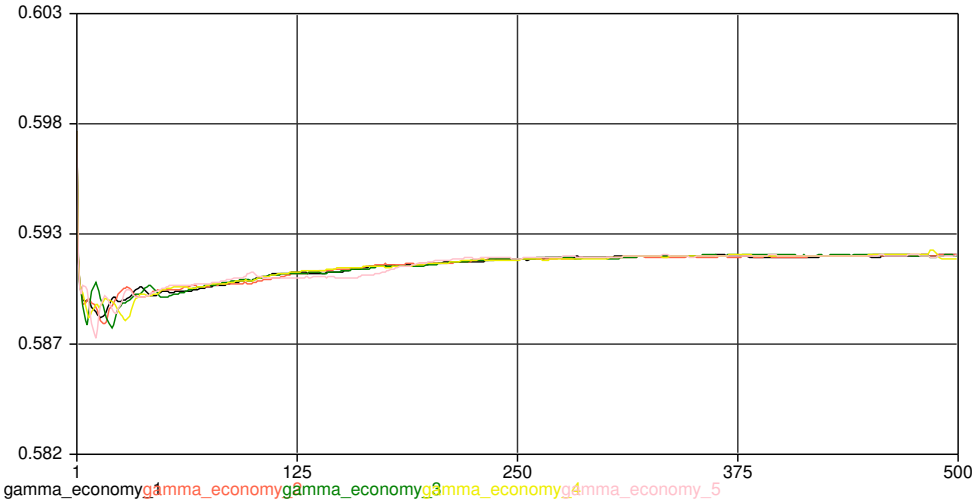


Figure 9: Markups change with $\nu_{1,j} = 1$

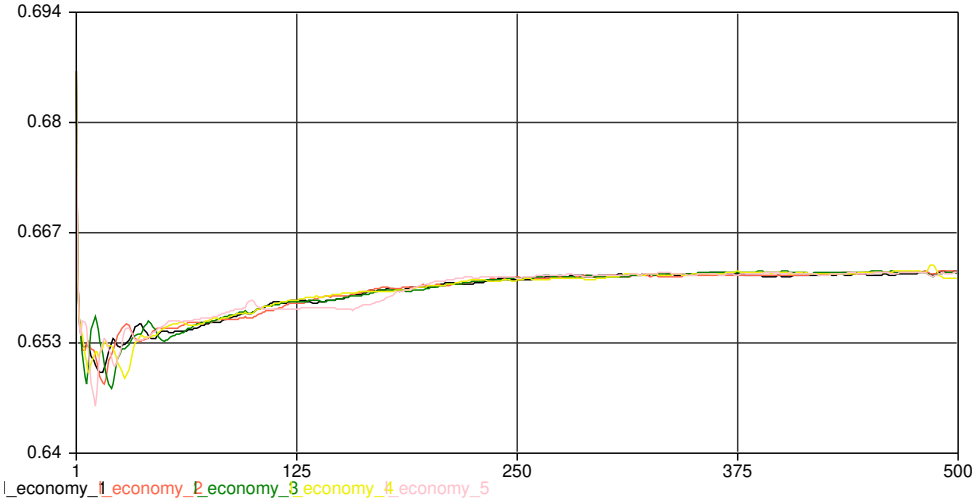


Figure 10: Employment rate with $\nu_{1,j} = 1$

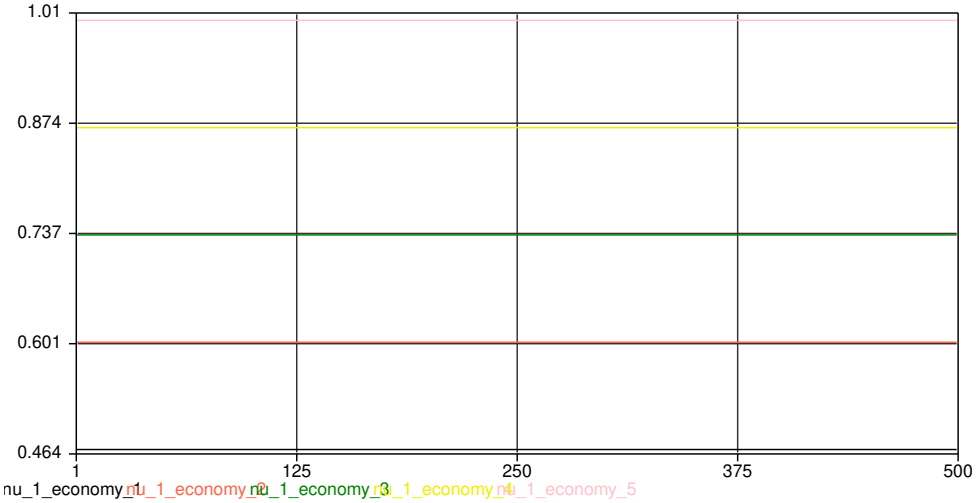


Figure 11: Phillips curve parameter $\nu_{1,j}$'s values in presence of heterogeneity

