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CHAPTER III

INDUCED INNOVATION, THE DISTRIBUTIVE CYCLE, AND THE CHANGING PATTERN OF LABOUR PRODUCTIVITY CYCLICALITY: A SVAR ANALYSIS FOR THE US ECONOMY

INTRODUCTION

The distributive conflict is a key characteristic of capitalist economies. Although typically neglected in neoclassical literature, the role of power relations among social classes has always been at the very core of the theories falling within the classical-Keynesian paradigm. Most notably, the classical-Marxian approach to the theory of distribution-induced technical change has emphasized the role of labour-saving innovations as a crucial device in the distributive conflict to prevent workers from undermining the capitalists' economic and social position.

This thesis is a collection of three essays aimed at analyzing the interplay between labour market institutions, technical change, and income distribution in labour-constrained economies in light of the theory of induced technical change. More specifically, it deploys the theory of induced technical change to contribute to the debates on (i) the relationship between the decline in the labour share and stagnation of income and labour productivity in mature economies, (ii) the determinants of wage inequality and skill-biased technical change in a growth context, and (iii) the empirical evidence on the distributive cycle and the changing pattern of cyclicality of wages and labour productivity in the US economy.

Chapter I works out a Kaleckian model of a labour-constrained economy with induced innovation. The traditional "underconsumptionist" Kaleckian argument – i.e. in demand-led economies, a decline in the labour share slows down capital accumulation via reduced consumption demand – is briefly contrasted with the more recent classical/Goodwinian narrative on secular stagnation – i.e. in labour-constrained economies, a decline in the labour share slows down long-run capital accumulation via reduced pressure to innovate. Then, three modifications are made to a standard Kaleckian model with a Bhaduri-Marglin investment function: (a) the economy is labour-constrained, (b) the employment rate hurts the investment rate of firms, and (c) labour productivity growth is endogenous to the labour share. This essay shows that, conditional on institutional shocks, the long-run rate of growth of the economy is increasing in the labour share, irrespective of the short-run demand and growth regime of the economy, consistently with a classical/Goodwinian argument. Conversely, the demand and growth regime of the economy appears to be still crucial for assessing the long-run effects of income distribution conditional on technology shocks.

Chapter II extends the basic classical-Marxian framework with distribution-induced technical change to include both high-skilled- and low-skilled-labour-saving innovations. The economy is assumed to face labour supply constraints only in the high-skilled segment of the labour market. Thus, the profit share interacts with the high-skilled employment rate, whereas the low-skilled labour supply is perfectly elastic. The essay then evaluates the steady-state effects of labour market institutions in a model economy in which both high-skilled- and low-skilled-labour productivities are made endogenous to income distribution and contrasts them with both the neoclassical account of skill-biased technical change and the standard Goodwin model with induced innovation. It is argued that, in contrast to the neoclassical view, skill-biased technical change is induced by exogenous shocks to the relative bargaining positions of high-skilled and low-skilled workers. Since the induced skill bias of technical change fully passes through to real wages at the steady state, labour market institutions are the ultimate driver of wage inequality.

Chapter III tests an extended version of the Goodwin model for the US economy (1948-2019) that includes aggregate demand and decomposes the labour share into real wages and labour productivity. The four-dimensional SVAR is identified by means of a non-recursive identification strategy with restrictions motivated by classical-Keynesian growth theory, as in more recent empirical works on the distributive cycle. The essay shows that: (a) the empirical evidence is consistent with distribution-induced innovation in both the post-war period (1948-1984) and the Great Moderation (1985-2019), (b) the argument of procyclical labour productivity invoked by Kaleckian authors to question the source of the Goodwin pattern is not well-founded; (c) the US economy exhibits profit-led activity at business cycle frequencies, though it appears to be driven more by technology than by distributive shocks. Moreover, it is argued that the vanishing procyclicality of US labour productivity during the Great Moderation can be explained by a lessened incentive to invest in labour-saving innovations in the expansionary phase of the business cycle. Thus, the decline in the cyclical correlation between output and productivity can be linked to the breakdown of the cyclical profit squeeze through the theory of induced innovation.

A Kaleckian growth model of secular stagnation with induced innovation

Marco Stamegna*

Abstract The present paper works out a demand-led growth model of a labour-constrained economy with an endogenous direction of technical change. It draws on the Kaleckian-Steindlian tradition to examine the short-run relation between income distribution, capacity utilization, and capital accumulation; on Goodwin-type growth cycle models to investigate the dynamic interaction between labour market and distributive conflict; on the induced innovation literature to link labour productivity growth to income distribution. The model defines a two-dimensional system of differential equations in the wage share and the employment rate at full capacity to investigate the properties of the long-run equilibrium. In a Kaleckian fashion, an endogenous rate of capacity utilization allows effective demand and income distribution to affect the long-run equilibrium. We find that: i) an exogenous increase in workers' bargaining power raises the long-run labour share, capital accumulation, labour productivity growth, and real wage growth, regardless of the short-run demand and growth regime of the economy; ii) a positive institutional shock to the labour share may cause the long-run employment rate to fall even in a wage-led demand regime; conversely, iii) positive technology shocks reduce the long-run rate of growth of the economy in a wage-led growth regime; thus, strengthening labour market regulation emerges as an unambiguously better strategy to raise the long-run labour share, capital accumulation, and labour productivity growth.

Keywords Functional income distribution, Effective demand, Growth regimes, Endogenous technical change

JEL classification E12, E24, E25, O40

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1. INTRODUCTION

The weak recovery that followed the global crisis of 2008 has given new energy to the old issue of "secular stagnation", that is, a long-lasting period of low or even negative growth in mature capitalist economies, originally put forward by Hansen (1939) in the aftermath of the Great Depression. After having been, for a long time, a topic reserved to those economists closer to the deep message of the Keynesian revolution, it has received renewed attention in the mainstream economic agenda with Summers' speech at the IMF in 2013.

The current popular explanation for secular stagnation rests on the pre-Keynesian notion of the Wicksellian "natural interest rate", i.e. the real interest rate clearing the market for loanable funds and associated with full employment (Summers, 2014a; 2014b; 2015). In this view, modern economies are confronted with a substantial increase in saving supply and reduced investment demand, which have led to a significant decline in the equilibrium interest rate for full-employment saving and investment. Low or even negative equilibrium interest rates have made it more difficult for central banks to achieve full employment, due to the zero-lower-bound constraint for the short-term nominal interest rates.

From a classical-Keynesian standpoint, the conventional debate on secular stagnation is largely unsatisfactory, since it ignores the effective demand dynamics and the linkage between income distribution and the long-run performance of the economy. Instead, the relation between income distribution, capital accumulation, and labour productivity growth has always been at the very core of the theories of demand-led growth and the classical-Marxian approach to the theory of induced technical change.

The literature on demand-led growth points to the chronic lack of effective demand as an intrinsic characteristic of a capitalist economy and hence as the main determinant of secular stagnation. Based on the seminal works of Michal Kalecki (1971) and Josef Steindl (1976), the Kaleckian-Steindlian approach to demand-led growth claims that income redistribution from wages to profits may imply a lower level of economic activity and slower capital accumulation. Since capitalists have a higher propensity to save than workers, a decrease in the labour share of income is supposed to dampen consumption demand and – via Keynesian accelerator – investment demand.[1] The Kaleckian-Steindlian approach relies upon the assumption of an endogenous rate of capacity utilization, which allows the contractionary effect of a decline in the labour share to have long-run effects.

The classical-Marxian approach to induced innovation points to the increase in unit labour costs as the main driver of labour productivity growth. A decline in the labour share of income (that is, the counterpart of unit labour costs at a macro level) is supposed to lessen the firms' incentive to invest in labour-saving innovations.[2] Recent contributions in this tradition (e.g. Petach and Tavani, 2020; Barrales-Ruiz, *et al.*, 2021; Cruz Luzuriaga and Tavani, 2021) claim that in mature economies, in which labour supply poses constraints to growth, a decline in the labour share leads to slower capital accumulation via a reduced pressure to innovate rather than via the Kaleckian-Steindlian "underconsumptionist" channel. The key argument is that, in mature economies, capital accumulation is anchored to the natural growth rate, and hence the poor macroeconomic performance of these countries over the last decades must be explained by factors affecting labour productivity growth.

The present paper adds to this debate by presenting a Kaleckian model of a labour-constrained

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1 See Hein (2016) for a comparison between the theoretical foundations of the conventional view and the alternative Kaleckian-Steindlian paradigm on secular stagnation. For a critique of the zero-lower-bound economic theory and the potentially detrimental effects of its policy recommendations, see Palley (2019).

2 See Hein (2017) or Dutt (2018) for a survey of the heterodox models of income distribution and growth. A survey of endogenous technical change theories falling within non-mainstream traditions is provided by Tavani and Zamparelli (2018).

economy with induced innovation. Three modifications are made to the standard model with a Bhaduri-Marglin investment function: (i) I introduce a labour market, which allows income distribution and the employment rate to interact with each other along Goodwinian lines, while emphasizing the role of labour supply constraints to economic growth; (ii) based on the arguments by Kalecki (1979), Steindl (1979), and Skott (1989; 2010), I modify the standard Bhaduri-Marglin investment function by assuming that the employment rate affects negatively firms' investment decisions; and (iii) labour productivity growth is assumed to be endogenous to the labour share, in accordance with the classical-Marxian view of wage-led labour-saving innovations.

We find that an increase in workers' bargaining power unambiguously raises the long-run labour share, capital accumulation, and labour productivity growth, irrespective of the short-run demand and growth regime of the economy. Thus, conditional on institutional shocks, the long-run rate of growth of the economy is increasing in the labour share of income. Differently from conventional Kaleckian findings, the long-run effects of distribution on capital accumulation do not rest on the assumption of an endogenous rate of capacity utilization, as a decline in the labour share impacts the long-run rate of growth via the induced innovation channel rather than underconsumption – a result in line with a classical account of secular stagnation.[3] Conversely, the long-run effects of exogenous technology shocks on capital accumulation and labour productivity growth rely entirely upon Kaleckian mechanisms since they are dependent on endogenous capacity utilization and the short-run demand and growth regime of the economy. Conditional on technology shocks, the long-run rate of growth of the economy is increasing (decreasing) in the labour share if the economy exhibits a wage-led (profit-led) demand and growth regime in the short run. Thus, since exogenous productivity shocks reduce the long-run labour share, strengthening labour market regulation emerges as an unambiguously better strategy to improve income distribution and raise long-run capital accumulation and labour productivity growth if the short-run growth regime is wage-led. However, positive institutional shocks to the labour share may cause the employment rate to fall even in a wage-led demand regime.

The remainder of this paper is organized as follows. Section 2 provides an extensive discussion of the related literature and the main contributions of this paper. Section 3 proposes a simple theoretical model and derives the basic equations for the analysis. Section 4 discusses the characteristics of the short-run equilibrium. Section 5 details the properties of the dynamical system and the long-run equilibrium. Section 6 derives the necessary and sufficient conditions for the local stability of the long-run equilibrium. Section 7 details the main results of comparative statics analysis. Section 8 then concludes.

2. Related literature

The present paper is related to different streams of literature. First, the model economy in the short run is formalized according to the Kaleckian-Steindlian tradition. Lavoie (2014) lists the distinctive features of this class of models: (i) an investment function, independent of savings, including the rate of capacity utilization, which captures the Keynesian accelerator principle; (ii) a fixed mark-up on unit variable costs; (iii) class-based saving behaviour, with workers having a lower propensity to save than capitalists; (iv) an endogenous rate of capacity utilization that may diverge

[3] A similar argument is put forward by Rada, *et al.* (2021) in a neo-Goodwinian framework.

from the normal level even in the long run. In fact, only (iv) is essential to this tradition,[4] since the assumption of an endogenous rate of capacity utilization is crucial for this class of models to allow functional income distribution to affect steady-state capital accumulation.[5]

The earlier formulations of the Kaleckian growth models, developed by Rowthorn (1981), Dutt (1984), Taylor (1985), and Amadeo (1986), reflect the "underconsumptionist" view that income redistribution from profits to wages has long-run positive effects on capital accumulation via increased consumption demand. The more flexible Bhaduri-Marglin model, that has progressively become a benchmark model in the Kaleckian-Steindlian literature, claims that, if the dual role of wages as a cost of production to the firm and as the main source of demand in the economy is considered, economic growth may either be "wage-led" or "profit-led", depending on the differential in propensities to save and the relative responsiveness of investment to the profit share and the rate of capacity utilization (Bhaduri and Marglin, 1990; Marglin and Bhaduri, 1990).