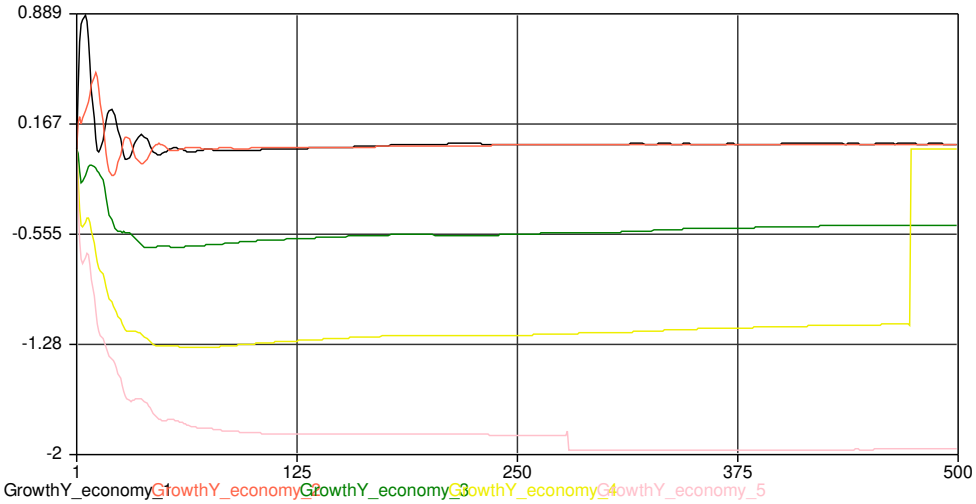


Figure 12: Output Growth with heterogeneity in $\nu_{1,j}$

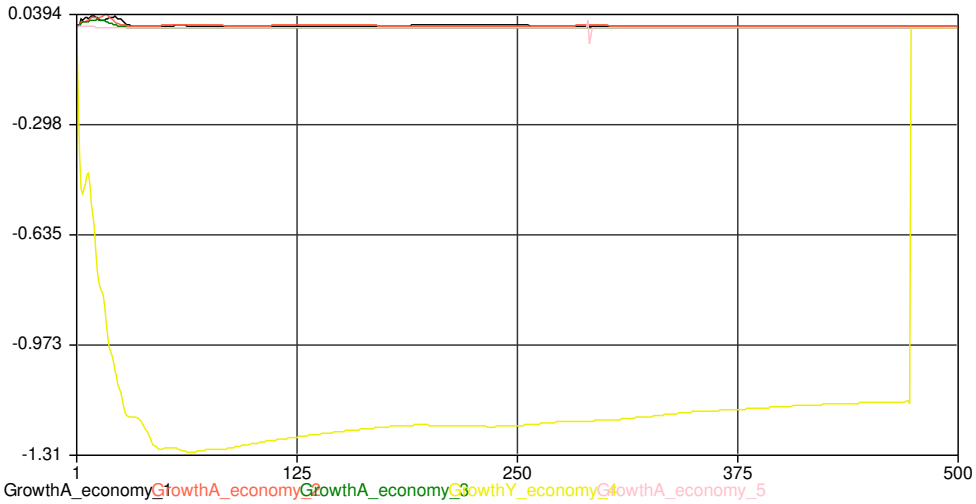


Figure 13: Productivity Growth with heterogeneity in $\nu_{1,j}$

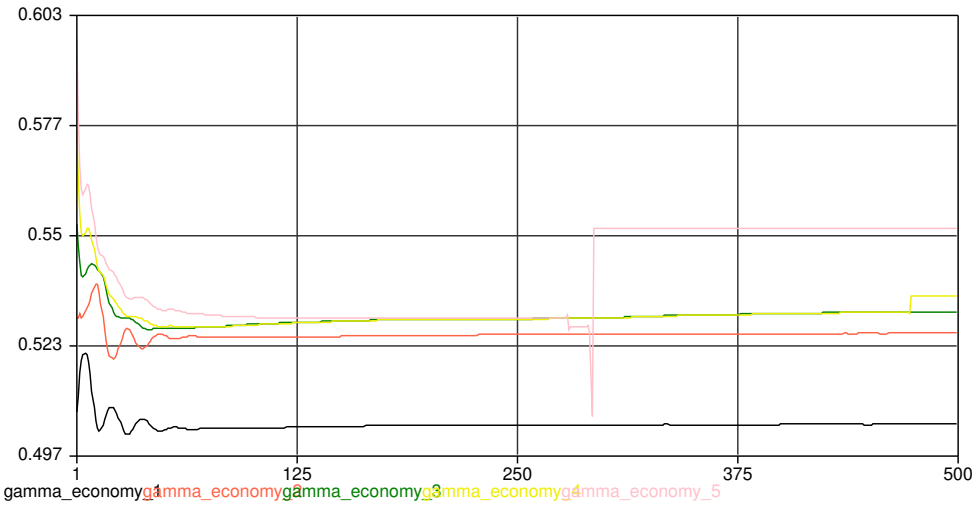


Figure 14: Markups change with heterogeneity in $\nu_{1,j}$

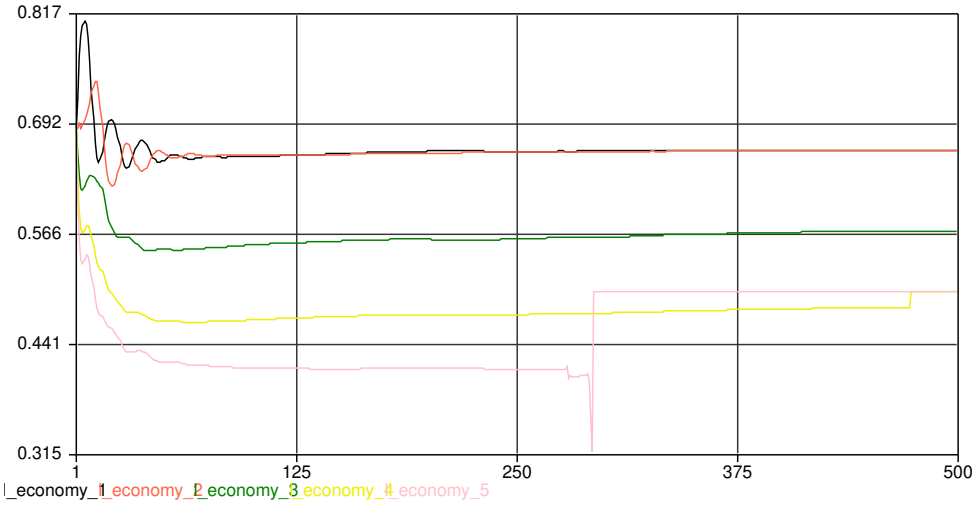


Figure 15: Employment rate with heterogeneity in $\nu_{1,j}$

As a robustness check, a heterogeneity is introduced the level of technological opportunities for innovators ($\overline{\sigma}_j$), ranging from 0.075 to 0.125, both in the case where the economies have their parameter $\nu_{1,j}$ equal to 0.469, and in the case where it is equal to 1. As expected, and as in the seminal model, a powerful Phillips curve for employees greatly attenuates differences in innovation capacity by absorbing these gains before they create divergences in growth. Conversely, a weak Phillips curve amplifies them, but the cyclical and bounded nature of the model still causes the economies to converge towards the same growth rate in the long term (simulations available on request, not presented here so as not to overload the model). Thus, it seems that a high level of workers' power makes it possible to avoid strong divergence phenomena, by rapidly capturing the gains linked to differences in innovation. Strong workers' power is therefore a stabiliser of inter-country technical change-driven growth dynamics.

5 Discussion and conclusion

5.1 Discussion and further research

Il manque ici le rôle central de la demande, qu'il faudrait endogénéiser, du fait du rôle de cette dernière et de la distribution des revenus dans la croissance économique et la détermination de l'investissmement:

"The choice of technique problem cannot generally be considered to be decided in terms of the technical conditions of production alone: the degree of capacity utilization matters too. The latter, however, reflects a multiplicity of influences, such as the state of income distribution and savings and investment behavior [...]. In particular, there is the possibility that, assessed in terms of the degree of utilization associated with the existing technique, a new technique proves superior, while in terms of its own characteristic steady-state degree of utilization it turns out to be inferior " (Kurz, 1990, pp. 232-233).

The neutral or biased role of technical change in its relationship to labour and its possibility of substitution or "replacement" must also be taken into account, as well as its impact on income distribution, a role here constrained by the complementary form of Leontief's production technology, although it can have important feedbacks, c.f. the work of Pasinetti[16].