However, traditional Kaleckian growth models fail to consider the labour market satisfactorily, since they do not define an equilibrium rate of employment and rely on the implicit assumption that firms face an infinitely elastic labour supply at a constant real wage rate. Thus, the canonical framework does not allow considering the positive impact of the employment rate on the real wage rate and its feedback effect on capital accumulation and labour productivity growth. Some exceptions are the works of Dutt (1992), Lima (2004), and Sasaki (2013), which incorporate a theory of inflation based on conflicting income claims of workers and firms and make the workers' target share in income depend on the employment rate, so that capacity utilization, employment rate, capital accumulation, and income distribution are all endogenously determined.[6]

This is a severe limitation since mature economies, although demand-led, are in fact labour-constrained economies, that is, they face relevant labour supply constraints to economic growth. As Flaschel and Skott (2006) and Skott (1989, 2010) claim, assuming that capital accumulation is not constrained by the growth of the labour force may be reasonable only for less developed countries, having a hidden reserve army in agriculture, among women, and from immigration. In OECD countries, from at least the 1960s, "[t]he hidden reserve army gradually became depleted (…) and immigration was hampered by growing political resistance. As a result, the economy became mature in Kaldor's (1966) sense of the term: its growth rate became constrained by the growth in the labour force" (Flaschel and Skott, 2006, pp. 327-328). In his well-known list of six "stylized facts" of economic growth in industrialized economies, Kaldor (1957) posited that, over long periods, factor shares of national income are roughly constant, and hence the real wage rate grows at the same rate as labour productivity. Taylor, *et al.* (2018) also include a constant employment rate in the long run.[7]

In the present paper, capital accumulation is assumed to be constrained by the growth rate of

[4] The assumptions of class-based saving behaviour and demand-driven investment are indeed common to all demand-led growth models. Furthermore, Kaleckian growth models have been investigated under different pricing procedures (see, for instance, Lavoie (2019), who assumes that the profit share depends on target-return pricing at a firm level). In this paper, I assume that the profit share is determined along classical-Marxian lines as a residual after workers are paid their share in national income, without any specific assumption on firms' pricing procedures.

[5] The potential divergence of the rate of capacity utilization from its normal rate is controversial and has been questioned by a number of authors. For a discussion, see Lavoie (1995), Nikiforos (2016), Girardi and Pariboni (2019), and Trezzini and Pignalosa (2021).

[6] Cassetti (2003) incorporates conflicting claims inflation into a Kaleckian model, but makes the workers' target share depend on the *growth* of the employment rate, rather than on the *level* of the employment rate, thus he can endogenize income distribution through the labour market channel even without stabilizing the employment rate. Stockhammer (2004) finds that in a wage-led growth regime the long-run equilibrium rate of employment is unstable. Yet, labour productivity growth is exogenous, hence he does not consider the stabilizing effect of induced technical change.

[7] The downward trend of the labour share and the upward trend of the employment rate over the last decades need not imply a rejection of the steady-state growth assumption, since they can be interpreted as a transition towards a new steady-state growth path.

effective labour supply so that the employment rate is constant in the long run. For the long-run analysis, I define a two-dimensional system of differential equations in the wage share and the long-run component of the employment rate, describing the motion of the two variables around their long-run equilibrium values. The assumption that the economy is labour-constrained allows dealing with labour scarcity, which is a distinctive feature of a mature economy, while keeping that growth is demand-driven.

The introduction of a labour market relates this paper to Goodwin's (1967) seminal work on the growth cycle, which formalizes Marx's (1976) view of economic fluctuations, based on the interaction between profit-constrained capital accumulation and an employment-driven labour share. The model predicts a counterclockwise cycle in the employment rate-labour share space, as a result of profit-led employment and profit squeeze in income distribution. In the upturn of the business cycle, that is, a period of faster capital accumulation, and hence faster growth of labour demand, the labour share rises; the erosion of profitability leads to the downward phase of the business cycle, in which capital accumulation and the growth of labour demand slow down; as a result, the labour share falls, restoring profitability and inducing a new phase of expansion.

The original model has been progressively extended in different directions. Since Goodwin (1967) assumes the validity of Say's law, several contributions have been proposed to incorporate the disequilibrium in the goods market and a counterclockwise cycle in the utilization-labour share plane of the kind observed in the US and other OECD countries (Zipperer and Skott, 2011). Barbosa-Filho and Taylor (2006) develop a "structuralist Goodwin model", with a system of differential equations in the wage share and the rate of capacity utilization. Sasaki (2013) examines the motion of the rate of capacity utilization jointly with the wage share and the employment rate in a model with endogenous technical change. Von Arnim and Barrales (2015) examine Harrodian and Kaleckian narratives on demand-driven distributive cycles with fluctuations in employment, labour share, and capacity utilization.

Following You (1994) and Lima (2004), in the present paper, I distinguish between a short-run component and a long-run component of the employment rate. The short-run component follows the cyclical fluctuations of the rate of capacity utilization, which is supposed to adjust instantaneously to bring the goods market back to equilibrium. The long-run component, i.e. the employment rate at full capacity utilization, is treated as a state variable that adjusts slowly in the long run, along with the wage share.[8] Thus, differently from the literature originated from the Goodwin model of growth cycle, this paper does not adopt a dynamic specification for the rate of capacity utilization, since it assumes that the goods market clears much faster than income distribution and the long-run component of the employment rate. Naturally, both the cyclical and the long run components of the employment rate exert downward pressure on profitability.

In addition, following Flaschel and Skott (2006) and Skott (1989; 2010), I modify the standard Bhaduri-Marglin investment function letting the employment rate affect negatively firms' investment decisions. The inclusion of the employment rate as an argument of the investment function can be motivated on both macroeconomic and microeconomic grounds. In Flaschel and Skott (2006), this assumption represents an attempt to formalize the argument put forward by Kalecki (1971) and Steindl (1979) that persistently high employment, by strengthening the economic and social position of workers and trade unions, undermines the capitalists' state of confidence. Even though the original argument referred to a political opposition of capitalists to full employment, it seems indeed reasonable to expect that the capitalists' general decline of confidence associated with high employment could impact negatively firms' investment plans. At a micro level, the employment rate affects firms' investment decisions through its effects on the costs of recruitment. Due to the not

[8] The Goodwin original model considers implicitly only the long-run component since it assumes full capacity utilization.

perfectly competitive nature of the labour markets, higher employment rates make it harder for firms to hire and retain workers with the desired skills (Skott, 1989; 2010). Thus, in a mature economy, the costs of changing output are associated positively with labour market tightness, as measured by the employment rate. Furthermore, a fall in the size of the reserve army, "may lead to increased worker militancy, and increased monitoring and additional managerial input may also be needed in order to maintain discipline and prevent shirking" (Skott, 2010, p. 120). The impact of labour market tightness on the costs of recruitment, shirking, worker militancy, and power relations in capitalist economies motivates the inclusion of the employment rate as an additional argument in the investment function, in that these effects are independent of the impact of labour market tightness on the wage-profit divide.

The assumption of a constant rate of employment in the long run implies that the actual rate of growth is equal to the natural rate of growth, thus relating the present paper to the literature concerned with the reconciliation of aggregate demand and aggregate supply in economic growth theory (Dutt, 2006; 2010; Storm and Naastepad, 2012a; 2012b). In this paper, the natural rate of growth is made endogenous to the labour share according to the theory of distribution-induced technical change.

The core idea of the theory of distribution-induced technical change is that the direction of technical change is endogenously determined by the relative size of the labour and capital shares in total costs. An increase in the labour share of income is then supposed to encourage firms to adopt innovations that allow them to save on unit labour costs. Within the classical-Marxian tradition, induced technical change is thought of as an instrument in the hands of capitalists in the class conflict to regenerate the reserve army of labour in the face of rising workers' bargaining power (Tavani and Zamparelli, 2018; Foley, *et al.*, 2019). Within the neoclassical tradition, it has been conceived as being driven by relative factor endowments (Brugger and Gehrke, 2017). This interpretation dates back to Hicks's (1932) claim that an increase in relative input prices stimulates innovations that replaces the factor of production that has become relatively more scarce. This argument has been formalized by Kennedy (1964) and Samuelson (1965) by means of a decreasing and concave "innovation possibility frontier", whose shape and position are exogenously given by technical factors, and representing all feasible combinations of labour- and capital-saving innovations. The microeconomic choice of the optimal direction of technical change makes labour productivity growth an increasing function of the labour share at a macro level.

The induced innovation hypothesis has been integrated into Goodwinian and classical-Marxian models, as a firm's maximization problem *à la* Kennedy is consistent with the Okishio (1961) rule for viable innovations in the classical analysis of the choice of techniques (Shah and Desai, 1981; van der Ploeg, 1987; Foley, 2003; Julius, 2005; Tavani, 2012, 2013; Zamparelli, 2015).[9] However, some contributions in classical-Marxian and post-Keynesian literature simply postulate a positive dependence of labour productivity growth on the labour share, with no microeconomic foundations (e.g. Lima, 2004; Dutt, 2013).

More recent works in classical-Marxian and neo-Goodwinian traditions have shown that the theory of induced technical change can be deployed to build a classical narrative on secular stagnation for labour-constrained economies, in which the slowdown in capital accumulation is linked to the decline in the labour share via the balanced growth condition rather than the Kaleckian-Steindlian underconsumptionist channel (Petach and Tavani, 2020; Barrales-Ruiz, *et al.*, 2021; Cruz Luzuriaga and Tavani, 2021, Rada, *et al.*, 2021). The central argument is that, provided that technical change is induced by income distribution, the natural rate of growth is endogenous and positively related to the labour share. Thus, in labour-constrained economies, in which the actual rate of growth is anchored to the natural rate of growth, the steady-state rate of capital accumulation is wage-led, even though

[9] For a more detailed discussion of these contributions, with a special focus on the steady-state effects of labour market institutions, see Sections 2 and 6.2 of Chapter II.

capital accumulation is profit-led at business cycle frequencies. Thus, an institutional shock against the labour share, despite its initial positive impact on capital accumulation, unambiguously lowers the actual rate of growth of the economy in the long run.

This paper shows that, even in a Kaleckian model of a labour-constrained economy, labour market deregulation is detrimental to the long-run actual rate of growth, irrespective of the short-run demand and growth regime of the economy and the assumption of an endogenous rate of capacity utilization, as the relevant channel is induced innovation. Thus, conditional on institutional shocks, long-run capital accumulation is increasing in the labour share even if the economy exhibits profit-led activity in the short run, as predicted by more recent works in the classical tradition. However, the short-run demand and growth regime still appears to be crucial for assessing the long-run effects of technology shocks.

3. THE STRUCTURE OF THE MODEL

Consider a closed economy with no government, in which only one good is produced with two homogeneous inputs, labour and a non-depreciating capital. The homogeneous good is used for both consumption and investment. There are two social classes: capitalists, who own the economy's capital stock and receive profits, and workers, that inelastically supply one unit of labour in each period and receive wages. The relation between labour and capital inputs and the homogenous output is represented by a fixed-coefficients or Leontief production function:

$$Y = \min\{a_L L, a_K u K\} \tag{1}$$

where Y denotes actual output in real terms; L, labour employed in production; K, capital; $u = Y/Y_p$, the rate of capacity utilization, with Y_p being full-capacity output; $a_L = Y/L$, labour productivity; and $a_K = Y_p/K$, the ratio of full-capacity output to capital stock. The assumption of a fixed-coefficients production function implies that demands for labour and capital are inelastic to input prices, and one or both inputs may not be fully employed. Since the economy is demand-constrained, we assume that the economy operates at less than full capacity and full employment of labour.[10] Following the Kalecki-Steindl tradition, we consider the rate of capacity utilization as an accommodating variable, that adjusts to bring saving into equilibrium with investment, without any tendency to converge to a unique normal rate.

Denoting the workers' real wage rate by w and the profit rate on capital stock by $r = \pi u a_K$, where π is the profit share, in each period t national income in real terms is given by:

$$Y = wL + rK \tag{2}$$

National income accrues to the two social classes in the economy, workers and capitalists, which only receive wages and profits, respectively. Workers devote all their income to consumption, whereas capitalists have propensity to save $s \in (0,1)$. These behavioural assumptions are in line with the classical and Keynesian traditions. They follow Kaldor (1955-56; 1966) argument that the functional nature of profits implies that a major part of profits is retained for investment purposes and, to the extent that profits and wages are unequally distributed across individuals, they are also consistent with Keynes's (1936) absolute income hypothesis that the propensity to save of high income individuals exceeds the propensity to save of low income earners.

[10] For the reasons for which firms voluntarily choose to hold excess capacity, see Hein (2014).

The profit share is defined along classical-Marxian lines as a residual after the workers are paid their share in national income:

$$\pi = 1 - \omega \tag{3}$$

where the wage share is given by $\omega = w/a_L$.

Since total savings are given by $S = srK$, the saving function, i.e. the ratio of savings to capital stock, is:

$$g^s \equiv \frac{S}{K} = s\pi u a_K \tag{4}$$

Let us assume an investment function independent of savings, in which the ratio of investment to capital stock is increasing in the profit share, the rate of capacity utilization, and an exogenous variable γ, and decreasing in the employment rate. Denoting the employment rate by $e = L/N$, with N being labour supply, we have:

$$g^i \equiv \frac{I}{K} = g^i(u, \pi, e, \gamma) \qquad g_u^{i'} > 0,\; g_\pi^{i'} > 0,\; g_e^{i'} < 0,\; g_\gamma^{i'} > 0 \tag{5}$$

We define equation (5) as a "Bhaduri-Marglin-Skott investment function". The rate of capacity utilization captures the Keynesian accelerator principle, namely the positive response of investment to a positive variation in actual output. The economic rationale for the inclusion of the profit share is that it may be considered as an index for firms' profit margins. Thus, based on the argument of Bhaduri and Marglin (1990) and Marglin and Bhaduri (1990), the rate of capacity utilization and the profit share capture the demand-side and the cost-side of the expected profit rate, respectively, provided that the actual profit rate can be seen as an indicator for expected profitability. Moreover, since firms operate in incomplete financial markets and realized profits provide internal funds for firms' investment plans, higher profit share and capacity utilization, as components of the realized profit rate, make it easier to have access to external funding. The employment rate has a negative effect on firms' investment decisions because a fall in the reserve army of labour strengthens the economic and political position of workers, thus making capitalists' state of confidence decline (Kalecki, 1971; Steindl, 1979), and increases firms' costs of recruitment and monitoring to prevent workers' militancy and shirking (Skott, 2010). The exogenous parameter γ represents autonomous investment, and can be interpreted as the "animal spirits" of capitalists or the expected trend of future sales (Lavoie, 2014).

At each point in time, labour supply is $N = N_0 e^{nt}$, where N_0 denotes the initial value of labour supply and $n > 0$ denotes the exogenous growth rate of N.

Since balanced growth requires the ratio of full-capacity output to capital stock to be constant, and the equilibrium condition in the goods market requires the rate of capacity utilization to be also constant, in the long run actual output and capital stock grow at the same rate $g = \hat{K} = \hat{Y}$.[11] For the sake of simplicity and without loss of generality, we assume $a_K = 1$ in the reminder of the paper. Then, we define $a_L \equiv a$ to save notation.

The fixed-coefficients nature of the production function implies that the rate of capacity utilization and the employment rate cannot be taken as independent of each other, since an increase in output in the short run will necessarily be associated with an increase in the employment rate. From equation (1), the employment rate is related to the state of the goods market by:

$$e = uk \tag{6}$$

[11] For any variable x, $\dot{x} = dx/dt$ and $\hat{x} = \dot{x}/x$.

where $k = K/aN$. Equation (6) shows that the employment rate comprises two components: a short-run component, following the cyclical fluctuations of output as measured by variations in the rate of capacity utilization, and a long-run component k, namely the current capital stock in effective labour supply units. The latter is the employment rate at full capacity utilization and is determined by long-run changes in the growth of labour productivity, capital accumulation, and the growth of labour supply.

Substituting from equation (6) into equation (5), the investment function becomes:

$$g^i \equiv \frac{I}{K} = G(u, \pi, k, \gamma) \qquad G'_u > 0,\ \ G'_\pi > 0,\ \ G'_k < 0,\ \ G'_\gamma > 0 \tag{7}$$

A rise in output will have both a positive effect on firms' investment decision via the Keynesian accelerator principle and a negative effect due to the resulting fall in the size of the reserve army. The sign $G'_u > 0$ means that we assume that the first effect dominates, consistently with the observation that investment responds positively to an increase in capacity utilization.

As in Goodwin (1967) original model, the growth rate of the real wage is assumed to be an increasing function of the employment rate and an exogenous variable, that we call α.

$$\frac{\dot{w}}{w} = h(e, \alpha) \qquad h'_e > 0,\ \ h'_\alpha > 0 \tag{8}$$

Equation (8) formalizes the source of the Marxian profit-squeeze mechanism and is consistent with the real Phillips curve in mainstream economics. An increase in the employment rate and labour market tightness raises workers' relative bargaining strength, leading to faster growth of the real wage rate.[12] However, in contrast to the original model, the employment rate is also determined by the cyclical fluctuations of the aggregate demand (equation (6)). We interpret the exogenous variable α in a broad sense as a parameter that captures all institutional factors favouring workers' relative bargaining power.

As stated above, Harrod-neutral technical change is the only one consistent with balanced growth, thus we assume that only labour productivity growth is affected by technological innovations. The growth rate of labour productivity depends on the prevailing income distribution, being positively related to the wage share in national income, and an exogenous variable τ:

$$\frac{\dot{a}}{a} = f(\omega, \tau) \qquad f'_\omega > 0,\ \ f'_\tau > 0 \tag{9}$$

Equation (9) is consistent with a classical-Marxian approach to induced innovation, in which labour-saving innovations are regarded as a weapon of capitalists for restoring profitability in the face of rising unit labour costs. It can also be seen as the solution of a firm's maximization problem *à la* Kennedy, which results in a growth rate of labour productivity being positively related to the labour share at a macro level (Kennedy, 1964; Samuelson, 1965).[13] The variable τ represents all exogenous factors affecting labour productivity growth.

[12] For the sake of simplicity, we expressed all variables in real terms, thus avoiding to frame the distributive conflict in the context of a conflicting income claims theory of inflation. However, the growth rate of the real wage as determined by equation (8) can be seen as the outcome of the bargaining process between workers and firms after their conflicting targets have been reconciled by the price inflation rate, provided that the workers' target wage share is made to depend on the employment rate.

[13] In our version, however, differently from models with microfounded induced technical change, the output-capital ratio is assumed to be constant even out of the steady state.

4. The short-run equilibrium

The short run is defined as a time period in which the capital stock K, the labour supply N, the real wage rate w, and the labour productivity a are all taken as given. The rate of capacity utilization is the adjusting variable in the goods market, thus it will increase (decrease) when demand exceeds (falls short of) supply in the goods market. Any disequilibrium in the goods market will be self-correcting (and hence the short-run equilibrium will be stable) if the investment/capital ratio is less responsive than the saving/capital ratio to changes in the rate of capacity utilization (the so-called Keynesian stability condition):

$$G'_u < s(1-\omega) \tag{10}$$

In what follows, we assume that the Keynesian stability condition holds, and hence inequality (10) is always satisfied.[14] The goods market is in equilibrium when $g^s = g^i$.

Total differentiation of $g^s = g^i$, with (3), (4), and (7), with respect to the wage share ω in the equilibrium point yields:

$$\frac{du^*}{d\omega} = \frac{su - G'_\pi}{s(1-\omega) - G'_u} \tag{11}$$

where "$*$" stands for short-run equilibrium.

Using equation (11) and totally differentiating equations (6) and (7) we obtain:

$$\frac{de^*}{d\omega} = \frac{(su - G'_\pi)k}{s(1-\omega) - G'_u} \tag{12}$$

$$\frac{dg^*}{d\omega} = \frac{s[G'_u u - G'_\pi(1-\omega)]}{s(1-\omega) - G'_u} \tag{13}$$

Given the Keynesian stability condition (equation (10)), $du^*/d\omega > 0$ (and $de^*/d\omega > 0$) if $su > G'_\pi$, that is, when the propensity to save s is high and the partial effect G'_π is weak, whereas $dg^*/d\omega > 0$ if $G'_u u > G'_\pi(1-\omega)$, namely with a strong partial effect G'_u and a weak partial effect G'_π. Since we have $G'_\pi < s(1-\omega)G'_\pi/G'_u$ from the Keynesian stability condition, $dg^*/d\omega > 0$ implies $du^*/d\omega > 0$ (and $de^*/d\omega > 0$), whereas $dg^*/d\omega < 0$ is compatible with either $du^*/d\omega > 0$ (and $de^*/d\omega > 0$) or $du^*/d\omega < 0$ (and $de^*/d\omega < 0$). Thus, three different configurations are possible, depending on the relative sizes of the elasticities of the investment rate to the profit share G'_π and the rate of capacity utilization G'_u, and the capitalists' propensity to save s:[15]

i) a "pure" profit-led growth regime (i.e. profit-led demand and profit-led growth), in which $dg^*/d\omega < 0$, $du^*/d\omega < 0$, and $de^*/d\omega < 0$;
ii) an intermediate case (i.e. wage-led demand and profit-led growth), in which $dg^*/d\omega < 0$, $du^*/d\omega > 0$, and $de^*/d\omega > 0$;
iii) a "pure" wage-led growth regime (i.e. wage-led demand and wage-led growth), in which $dg^*/d\omega > 0$, $du^*/d\omega > 0$, and $de^*/d\omega > 0$.

[14] This is a standard assumption in the relevant literature. However, some have criticized this hypothesis on both theoretical and empirical grounds. See, for instance, Skott (2017).

[15] The three cases were originally called "exhilarationism", "conflicting stagnationism", and "cooperative stagnationism" respectively by Bhaduri and Marglin (1990).

These results are in line with the relevant literature originated from Bhaduri and Marglin (1990) and Marglin and Bhaduri (1990). A redistribution from profits to wages has an expansionary effect on consumption demand and a direct contractionary effect on investment demand. The overall effect on the rates of capacity utilization and employment will be positive (negative) if the effect on consumption (investment) dominates the effect on investment (consumption). Moreover, a higher wage share causes the cost-side profitability of investment to fall, but has an ambiguous effect on the demand-side profitability; thus, it results in an overall decline in the rate of capital accumulation only if the new equilibrium rate of capacity utilization is lower or it is impossible for the rate of capacity utilization to rise enough to offset the negative effect of the fall in cost-side profitability.[16]

In a pure wage-led (profit-led) growth regime, in which the partial effect of the profit share on investment G'_π is weak (strong) relative to the capitalists' propensity to save s and the responsiveness of investment to capacity utilization G'_u, a redistribution from profits to wages results in an increase (decrease) in capacity utilization, employment rate and capital accumulation. In the intermediate case, capitalists' propensity to save s is high relative to the response of the investment rate to the profit share G'_π, but the response of the investment rate to capacity utilization G'_u is too weak to prevent firms' investment from decreasing; thus, a redistribution from profits to wages results in higher capacity utilization and employment but slower capital accumulation.

Both a fall in the propensity to save out of profits and an increase in autonomous investment lead to higher capacity utilization and employment and faster capital accumulation.

Totally differentiating $g^s = g^i$, with (3), (4), and (7), with respect to the propensity to save s in the equilibrium yields:

$$\frac{du^*}{ds} = -\frac{(1-\omega)u}{s(1-\omega) - G'_u} < 0 \tag{14}$$

If we totally differentiate equations (6) and (7), using equation (14), we obtain:

$$\frac{de^*}{ds} = -\frac{(1-\omega)uk}{s(1-\omega) - G'_u} < 0 \tag{15}$$

$$\frac{dg^*}{ds} = -\frac{(1-\omega)G'_u u}{s(1-\omega) - G'_u} < 0 \tag{16}$$

Equations (14), (15), and (16) show that in the short-run equilibrium the paradox of thrift holds. A fall in propensity to save out of profits expands consumption demand and hence causes the rate of capacity utilization and employment to increase. The rise in output stimulates investment and hence capital accumulation via the Keynesian accelerator. No counterbalancing effects lowering investment demand are exerted now, thus a fall in the propensity to save out of profits unambiguously leads to higher capacity utilization, employment, and capital accumulation.

If we totally differentiate $g^s = g^i$, with (3), (4), and (7), with respect to the autonomous investment parameter γ (the "animal spirits"), we have:

$$\frac{du^*}{d\gamma} = \frac{G'_\gamma}{s(1-\omega) - G'_u} > 0 \tag{17}$$

Using equation (17), total differentiation of equations (6) and (7) yields:

[16] Naturally, this result is strictly dependent on the assumptions of an investment function independent of savings and the rate of capacity utilization as an accommodating variable in the goods market. If $u = \bar{u}$, from equation (4) the equilibrium rate of capital accumulation would be $g^* = s(1-\omega)\bar{u}$, being unambiguously negatively related to the wage share, as in classical-Marxian growth models.

$$\frac{de^*}{d\gamma} = \frac{G'_\gamma k}{s(1-\omega) - G'_u} > 0 \qquad (18)$$

$$\frac{dg^*}{d\gamma} = \frac{s(1-\omega)G'_\gamma}{s(1-\omega) - G'_u} > 0 \qquad (19)$$

An increase in autonomous investment or "animal spirits" has a direct positive effect on capital accumulation. The increase in autonomous investment, as a component of the aggregate demand, affects positively the rate of capacity utilization, leading to a further increase in capital accumulation. As a result, the short-run equilibrium rates of capacity utilization, employment, and capital accumulation will rise.