Similarly, the analysis of endogenous markups and their (direction of) variation could be much more refined: when demand is high, firms with high markups can provide commodities at a high price, and the average markup (weighted by sales) is boosted; conversely, when demand is weak, firms with high markups do not manage to sell their production, and the average markup

[16]Or Robinson, in her French translation: *"L'impuissance des travailleurs est due à l'armée de réserve industrielle tant qu'il y a du chômage, leur pouvoir de négociation est chroniquement faible. L'accumulation du Capital, cependant, se poursuit sans cesse, et à certaines périodes, le stock de capital, qui gouverne le nombre d'emplois offerts rattrape l'offre de travail. Leur pouvoir de négociation se renforce alors et les salaires réels commencent à augmenter. Les profits diminuent en conséquence, et le taux d'accumulation ralentit par rapport à la croissance de la population, de sorte que l'armée de réserve croit de nouveau.* ***Pendant ce temps, le système capitaliste, qui ne peut pas tolérer des profits bas réagit en adoptant de nouvelles techniques économes en travail. Les hauts salaires encouragent des inventions économes en travail, si bien qu'un quantité donnée de capital offre désormais moins d'emploi. Le chômage technologique vient donc grossir les rangs de l'armée de réserve du travail****. Les hauts salaires donnent aussi un incitation de plus à l'extension du Capitalisme à de nouvelle sphères et à l'exploitation de nouveaux travailleurs. Par l'ensemble de ces moyens, le pouvoir de négociation temporaire des travailleurs est battu en brèche, et les salaires réels baissent de nouveau."* Joan Robinson (1947), *Essai sur l'économie de Marx* chap.4 p.86)

(weighted by sales) is brought down. This phenomenon is exacerbated in the medium run by the fact that firms with the more adequate markups will realize more profits than the others, and hence will grow faster, so that their weight becomes more important in the following periods. This phenomenon of collective adaptation does not require any individual adaptation, but only the heterogeneity of the population of firms (the economic equivalent of bio-diversity).

It should be noted that this pro-cyclical pattern does not contradict the counter-cyclical pattern of markups extensively discussed in Rotemberg & Woodford (1999). The latter envisions a markup over an increasing marginal cost, caused by diminishing returns, while prices are sticky in the short run, so that the real marginal cost is generally increasing with production. We consider markups over unit costs that are also increasing with production, but this is not because of diminishing returns but rather because nominal wages and the prices of intermediate goods are rising in a boom. Our findings simply say that, in our model, firms are able to increase their prices more than the increase in their unit costs, so that the markup over unit costs (the ratio of the price to unit costs) actually increases with production. Moreover, the discussion in Rotemberg & Woodford (1999) is set at the aggregate level, and is not incompatible with procyclical adjustments of the markup in individual firms and with the positive relationship between the markup and market shares at the micro level, which our model also reproduces.

To go further, some might argue that a distinction should be made between firms present on international markets and firms present only on domestic markets, as well as the impact of openness to international trade on markups and profits for financing innovation, since exporters obtain on average higher markups and these markups increase when entering export markets (De Loecker & Warzynski, 2012). Nevertheless, it has been empirically shown that the positive association between exporting and productivity can be explained by the self-selection of the most efficient firms on the export market (Clerides et al., 1998), which reduces the magnitude of the Kaldor-Verdoorn law. So it would not add much to the present analysis.

In terms of extensions, it might be possible, for example, to integrate natural resource constraints (e.g. resources in the Leontief production function) to study the capacity of innovation to overcome these constraints. The question of financing could also be addressed, by integrating financing from outside the company through private debt (e.g. à la Keen, 1995). This could call for a multi-sector framework with technical changes, factor intensities, market share distribution and differentiated wage dynamics. To be truly relevant and create total dependence on the path and historical time, the integration of generations of vintages of Putty-Clay capital goods as mentioned above, where the productive mix is flexible before installation but fixed afterwards, would make it possible in this growth model to obtain business cycles, due to the problems of capital overshooting, malinvestment and liquidation difficulties. With such an Austrian and Cambridgian approach to the structure of productive capital, capital can no longer serve as a stock of constant adjustment marmalade in the face of the economic situation like in RBC models, always reversible to maximise its marginal return. The role of innovation in these business cycles, and the role of business cycles in innovation, are resolutely interesting questions.

5.2 Conclusion

The extension consists of an endogenisation of the markup by its various determinants (wage and union bargaining power proxied by a Phillips curve, imperfect competition defined by the price elasticity of demand, and the degree of concentration proxied by market share), a specification of wage dynamics using a Phillips curve, and the development of a labour market.

This extension, which is relatively realistic and empirically justified, allows the emergence of endogenous and non-linear fluctuations (e.g. à la Goodwin), which appear realistic in terms of the cyclical nature of interest phenomena, and are fully consistent with the objective of adopting an "out-of-equilibrium" modelling framework. It confirmed the mitigating role of strong workers' power on the risks of divergence between countries linked to innovation differentials, and vice versa.

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