Finally, we may assess the effect of an increase in the long-run component of the employment rate on the short-run equilibrium values of capacity utilization, employment rate, and capital accumulation. Total differentiation of $g^s = g^i$, with (3), (4), and (7), with respect to k in the equilibrium point yields:

$$\frac{du^*}{dk} = \frac{G'_k}{s(1-\omega) - G'_u} < 0 \qquad (20)$$

Using equation (20) and totally differentiating equations (6) and (7) we have:

$$\frac{de^*}{dk} = \frac{G'_k k + [s(1-\omega) - G'_u]u}{s(1-\omega) - G'_u} \qquad (21)$$

$$\frac{dg^*}{dk} = \frac{s(1-\omega)G'_k}{s(1-\omega) - G'_u} < 0 \qquad (22)$$

An increase in the long-run component of the employment rate reduces the rate of capital accumulation both directly, since a fall in the reserve army is detrimental for the economic and political position of capitalists, and indirectly, through its negative effect on the rate of capacity utilization. Conversely, an increase in k has an ambiguous effect on the employment rate, since the positive direct effect may be offset by the decline in the rate of capacity utilization. In what follows, we assume $[s(1-\omega) - G'_u]u > -G'_k k$, meaning that the first effect dominates and $de^*/dk > 0$. Even though this assumption may be questionable for the short run, in which the level of the employment rate is mainly determined by the cyclical fluctuations of output, it seems reasonable for a long-run analysis, in which the employment rate is fully endogenized and its long-run component will presumably play a major role in directly determining the employment rate.

5. THE LONG-RUN EQUILIBRIUM

In the long run we assume that the economy has already attained the short-run equilibrium values of capital accumulation $g^*(\omega, k, s, \gamma)$, capacity utilization $u^*(\omega, k, s, \gamma)$, and employment $e^*(\omega, k, s, \gamma)$. Thus, the long-run dynamics is the movement over time of the short-run equilibrium due to variations in capital stock K, labour supply N, real wage rate w, and labour productivity a. We examine the dynamic behaviour of these variables by defining a two-dimensional system of differential equations in the wage share ω and the ratio of capital stock to effective labour supply k. From the definitions of these variables, we have:

$$\frac{\dot{\omega}}{\omega} = \frac{\dot{w}}{w} - \frac{\dot{a}}{a} \tag{23}$$

$$\frac{\dot{k}}{k} = \frac{\dot{K}}{K} - \frac{\dot{a}}{a} - n \tag{24}$$

Substituting from the short-run equilibrium rate of employment into equation (8), and then from the resulting expression, along with equation (9), into equation (23), we obtain the equation of motion for the wage share. Substituting from the short-run equilibrium rate of capital accumulation and equation (9) into (24), we obtain the equation of motion for the capital stock in effective labour supply units.

$$\frac{\dot{\omega}}{\omega} = h[e(\omega, k, s, \gamma), \alpha] - f(\omega, \tau) \tag{25}$$

$$\frac{\dot{k}}{k} = g(\omega, k, s, \gamma) - f(\omega, \tau) - n \tag{26}$$

where "$*$" has been omitted to save notation.[17] It is immediate to check that $\dot{\omega}/\omega = \dot{k}/k = 0$ implies $\dot{u}/u = \dot{e}/e = 0$, that is, if the income shares and the ratio of the capital stock to effective labour supply are constant, the rate of capacity utilization and the employment rate will also be constant over time, thus making our long-run analysis consistent with the short-run analysis.[18] Remind that, in a long-run analysis, the short-run demand and growth regime are reflected in the signs of e'_ω and g'_ω. Thus, the short-run demand regime is profit-led (wage-led) if $e'_\omega < (>)\ 0$; the short-run growth regime is profit-led (wage-led) if $g'_\omega < (>)\ 0$. Moreover, our assumption about the short-run effect of k on the employment rate translates into $e'_k > 0$.

Equations (25) and (26) imply that the equilibrium size of the long-run component of the reserve army of labour and the equilibrium wage share will stabilize at the level that makes the rate of capital accumulation equal to the rate at which the reserve army is replenished (i.e. labour supply growth plus labour productivity growth) and that makes real wages grow at the same rate as labour productivity. Thus, the economy is labour-constrained: in the steady-state equilibrium, economy will grow at the same rate as the full-employment growth rate.[19] However, the dynamic interaction between the two variables is quite different from the Goodwin model (with or without induced technical change). In the latter, the steady-state value of the wage share is fully determined by the dynamic equation of the employment rate at full capacity, and the dynamic equation of the wage share determines the size of the reserve army of labour that makes the workers' bargaining power compatible with it. Conversely, in the present model, the size of the reserve army affects the dynamic behaviour of both variables, and hence both the wage share and the long-run component of the employment rate will adjust to make the employment rate at full capacity stable.[20]

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[17] Total effects of exogenous variables in the short-run analysis are now converted into partial effects. The effect of any variable x on the short-run equilibrium value of a generic y, i.e. dy^*/dx, is now denoted by y'_x.

[18] See Appendix A.

[19] Naturally, this does not imply that the economy will achieve the full-employment *level* of output. Steady-state growth only requires that the employment rate would be constant. In our model, the equilibrium rate of employment is jointly determined by the cyclical fluctuations of the aggregate demand and by a slowly-adjusting ratio of capital stock to effective labour supply.

[20] Thus, institutional factors influencing workers' bargaining power will affect permanently income distribution, capital accumulation and labour productivity growth, unlike in the Goodwin model (see Section 7 in this chapter and Section 6.2 in Chapter II). A further difference is that the employment rate is also affected by the aggregate demand, whereas the original Goodwin model assumes implicitly that Say's law holds. It is also worth remembering that the

In the long-run equilibrium, we have $\dot{\omega} = \dot{k} = 0$. Therefore, the steady-state values of the wage share $\omega^*(\alpha, \tau, n, s, \gamma)$ and the employment rate at full capacity $k^*(\alpha, \tau, n, s, \gamma)$ solve the following two equations:

$$h[e(\omega, k, s, \gamma), \alpha] - f(\omega, \tau) = 0 \tag{27}$$

$$g(\omega, k, s, \gamma) - f(\omega, \tau) - n = 0 \tag{28}$$

Equation (27) gives the conditions on the labour share and the ratio of capital to effective labour supply that keep income distribution constant. Equation (28) gives the corresponding conditions for the equilibrium in the labour market. Let us call the two isoclines Ω and X, respectively. Figure 1 depicts four alternative configurations of the Ω and X isoclines.[21] For the sake of simplicity, both curves are assumed to be linear.

In the (ω, e) plane, the Ω isocline is upward (downward) sloping if $h'_e e'_\omega < (>) f'_\omega$,[22] which implies that it unambiguously slopes upward in a short-run profit-led demand and growth regime. An increase in the long-run component of employment exerts upward pressure on the wage share, as a tighter labour market allows workers to claim for higher real wages. In a "pure" profit-led regime, an increase in the labour share unambiguously has negative feedback on itself, as any positive deviation would be self-corrected via both a decrease in employment and real wages and an increase in labour productivity. Thus, a constant income distribution requires ω and k to go in the same direction. In intermediate and "pure" wage-led regimes, the slope of the Ω isocline may be either positive or negative, depending on the relative sizes of the induced innovation effect (f'_ω), the wage-led demand (e'_ω), and the reserve-army effect (h'_e). With strongly wage-led demand and a strong reserve-army effect relative to the induced innovation effect, the Ω isocline turns downward sloping.

The X isocline is upward (downward) sloping if $g'_\omega > (<) f'_\omega$, which implies that it always has a negative slope in a short-run profit-led growth regime. An increase in the ratio of capital to effective labour supply now unambiguously puts downward pressure on the employment rate, as the Bhaduri-Marglin-Skott investment function postulates an adverse effect of labour market tightness on firms' investment plans. Conversely, an increase in the labour share gives rise to two effects on the employment rate: on the one hand, it induces a higher rate of labour-saving innovations, which puts downward pressure on employment; on the other hand, it has a negative (positive) effect on capital accumulation if the short-run growth regime is profit-led (wage-led), thus exerting downward (upward) pressure on employment. Thus, in intermediate and pure profit-led regimes, an increase in k needs to be counteracted by a decrease in ω to keep the labour market in equilibrium, whereas the slope of the X isocline turns positive only in a strongly wage-led growth regime with a relatively weak induced innovation effect ($g'_\omega > f'_\omega$).

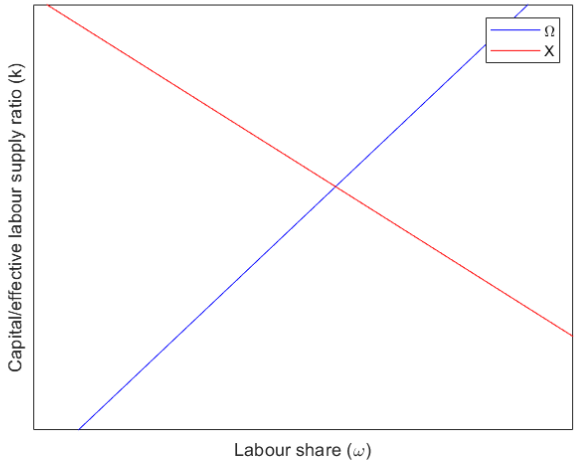
In what follows, we assume that there exists a unique economically meaningful pair of long-run equilibrium solution (ω^{**}, k^{**}).

present model departs from growth cycle models with cyclical fluctuations of aggregate demand (e.g. Barbosa-Filho and Taylor, 2006; Sasaki, 2013; Rada, *et al.*, 2021), in that the rate of capacity utilization is supposed to instantaneously adjust to clear the saving-investment market, while the full adjustment of the wage share and the employment rate takes place more gradually.

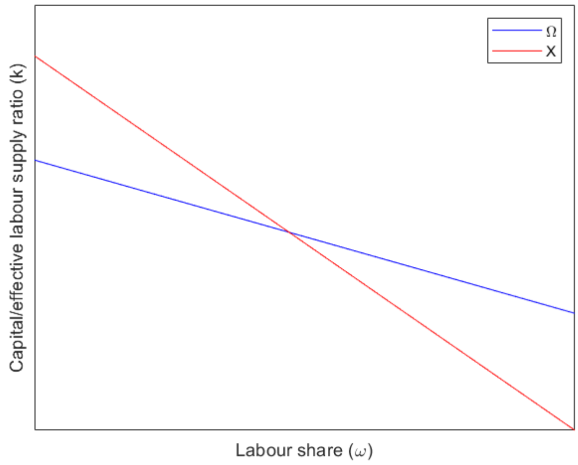
21 The next section shows that only in the first three configurations the long-run equilibrium is locally stable.

22 For the computation of the slopes of the Ω and X isoclines, see Appendix B.

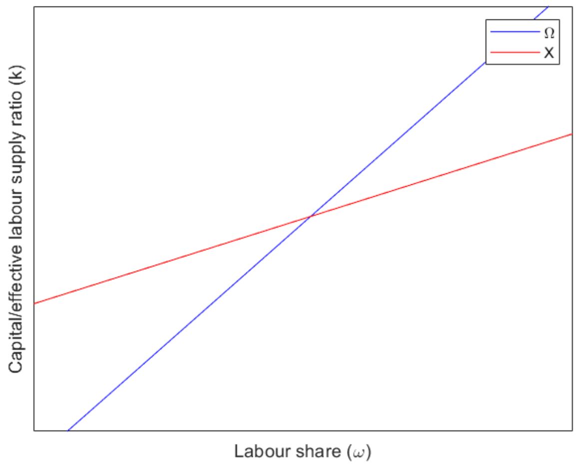
Fig. 1. *Ω and X isoclines*



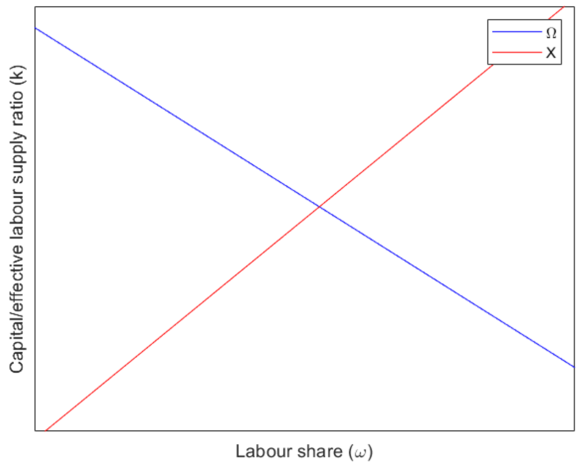
a) Case I: $g'_\omega < f'_\omega$, $h'_e e'_\omega < f'_\omega$



b) Case II: $g'_\omega < f'_\omega$, $h'_e e'_\omega > f'_\omega$



c) Case III: $g'_\omega > f'_\omega$, $h'_e e'_\omega < f'_\omega$



d) Case IV: $g'_\omega > f'_\omega$, $h'_e e'_\omega > f'_\omega$

6. LOCAL STABILITY OF THE LONG-RUN EQUILIBRIUM

We investigate the local stability of the long-run equilibrium linearizing the system of differential equations (25) and (26) around the steady-state equilibrium values of the wage share and the capital/effective labour supply ratio:

$$\begin{bmatrix} \dot{\omega} \\ \dot{k} \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} \omega - \omega^{**} \\ k - k^{**} \end{bmatrix} \tag{29}$$

where the elements of the Jacobian matrix $\boldsymbol{J}$ evaluated at the steady-state values $\omega^{**}(\alpha, \tau, n, s, \gamma)$ and $k^{**}(\alpha, \tau, n, s, \gamma)$ are given by:

$$J_{11} \equiv \frac{\partial \dot{\omega}}{\partial \omega}\bigg|_{\omega=\omega^{**},k=k^{**}} = (h'_e e'_\omega - f'_\omega)\omega^{**} \tag{30}$$

$$J_{12} \equiv \frac{\partial \dot{\omega}}{\partial k}\bigg|_{\omega=\omega^{**},k=k^{**}} = h'_e e'_k \omega^{**} > 0 \tag{31}$$

$$J_{21} \equiv \frac{\partial \dot{k}}{\partial \omega}\bigg|_{\omega=\omega^{**},k=k^{**}} = (g'_\omega - f'_\omega)k^{**} \tag{32}$$

$$J_{22} \equiv \frac{\partial \dot{k}}{\partial k}\bigg|_{\omega=\omega^{**},k=k^{**}} = g'_k k^{**} < 0 \tag{33}$$

Only partial derivatives (31) and (33) are unambiguously signed, whereas the signs of (30) and (32) are crucially dependent on the direct impact of income distribution on capacity utilization and capital accumulation, and on the strength of the reserve-army effect. Equation (31) shows that an increase in the ratio of capital stock to effective labour supply, by increasing the employment rate, will raise the growth rate of the wage share. Equation (33) shows that an increase in k affects negatively its growth rate, since the resulting increase in the employment rate has a negative effect on capital accumulation via Bhaduri-Marglin-Skott investment function. Equation (32) shows that the effect of an increase in the wage share on the growth rate of the long-run component of the employment rate is mediated by its impact on labour productivity growth and capital accumulation. The growth of the capital/effective labour supply ratio is negatively affected in a profit-led growth regime and in a weakly wage-led growth regime with a relatively strong induced innovation effect. Equation (30) shows that the effect of an increase in the wage share on its growth rate is negative in a short-run profit-led demand regime and in a weakly wage-led demand regime with a weak reserve-army effect and a relatively strong induced innovation effect.

The characteristic equation of the Jacobian matrix $\boldsymbol{J}$ in (29) is given by:

$$\lambda^2 + a_1\lambda + a_2 = 0 \tag{34}$$

in which λ denotes a characteristic root and $a_1 = -\mathrm{Tr}(\boldsymbol{J})$ and $a_2 = \mathrm{Det}(\boldsymbol{J})$.

A necessary and sufficient condition for the local stability of the dynamic system is that all characteristic roots are negative or have a negative real part, which occurs when $a_1 > 0$ and $a_2 > 0$ or, equivalently:

$$\mathrm{Tr}(\boldsymbol{J}) < 0, \;\; \mathrm{Det}(\boldsymbol{J}) > 0 \tag{35}$$

where:

$$\mathrm{Tr}(\boldsymbol{J}) = (h'_e e'_\omega - f'_\omega)\omega^{**} + g'_k k^{**} \tag{36}$$

$$\mathrm{Det}(\boldsymbol{J}) = [(h'_e e'_\omega - f'_\omega)g'_k - (g'_\omega - f'_\omega)h'_e e'_k]\omega^{**}k^{**} \tag{37}$$

From equation (36), we have that a sufficient condition for $\mathrm{Tr}(\boldsymbol{J}) < 0$ is $h'_e e'_\omega < f'_\omega$. Equation (37) implies that a necessary condition for $\mathrm{Det}(\boldsymbol{J}) > 0$ is $f'_\omega > \min\{h'_e e'_\omega, g'_\omega\}$, whereas a sufficient condition is $f'_\omega > \max\{h'_e e'_\omega, g'_\omega\}$. Thus, if the economy exhibits both profit-led demand and profit-led growth in the short run, the conditions for the local stability of the long-run equilibrium are always satisfied. If the economy has a short-run intermediate regime, with wage-led demand and profit-led growth, $h'_e e'_\omega < f'_\omega$ is a sufficient, albeit not necessary, condition for the long-run equilibrium to be locally stable. If the economy exhibits both wage-led demand and wage-led growth in the short run, we need to evaluate the more general necessary and sufficient conditions stated above.

The intuition is straightforward. An increase in the capital/effective labour supply ratio is self-stabilizing via Bhaduri-Marglin-Skott investment function (equation (33)) but has a destabilization effect on the rate of growth of the labour share via reserve-army effect (equation (31)). An increase in the labour share has a stabilization effect via distribution-induced technical change and profit-led demand and growth. By contrast, wage-led demand and wage-led growth act as destabilization forces, as any deviation of ω from its steady-state value will be exacerbated by the positive response of capacity utilization, capital accumulation, and real wages to the labour share (equations (30) and (32)). Thus, a necessary condition for the local stability of the long-run equilibrium is that the induced innovation effect would be strong enough to prevent income distribution from causing an explosive growth of the labour share *or* the capital/effective labour supply ratio (i.e. J_{11} *or* J_{21} must be negatively signed). If the induced innovation effect offset the destabilizing effect of wage-led demand and growth so as to allow the labour share to have a negative effect on *both* its own rate of growth and the rate of growth of the capital/effective labour supply ratio, the long-run equilibrium will be always locally stable (i.e. a negative sign for *both* J_{11} and J_{21} is a sufficient condition for the local stability).

The conditions for the local stability of the long-run equilibrium can be phrased in terms of conditions on the slopes of the Ω and X isoclines. Equation (36) implies that an upward-sloping Ω isocline is a sufficient condition for stability. Equation (37) implies that the equilibrium will be stable only if the slope of the Ω isocline is greater than the slope of the X isocline:[23]

$$\left.\frac{dk}{d\omega}\right|_{\Omega} > \left.\frac{dk}{d\omega}\right|_{X} \tag{38}$$

where:

$$\left.\frac{dk}{d\omega}\right|_{\Omega} = -\frac{h'_e e'_\omega - f'_\omega}{h'_e e'_k} \tag{39}$$

$$\left.\frac{dk}{d\omega}\right|_{X} = -\frac{g'_\omega - f'_\omega}{g'_k} \tag{40}$$

Figure 1 depicts four alternative configurations depending on the slopes of the Ω and X isoclines. In panel a), we have $g'_\omega < f'_\omega$ and $h'_e e'_\omega < f'_\omega$, so the Ω isocline slopes upward while the X isocline slopes downward. In this scenario, the long-run equilibrium is always locally stable, as the conditions $\mathrm{Tr}(\boldsymbol{J}) < 0$ and $\mathrm{Det}(\boldsymbol{J}) > 0$ are both satisfied. This case is consistent with all possible short-run demand and growth regimes, as no restrictions are imposed on the signs of e'_ω and g'_ω. In panel b), we have $g'_\omega < f'_\omega < h'_e e'_\omega$. Both curves slope downward but the Ω isocline is flatter than the X isocline, which implies that the long-run equilibrium is locally stable provided that $\mathrm{Tr}(\boldsymbol{J}) < 0$. This scenario rules out a "pure" profit-led regime, as capital accumulation may be either profit- or wage-led but capacity utilization is unambiguously wage-led. In panel c), in which $h'_e e'_\omega < f'_\omega < g'_\omega$ both curves slope upward but the X isocline is steeper. Thus, both necessary and sufficient conditions for local stability are satisfied. This case is consistent only with a strongly wage-led growth regime, in which both capacity utilization and capital accumulation respond positively to the labour share in the short-run, and the induced innovation effect is relatively weak as compared to the partial effect of distribution on capital accumulation. In panel d), we have $g'_\omega > f'_\omega$ and $h'_e e'_\omega > f'_\omega$, so the Ω isocline slopes downward while the X isocline slopes upward. In this scenario, the long-run equilibrium will be unambiguously unstable since the induced innovation effect is too weak to prevent wage-led

[23] See Appendix B.

demand and growth from causing an explosive growth of ω and k. Suppose, for instance, that a temporary shock brings the capital/effective labour supply above its steady-state value. The increase in k raises the labour share via reserve-army effect. If the Ω curve is downward sloping, as in panel d), the expansionary effect of an increase in the labour share causes the labour share to rise even further, which in turn speeds up capital accumulation and causes the long-run component of employment to increase more, and so on in an explosive way. If the Ω curve were upward sloping, as in panel c), the positive feedback of the wage share on itself would turn into a negative one. Thus, any deviation of the labour share from its steady-state value would be self-correcting rather than self-reinforcing and would bring the economy back to its long-run equilibrium point.

It is worth emphasizing the role of the induced innovation effect and a Bhaduri-Marglin-Skott investment function in the stability of an economy with a short-run wage-led growth regime. Suppose that $f'_{\omega} = g'_k = 0$. If the economy exhibits a wage-led growth regime in the short run, and labour productivity does not react to the labour share, an increase in the labour share will always have a destabilizing effect on both its own rate of growth and the rate of growth of k. The presence of the induced innovation effect (i.e. $f'_{\omega} > 0$) opens up the possibility of a stable wage-led growth regime, provided that $f'_{\omega} > \max\{h'_e e'_{\omega}, g'_{\omega}\}$. If we postulate that the employment rate has a dampening effect on firms' investment plans (i.e. $g'_k < 0$), as in a Bhaduri-Marglin-Skott investment function, the necessary condition for a stable wage-led growth regime becomes even weaker (i.e. $f'_{\omega} > \min\{h'_e e'_{\omega}, g'_{\omega}\}$). In terms of conditions on the slopes of the Ω and X isoclines, if $f'_{\omega} = g'_k = 0$, only the scenario depicted in panel a), with a vertical straight line for X and a short-run profit-led demand and growth regime, would be locally stable. The induced innovation effect makes it possible for the long-run equilibrium in panel a) with a vertical X to be locally stable even if the economy exhibits wage-led demand and growth in the short run. Postulating a negative effect of the employment rate on capital accumulation allows for a stable long-run equilibrium in the cases depicted in panels b) and c). However, it has to be noted that assuming a Bhaduri-Marglin investment function is not sufficient to make an economy with a short-run wage-led growth regime stable. Indeed, even if $g'_k < 0$, a "pure" wage-led growth regime without induced innovation would never satisfy the conditions to be locally stable. The Bhaduri-Marglin-Skott investment function may only increase the chance for a stable wage-led growth regime with distribution-induced technical change.

7. Comparative statics analysis

This section addresses the long-run effects of institutional and technological shocks on income distribution, employment, and the macroeconomic outcomes of the economy. The parameters of major concern are the institutional variable α, denoting all institutional and political factors which strengthen the workers' bargaining power, and the exogenous variable τ, representing all exogenous factors affecting labour productivity growth. However, we can also evaluate the effects of changes in the growth rate of labour supply n, the propensity to save out of profits s, and the exogenous component of investment γ. We then investigate the effects of changes in the exogenous variables on the steady-state values of the wage share, the capital/effective labour supply ratio, the employment rate, the rate of capital accumulation, and the growth rates of real wages and labour productivity both analytically and graphically. The main results of comparative statics analysis are summarized in Table 1.

Let us define $\Gamma \equiv (h'_e e'_{\omega} - f'_{\omega})g'_k - (g'_{\omega} - f'_{\omega})h'_e e'_k$. Since the implementation of a comparative statics analysis requires the stability of the equilibrium, in what follows we assume $\Gamma > 0$.

Furthermore, for the sake of simplicity, we limit ourselves to the discussion of the case of an upward sloping Ω isocline. This corresponds to the scenarios depicted in panels a) and c) in Figure 1, in which both necessary and sufficient conditions for local stability are satisfied.[24]

Proposition 1 The long-run labour share, capital accumulation, labour productivity growth, and real wage growth are increasing in α; the equilibrium capital/effective labour supply ratio is a positive function of α if and only if the economy exhibits a short-run wage-led growth with $g'_\omega > f'_\omega$; the long-run employment rate is decreasing (increasing) in α if the economy exhibits a short-run profit-led demand and growth regime (wage-led demand and growth regime with $g'_\omega > f'_\omega$).

Proof Total differentiation of equations (27) and (28) with respect to α yields:

$$\frac{d\omega^{**}}{d\alpha} = -\frac{g'_k h'_z}{\Gamma} > 0 \tag{41}$$

$$\frac{dk^{**}}{d\alpha} = \frac{(g'_\omega - f'_\omega)h'_z}{\Gamma} \tag{42}$$

Given that $\hat{w}^{**} = \hat{a}^{**}$, if we totally differentiate equations (9) and $e(\omega, k, s, \gamma)$, using equations (28), (41), and (42), we obtain:

$$\frac{de^{**}}{d\alpha} = \frac{[(g'_\omega - f'_\omega)e'_k - g'_k e'_\omega]h'_z}{\Gamma} \tag{43}$$

$$\frac{dg^{**}}{d\alpha} = \frac{d\hat{w}^{**}}{d\alpha} = \frac{d\hat{a}^{**}}{d\alpha} = -\frac{g'_k f'_\omega h'_z}{\Gamma} > 0 \tag{44}$$

An increase in workers' bargaining strength, as measured by the institutional variable α, leads to a downward shift in the Ω isocline, while leaving the X isocline unaffected (Figure 2).[25]

Positive institutional shocks allow workers to claim for higher real wages, for a given capital/effective labour supply ratio, thus increasing the income share they are able to attain in the labour market. The increase in the labour share puts pressure on the employment rate at full capacity via both the goods market and induced technical change. Indeed, rising labour costs induce the adoption of labour-saving innovations and also affect capital accumulation according to the nature of the short-run demand and growth regime of the economy. In the case of a downward sloping X isocline, corresponding to profit-led or weakly wage-led growth regimes, increases in the income share of workers exert downward pressure on the capital/effective labour supply ratio, thus k must decrease to restore a constant employment rate at full capacity (Figure 2a). In the case of a strongly wage-led growth regime, in which the X isocline slopes upward, a constant employment rate at full capacity requires k to increase (Figure 2b). In both cases, the stronger the partial effect of k on capital accumulation $|g'_k|$, the flatter the X isocline, and the more institutional shocks will affect long-run income distribution.

The increase in the long-run wage share is associated with an increase in steady-state labour productivity growth and also with an increase in steady-state capital accumulation, which in a labour-constrained economy is anchored to labour productivity growth via the dynamic equation of employment (equation (28)). Thus, irrespective of the short-run demand and growth regime, redistribution from capital to labour fosters the long-run rate of growth of the economy via the induced

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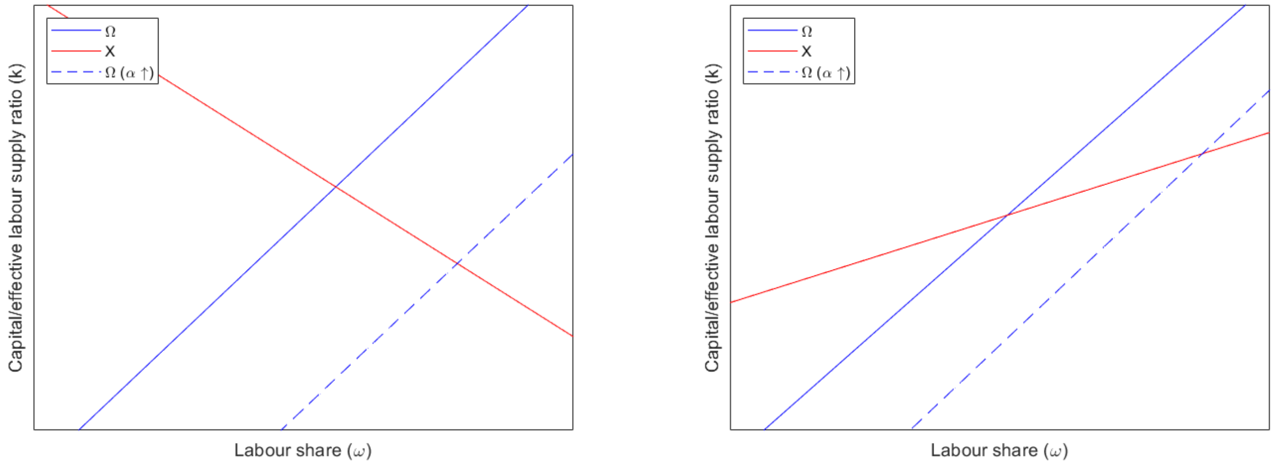
[24] The coefficient a_2 of the Jacobian matrix is positive if and only if $\Gamma > 0$. An upward sloping Ω isocline is a sufficient condition for $a_1 > 0$.

[25] For a formal proof, see Appendix B.

Fig. 2. *The effect of an institutional shock*



a) $g'_\omega < f'_\omega,\ h'_e e'_\omega < f'_\omega$ *b)* $g'_\omega > f'_\omega,\ h'_e e'_\omega < f'_\omega$

innovation effect, that is, capital accumulation is wage-led in the long run. Conversely, the long-run effect of institutional shocks on employment crucially depends on the short-run demand and growth regime of the economy. If the economy exhibits profit-led demand and growth in the short run, an increase in workers' bargaining power will unambiguously lower the long-run employment rate. Indeed, in the scenario depicted in panel a) with profit-led demand, the capital/effective labour supply decreases and the increase in the labour share is associated with a negative partial effect on capacity utilization, which unambiguously lead to a reduction in the employment rate. If the economy exhibits a strongly wage-led demand and growth regime in the short run, as in panel b), positive institutional shocks will raise the long-run employment rate, as the capital/effective labour supply rises and the increase in the labour share is associated with a positive partial effect on utilization. In intermediate and weakly wage-led growth regimes, the effect on long-run employment depends on the relative strength of the partial effect of distribution on capacity utilization and the partial effect of the capital/effective labour supply ratio on employment. In the case depicted in panel a), the long-run employment rate will then rise if and only if $e'_\omega d\omega^{**}/d\alpha > e'_k|dk^{**}/d\alpha|$.

Our results are close to the ones identified by the more recent classical literature on secular stagnation in labour-constrained economies, which links the slowdown in capital accumulation to labour market deregulation (e.g. Petach and Tavani, 2020; Barrales-Ruiz, *et al.*, 2021; Cruz Luzuriaga and Tavani, 2021). The key message of this literature is that, provided that technical change is distribution-induced, the long-run rate of growth of an economy turns out to be wage-led even if capital accumulation is assumed to be profit-led at business cycle frequencies. Indeed, in a labour-constrained economy, in which the actual rate of growth is equal to the natural rate of growth, long-run capital accumulation is linked positively to the labour share via the balanced growth condition rather than via the Kaleckian-Steindlian mechanism of a boosting effect of the labour share on consumption demand.

We find that, in a neo-Kaleckian model of a labour-constrained economy with induced innovation, labour market institutions affect growth in the long run via the natural rate of growth rather than via the "traditional" underconsumptionist channel. Indeed, conditional on institutional shocks, the short-run demand and growth regime of the economy does not matter for addressing the long-run effects of income distribution on capital accumulation and labour productivity growth. Thus, labour market deregulation will depress both the labour share and the long-run rate of growth even when a higher labour share is associated with slower capital accumulation in the short run, as is the case in economies with profit-led activity.

These results rely upon the presence of an adverse effect of labour market tightness on firms' investment plans, as made explicit by the Bhaduri-Marglin-Skott investment function.[26] Consider a simple version of a Kaleckian model of a labour-constrained economy with induced innovation and a standard Bhaduri-Marglin investment function:

$$\frac{\dot{\omega}}{\omega} = h[e(\omega, k), \alpha] - f(\omega) \tag{45}$$

$$\frac{\dot{k}}{k} = g(\omega) - f(\omega) - n \tag{46}$$

where $e(\omega, k) = u(\omega)k$, short-run demand is profit-led (wage-led) if $e'_\omega < (>)\ 0$, short-run growth is profit-led (wage-led) if $g'_\omega < (>)\ 0$, and s and γ have been omitted for the sake of simplicity. In this model, the steady-state level of the wage share is determined by the dynamic equation of the employment rate at full capacity, whereas the dynamic equation of the wage share determines the corresponding equilibrium employment rate at full capacity. Thus, a positive institutional shock only lowers the long-run employment rate, while leaving long-run income distribution, capacity utilization, capital accumulation, and labour productivity growth unaffected.[27] It is indeed immediate to check that $d\omega^*/d\alpha = du^*/d\alpha = dg^*/d\alpha = d\hat{a}^*/d\alpha = 0$, whereas $dk^*/d\alpha = -h'_\alpha / h'_e e'_k < 0$ and $de^*/d\alpha = -h'_\alpha / h'_e < 0$. Conversely, postulating a Bhaduri-Marglin-Skott investment function restores a channel through which labour market institutions may have long-run effects, as different combinations of ω and k are consistent with a constant employment rate at full capacity.

The key conclusion of the model about the effects of labour market institutions on long-run income distribution, capital accumulation, and labour productivity growth is independent of the endogeneity of the rate of capacity utilization. Indeed, it would hold even if we assume that the rate of capacity utilization adjusts to a predetermined and exogenously given normal level, that in our model would be equivalent to assume $g'_\omega < 0$ and $e'_\omega = 0$ – a result which is still different from standard Kaleckian findings, where the possibility of wage-led growth rests on an endogenous rate of capacity utilization.

The impact of labour market institutions on the long-run employment rate is instead dependent on the short-run demand and growth regime of the economy. In a pure profit-led growth regime, the overall impact of α on the equilibrium employment rate will be unambiguously negative, since a positive institutional shock is associated with a fall in both the short-run and the long-run components of the employment rate. However, employment needs not necessarily increase in intermediate and wage-led growth regimes. A positive institutional shock to the labour share causes the employment rate to fall even in intermediate and wage-led growth regimes, if labour productivity growth is more sensitive than capital accumulation to the labour share.

Proposition 2 The long-run labour share is decreasing in τ; the long-run employment rate, capital accumulation, labour productivity growth, and real wage growth are increasing (decreasing) in τ if the economy exhibits a short-run profit-led (wage-led) demand and growth regime.

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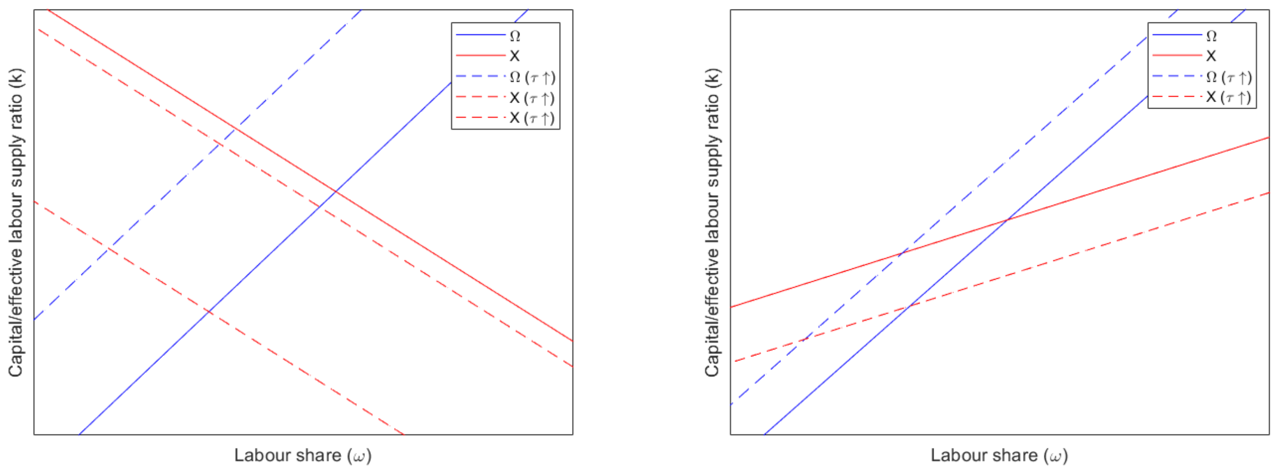
[26] In a similar vein, Rada, *et al.* (2021) find a positive effect of labour market institutions on the natural rate of growth in a neo-Goodwinian framework.

[27] A similar argument holds for the long-run effects of labour market institutions in a Goodwin model with induced technical change. See Chapter II, in particular Section 6.2, for a discussion in the context of a comparison with a classical model with heterogeneity across workers.

Fig. 3. *The effect of a technology shock*



a) $g'_\omega < f'_\omega$, $h'_e e'_\omega < f'_\omega$

b) $g'_\omega > f'_\omega$, $h'_e e'_\omega < f'_\omega$

Proof If we totally differentiate equations (27) and (28) with respect to τ, we have:

$$\frac{d\omega^{**}}{d\tau} = -\frac{(h'_e e'_k - g'_k) f'_\tau}{\Gamma} < 0 \tag{47}$$

$$\frac{dk^{**}}{d\tau} = \frac{(h'_e e'_\omega - g'_\omega) f'_\tau}{\Gamma} \tag{48}$$

Since we know that $\hat{w}^{**} = \hat{a}^{**}$, total differentiation of equations (9) and $e(\omega, k, s, \gamma)$, after using equations (28), (47), and (48), yields:

$$\frac{de^{**}}{d\tau} = \frac{(g'_k e'_\omega - g'_\omega e'_k) f'_\tau}{\Gamma} \tag{49}$$

$$\frac{dg^{**}}{d\tau} = \frac{d\hat{w}^{**}}{d\tau} = \frac{d\hat{a}^{**}}{d\tau} = \frac{(g'_k e'_\omega - g'_\omega e'_k) h'_e f'_\tau}{\Gamma} \tag{50}$$

An exogenous increase in labour productivity, as measured by the variable τ, leads to an upward shift in the Ω isocline and a downward shift in the X isocline (Figure 3).[28] Indeed, technology shocks exert downward pressure on both the labour share and the capital/effective labour supply ratio, as labour productivity growth rises. Therefore, for a given labour share, the employment rate (then k) must rise to restore a stable income distribution. Conversely, for a given labour share, a constant capital/effective labour supply ratio requires k to rise.

As shown in panels a) and b), irrespective of the short-run demand and growth regime, the labour share unambiguously declines following a technology shock. In the scenario depicted in panel a), the effect on the employment rate at full capacity depends on the relative responsiveness of the Ω and X isoclines to an increase in τ. In a strongly wage-led growth regime, depicted in panel b), the capital/effective labour supply ratio unambiguously declines. However, irrespective of the slope of Ω and X and their response to technology shocks, equation (49) shows that in a pure profit-led regime

[28] For a formal proof, see Appendix B.

an exogenous increase in labour productivity growth unambiguously raises the long-run employment rate, whereas in a pure wage-led regime a technology shock unambiguously lowers long-run employment; in an intermediate regime, the long-run employment rate will rise if and only if $e'_\omega |d\omega^{**}/d\tau| < e'_k dk^{**}/d\tau$. As real wage growth is determined by the employment rate (equation (8)), labour productivity growth is anchored to real wage growth via the dynamic equation of the labour share (equation (27)), and in a labour-constrained economy capital accumulation is tied up with labour productivity growth via the dynamic equation of the employment rate at full capacity (equation (28)), following a technology shock the steady-state values of real wages, capital accumulation, and labour productivity growth move together with the long-run employment rate. Thus, following a productivity shock, real wage growth, capital accumulation, and labour productivity growth unambiguously rise in a short-run profit-led demand and growth regime but fall in a short-run wage-led demand and growth regime.

Our results show that, differently from institutional shocks, the effect of technology shocks on the long-run rate of growth of the economy is crucially dependent on the short-run association between income distribution and capital accumulation. Conditional on technology shocks, if the economy exhibits profit-led demand and growth in the short run, a decrease in the labour share is associated with faster capital accumulation and labour productivity growth in the long run, whereas if the short-run demand and growth regime of the economy is wage-led, a decrease in the labour share is associated with slower capital accumulation and labour productivity growth. Therefore, if the economy has a pure profit-led regime in the short run, both institutional and technology shocks are conducive to faster capital accumulation and labour productivity growth but lead to opposite distributional outcomes; if the economy exhibits a pure wage-led regime in the short run, improving the workers' bargaining position represents an unambiguously better strategy to raise the long-run labour share, capital accumulation, and labour productivity growth, since exogenous productivity shocks would lead to worse outcomes in terms of both income distribution and long-run rate of growth.

Proposition 3 The long-run labour share, employment rate, labour productivity growth, and real wage growth are decreasing in n; the long-run capital accumulation is a positive function of n if the economy exhibits a short-run profit-led demand and growth regime.

Proof Totally differentiating equations (27) and (28) with respect to n, we have:

$$\frac{d\omega^{**}}{dn} = -\frac{h'_e e'_k}{\Gamma} < 0 \tag{51}$$

$$\frac{dk^{**}}{dn} = \frac{h'_e e'_\omega - f'_\omega}{\Gamma} \tag{52}$$

Using equations (28), (51), and (52), total differentiation of equations (9) and $e(\omega, k, s, \gamma)$, yields:

$$\frac{de^{**}}{dn} = -\frac{e'_k f'_\omega}{\Gamma} < 0 \tag{53}$$

$$\frac{d\hat{w}^{**}}{dn} = \frac{d\hat{a}^{**}}{dn} = -\frac{h'_e e'_k f'_\omega}{\Gamma} < 0 \tag{54}$$

$$\frac{dg^{**}}{dn} = \frac{(h'_e e'_\omega - f'_\omega) g'_k - g'_\omega h'_e e'_k}{\Gamma} \tag{55}$$

For what concerns the effects on long-run income distribution, employment, real wages, and labour productivity growth, our comparative statics analysis results with respect to labour supply growth are in line with those of a standard classical growth model. An increase in labour supply growth lowers the steady-state labour share, which in turn induces less labour-saving innovations and then slower real wage growth in the long run. The steady-state employment rate falls to the level associated with a lower rate of growth of real wages. If the economy exhibits a pure profit-led regime, as is the case in a standard classical growth model, the lower labour share induces faster capital accumulation.

Proposition 4 The long-run labour share, employment rate, capital accumulation, labour productivity growth, and real wage growth are decreasing in s.

Proof Total differentiation of equations (27) and (28) with respect to s yields:

$$\frac{d\omega^{**}}{ds} = -\frac{(g'_k e'_s - e'_k g'_s)h'_e}{\Gamma} < 0 \tag{56}$$

$$\frac{dk^{**}}{ds} = \frac{(g'_\omega - f'_\omega)h'_e e'_s - (h'_e e'_\omega - f'_\omega)g'_s}{\Gamma} \tag{57}$$

Since we know that $\hat{w}^{**} = \hat{a}^{**}$, total differentiation of equations (9) and $e(\omega, k, s, \gamma)$, after using equations (28), (56), and (57), yields:

$$\frac{de^{**}}{ds} = -\frac{(g'_k e'_s - e'_k g'_s)f'_\omega}{\Gamma} < 0 \tag{58}$$

$$\frac{dg^{**}}{ds} = \frac{d\hat{w}^{**}}{ds} = \frac{d\hat{a}^{**}}{ds} = -\frac{(g'_k e'_s - e'_k g'_s)h'_e f'_\omega}{\Gamma} < 0 \tag{59}$$

Comparative statics analysis with respect to s shows that the paradox of thrift holds even in the long run. An increase in the propensity to save out of profits reduces the steady-state values of employment rate, capital accumulation, labour productivity growth, and real wage growth, irrespective of the short-run demand and growth regime of the economy. Slower labour productivity growth is associated with a lower labour share in the long run. The appearance of the paradox of thrift in the long run relies on a genuine Kaleckian mechanism, that is, a contractionary effect of an increase in the propensity to save which is allowed to have long-run effects by means of an endogenous rate of capacity utilization. If we assume that the rate of capacity utilization adjusts to a predetermined and exogenously given normal level (i.e. $g'_s > 0$ and $e'_s = 0$), an increase in the propensity to save out of profits would have an expansionary effect on the long-run rate of growth and employment, and the labour share would increase accordingly, as in classical growth models.

Proposition 5 The long-run labour share, employment rate, capital accumulation, labour productivity growth, and real wage growth are increasing in γ.

Proof Totally differentiating equations (27) and (28) with respect to γ, we have:

$$\frac{d\omega^{**}}{d\gamma} = \frac{(e'_k g'_\gamma - g'_k e'_\gamma)h'_e}{\Gamma} > 0 \tag{60}$$

$$\frac{dk^{**}}{d\gamma} = \frac{(g'_\omega - f'_\omega)h'_e e'_\gamma - (h'_e e'_\omega - f'_\omega)g'_\gamma}{\Gamma} \tag{61}$$

Tab. 1. *Results of comparative statics analysis*

	α			
	Short-run profit-led demand and growth	Short-run wage-led demand and profit-led growth	Short-run wage-led demand and growth with $g'_\omega < f'_\omega$	Short-run wage-led demand and growth with $g'_\omega > f'_\omega$
ω^{**}	$+$	$+$	$+$	$+$
e^{**}	$-$	$+/-$	$+/-$	$+$
g^{**}	$+$	$+$	$+$	$+$
$\hat{a}^{**}$	$+$	$+$	$+$	$+$
$\hat{w}^{**}$	$+$	$+$	$+$	$+$
k^{**}	$-$	$-$	$-$	$+$
u^{**}	$+/-$	$+$	$+$	$+/-$

	τ			
	Short-run profit-led demand and growth	Short-run wage-led demand and profit-led growth	Short-run wage-led demand and growth with $g'_\omega < f'_\omega$	Short-run wage-led demand and growth with $g'_\omega > f'_\omega$
ω^{**}	$-$	$-$	$-$	$-$
e^{**}	$+$	$+/-$	$-$	$-$
g^{**}	$+$	$+/-$	$-$	$-$
$\hat{a}^{**}$	$+$	$+/-$	$-$	$-$
$\hat{w}^{**}$	$+$	$+/-$	$-$	$-$
k^{**}	$+/-$	$+/-$	$+/-$	$-$
u^{**}	$+/-$	$+/-$	$+/-$	$+/-$

Using equations (28), (60), and (61), total differentiation of equations (9) and $e(\omega, k, s, \gamma)$, yields:

$$\frac{de^{**}}{d\gamma} = \frac{(e'_k g'_\gamma - g'_k e'_\gamma) f'_\omega}{\Gamma} > 0 \tag{62}$$

$$\frac{dg^{**}}{d\gamma} = \frac{d\hat{w}^{**}}{d\gamma} = \frac{d\hat{a}^{**}}{d\gamma} = \frac{(e'_k g'_\gamma - g'_k e'_\gamma) h'_e f'_\omega}{\Gamma} > 0 \tag{63}$$

An increase in autonomous investment has an expansionary effect on the long-run rate of growth of the economy. Acceleration in capital accumulation requires faster labour productivity growth in order to keep the employment rate at full capacity constant in the long run, which in turn requires a higher labour share. Real wage growth and the employment rate rise accordingly.

8. CONCLUDING REMARKS

This paper presented a labour-constrained model of demand-led growth. More specifically, we have drawn on the Kaleckian-Steindlian tradition to examine the short-run relation between income distribution, capacity utilization, and capital accumulation; on growth cycle models *à la* Goodwin to formalize the dynamic interaction between employment rate at full capacity and distributive shares of national income; on the classical-Marxian approach to induced technical change literature to link labour productivity growth to the prevailing income distribution. The goods market is assumed to clear instantaneously through changes in the rate of capacity utilization, whereas variations in the wage share and the long-run component of the employment rate are supposed to take place at a lower speed.

We considered the adverse effect of persistently high employment on firms' investment plans, based on the argument that a high employment rate raises the adjustment costs related to monitoring and is associated with a decline in capitalists' "state of confidence", as a tighter labour market increases the chance for worker militancy and is detrimental to the economic, political and social position of capitalists *vis-à-vis* workers. The modification of the standard Bhaduri-Marglin investment function has been motivated on the ground that this effect is independent of the impact of labour market tightness on the wage-profit divide. We have shown that the negative impact of employment on capital accumulation acts as a stabilizing factor for a wage-led growth regime with induced technical change, since it allows firms, by reducing investment, to regenerate the reserve army of labour, thus counteracting the potentially explosive growth of the wage share and the employment rate.

As in canonical Kaleckian models, we left the rate of capacity utilization diverge from the normal level even in the long run. However, we have shown that the long-run effects of institutional shocks to the labour share are independent of the endogeneity of the rate of capacity utilization and the short-run demand and growth regime of the economy. Institutional factors strengthening the relative bargaining power of workers are found to have an unambiguously positive effect on wage share, capital accumulation, labour productivity growth, and real wages growth in the long run, as income distribution impacts the long-run rate of growth via the induced innovation channel rather than via underconsumption. Thus, improving the social protection system and labour market regulation, centralizing the industrial relation system and the collective bargaining structure, and reducing market concentration, along with any institutional change altering the balance of power in favour of workers, would lead to better results in terms of both income distribution and long-run performance of the economy. Provided that wages and profits are unequally distributed across individuals, a pro-labour distributive strategy reduces personal income inequality while stimulating economic growth and labour productivity.

Yet, a pro-labour distributive strategy may be detrimental for employment in the long run. Improving the bargaining power of workers results in a lower employment rate if the economy exhibits a short-run profit-led demand and growth regime. Furthermore, conditional on institutional shocks, the employment rate may be decreasing in the labour share even in a wage-led demand regime, if labour productivity growth is highly responsive to income distribution. Therefore, a pro-labour distributive policy does not emerge as an effective tool to counteract long-run unemployment, despite the positive effect on capital accumulation and labour productivity growth.

Differently from institutional shocks, the impact of positive exogenous shocks on labour productivity growth on the long-run rate of growth relies entirely upon Kaleckian mechanisms, since they are dependent on the assumption of an endogenous rate of capacity utilization and the short-run demand and growth regime of the economy. Technology shocks reduce the long-run labour share, thus long-run capital accumulation and labour productivity growth are decreasing in the labour share, conditional on technology shocks, if the economy exhibits a wage-led growth regime in the short run. Accordingly, if capital accumulation comoves positively with the labour share in the short run, improving the bargaining strength of workers emerges as an ambiguously better strategy than stimulating labour productivity growth exogenously.

However, in the present model we have only examined the role of institutional factors affecting the labour share, while other drivers of labour productivity growth are left unexplained. Thus, more work is needed to provide a more complete view of the interaction between income distribution, capital accumulation, and labour productivity growth. This analysis is left for future research.

APPENDIX A

Taking logarithms of $\dot{u} = g^i - g^s$ with (4) and (7) and differentiating with respect to time, we find:

$$\frac{\dot{\pi}}{\pi} + \frac{\dot{u}}{u} = \frac{G'_u \dot{u} + G'_\pi \dot{\pi} + G'_k \dot{k}}{G(u, \pi, k, \gamma)} \tag{A1}$$

After rearranging the terms:

$$\frac{\dot{u}}{u} = \left[\frac{G'_\pi \pi - G(u, \pi, k, \gamma)}{G(u, \pi, k, \gamma) - G'_u u}\right] \frac{\dot{\pi}}{\pi} + \left[\frac{G'_k k}{G(u, \pi, k, \gamma) - G'_u u}\right] \frac{\dot{k}}{k} \tag{A2}$$

Thus, $\dot{\pi}/\pi = \dot{k}/k = 0$ implies $\dot{u}/u = 0$. Since $e = uk$, it immediately follows that $\dot{e}/e = \dot{u}/u + \dot{k}/k = 0$.

APPENDIX B

Differentiating equations (27) and (28) with respect to ω, we find:

$$h'_e \left(e'_k \left.\frac{dk}{d\omega}\right|_\Omega + e'_\omega \right) - f'_\omega = 0 \tag{B1}$$

$$g'_\omega + g'_k \left.\frac{dk}{d\omega}\right|_X - f'_\omega = 0 \tag{B2}$$

After rearranging the terms, we have:

$$\left.\frac{dk}{d\omega}\right|_\Omega = -\frac{h'_e e'_\omega - f'_\omega}{h'_e e'_k} \tag{B3}$$

$$\left.\frac{dk}{d\omega}\right|_X = -\frac{g'_\omega - f'_\omega}{g'_k} \tag{B4}$$

Accordingly, $dk/d\omega|_\Omega > 0$ if and only if $h'_e e'_\omega < f'_\omega$, whereas $dk/d\omega|_X > 0$ if and only if $g'_\omega > f'_\omega$. Differentiating equation (27) with respect to α, we find:

$$\left.\frac{\partial k}{\partial \alpha}\right|_\Omega = -\frac{h'_\alpha}{h'_e e'_k} < 0 \tag{B5}$$

Differentiating equations (27) and (28) with respect to τ, we find:

$$\left.\frac{\partial k}{\partial \tau}\right|_\Omega = \frac{f'_\tau}{h'_e e'_k} > 0 \tag{B6}$$

$$\left.\frac{\partial k}{\partial \tau}\right|_X = \frac{f'_\tau}{g'_k} < 0 \tag{B7}$$

APPENDIX C

Since we have that $e'_\omega = u'_\omega k$, $e'_k = u'_k k + u$, $e'_s = u'_s k$, and $e'_\gamma = u'_\gamma k$, total differentiation of $u(\omega, k, s, \gamma)$ evaluated at the equilibrium point with respect to α, τ, n, s, and γ, after using equations (41), (42), (47), (48), (51), (52), (56), (57), (60), and (61), yields:

$$\frac{du^{**}}{d\alpha} = \frac{[(g'_\omega - f'_\omega)u'_k - g'_k u'_\omega]h'_z}{\Gamma} \tag{C1}$$

$$\frac{du^{**}}{d\tau} = \frac{[(g'_k - h'_e u)u'_\omega - g'_\omega u'_k]f'_\tau}{\Gamma} \tag{C2}$$

$$\frac{du^{**}}{dn} = -\frac{h'_e u u'_\omega + u'_k f'_\omega}{\Gamma} \tag{C3}$$

$$\frac{du^{*}}{ds} = -\frac{(g'_k u'_s - u'_k g'_s)f'_\omega - [u'_\omega g'_s - (g'_\omega - f'_\omega)u'_s]h'_e u}{\Gamma} \tag{C4}$$

$$\frac{du^{*}}{d\gamma} = \frac{(u'_k g'_\gamma - g'_k u'_\gamma)f'_\omega + \left[u'_\omega g'_\gamma - (g'_\omega - f'_\omega)u'_\gamma\right]h'_e u}{\Gamma} \tag{C5}$$

Wage inequality and induced innovation in a classical-Marxian growth model

Marco Stamegna*

Abstract The present paper works out a classical-Marxian growth model with an endogenous direction of technical change and a heterogeneous labour force, made up of high-skilled and low-skilled workers. It draws on the Kaleckian mark-up pricing to link wage inequality to the relative unit labour cost at a firm level; on growth cycle models *à la* Goodwin to formalize the dynamic interaction between labour market and distributive shares of income; on the induced innovation literature to link the bias of technical change to the firm's choice of the optimal combination of factor-augmenting technologies. We assume that economic growth is constrained by the growth rate of the high-skilled effective labour supply, whereas the low-skilled labour supply is perfectly elastic. Thus, we develop a three-dimensional system of differential equations for the output-capital ratio, the relative unit labour cost and the employment rate of the high-skilled workers, and investigate the stability and the main properties of the steady-state equilibrium. We find that, in contrast to the neoclassical literature on skill-biased technical change, the institutional framework governing the conflict over income distribution is the ultimate determinant of both wage inequality and the direction of technical change. A decline in low-skilled workers' bargaining strength or a rise in product market concentration lead to both an increase in wage inequality and a bias of technical change favouring high-skilled over low-skilled labour productivity growth. As opposed to the Goodwin model with induced technical change and homogeneous labour force, labour market institutions thus affect steady-state income distribution, capital accumulation and labour productivity growth, and no necessary trade-off arises between labour market regulation and employment. Finally, if the steady-state value of wage inequality exceeds a critical value, an exogenous increase in the mark-up or in the high-skilled workers' bargaining power allow both capitalists and high-skilled workers to increase their income shares at the expense of the low-skilled workers.

Keywords Wage inequality, growth, distribution, endogenous technical change

JEL classification D33, E11, E24, O33

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1. INTRODUCTION

Over the past decades, the US and the major European economies experienced a sharp rise in personal income inequality. This was the result of a decline in the labour share in income, an increase in the income share accruing to the top 1% of income recipients, and an increase in personal income inequality within the bottom 99% of the income spectrum. The rise in inequality at the very top of income distribution reflects the growth of executive compensation, the expansion of the financial sector, and the income redistribution from wages to profits. Outside the top 1%, the increase in personal income inequality is a result of rising wage dispersion between high-wage and low-wage earners (Piketty and Saez, 2003; Piketty, 2014; Mishel and Bivens, 2021).

The neoclassical approach to skill-biased technical change and human capital explains the trend of intra-working-class income distribution through the lenses of relative factor scarcity. According to this interpretation, the distribution of wages is shaped by the interaction between relative demand and relative supply of skills. Since, in the absence of exogenous shifts in the relative demand, the large increase in the relative supply of high-skilled labour that occurred over the last decades would have reduced the skill premium, neoclassical authors deduce that technical change must have been skill-biased.

The standard explanation for skill-biased technical change invokes the concept of "capital-skill complementarity". As capital is supposed to be more complementary to high-skilled labour than to low-skilled labour, the decline in the price of capital goods due to innovations in information and communication technologies would have caused firms to adopt more capital-intensive technologies and to substitute away from low-skilled labour. The implication is that an increase in the capital stock would lead to a constant rightward shift in the relative demand for high-skilled labour. Wage inequality between high-skilled and low-skilled workers would then rise, unless the increase in the supply of human capital keeps up with the pace of skill-biased technical change (Tinbergen, 1975; Katz and Autor, 1999; Krusell, *et al.*, 2000; Card and Lemieux, 2001; Goldin and Katz, 2008). Therefore, in a perfectly-competitive framework, the only role for policy is to make the relative endowment of high-skilled labour be "less scarce", namely to implement educational policies aiming to upgrade workers' skills (Goldin and Katz, 2008; Acemoglu and Autor, 2012). Besides reducing wage inequality, investment in human capital is supposed to be a central determinant of economic growth (Uzawa, 1965; Lucas, 1988; Acemoglu, 2009; Aghion and Howitt, 2010). In a non-perfectively competitive framework, other institutional factors like the decline in unionization and the decentralization of collective bargaining are argued to interact with skill-biased technical change in determining labour market outcomes. However, the role of labour market institution is explicitly neglected as a direct cause of changes in wage inequality. By altering the effectiveness of union activity or the internal organization of firms, labour market institutions may at most amplify the direct effect of skill-biased technical change on income distribution (Lindbeck and Snower, 1996; Acemoglu, *et al.*, 2001; Acemoglu, 2002b; Hornstein, *et al.*, 2005; Ortigueira, 2013).[1]

From a classical-Marxian standpoint, the conventional debate on wage inequality is largely unsatisfactory, because it ignores the role of the conflict over income distribution among social classes in determining the direction of technical change. In this view, induced technical change is

[1] Even changes in wage dispersion among workers with the same educational level are ultimately ascribed to a purely technological process, with no room for labour market institutions, as residual inequality is supposed to reflect returns to unobserved individual abilities (Nelson and Phelps, 1966; Card and Lemieux, 1996; Acemoglu, 2002b; Violante, 2002; Lemieux, 2006). Some neoclassical authors acknowledge that institutional factors like unionization, the degree of centralization of wage bargaining, and employment protection legislation affect labour market outcomes (see, for instance, Koeniger, *et al.*, 2007; Checchi and García-Peñalosa, 2008), but they don't investigate the role of labour market institutions jointly with skill-biased technical change.

regarded as a "weapon" of capitalists in the class conflict for breaking the bargaining power of the working class. An increase in unit labour cost stimulates labour-saving innovations, since replacing workers with machines allow capitalists to regenerate the reserve army of labour and restore profitability. Thus, labour productivity growth is an increasing function of the labour share, namely the counterpart of unit labour cost at a macro level (Marx, 1976; Brugger and Gehrke, 2018; Tavani and Zamparelli, 2018; Foley, *et al.*, 2019).

The present paper extends the classical-Marxian approach to induced innovation to the case of a heterogenous labour force, made up of high-skilled and low-skilled workers. It works out a classical growth model of a high-skilled-labour-constrained economy, based on a Kaleckian mark-up pricing, on a Goodwin-type interaction between labour market dynamics and income distribution, and on the induced innovation literature as a way to formalize endogenous cost-driven technical change. Since the direction of technical change is determined by the shares of high-skilled labour and low-skilled labour in total costs, high-skilled labour productivity growth turns out to be an increasing function of the high-skilled labour share in income, and low-skilled labour productivity growth becomes an increasing function of the low-skilled labour share.

In contrast to the conventional wisdom, we show that both wage inequality and the direction of technical change are jointly determined by the institutional and political factors affecting the conflict over income distribution between capitalists and (heterogeneous) workers. A fall in the low-skilled workers' bargaining strength or an increase in product market concentration are conducive to both an increase in wage inequality and an induced bias of technical change favouring high-skilled over low-skilled labour productivity growth. Thus, labour market institutions and product market regulation are found to play a relevant role in both the search for new techniques and the shape of long-run income distribution. The causality direction among technology, institutions and wage inequality predicted by the neoclassical authors is reversed. In a standard neoclassical framework, the distribution of wages is shaped by technological factors, and labour market institutions only act as a mediating factor between skill-biased technical change and wage inequality. Conversely, in the proposed framework, institutional factors related to labour market regulation affect wage inequality both directly, by altering the relative bargaining positions of high-skilled and low-skilled workers in the labour market, and indirectly, by inducing different rates of high-skilled- and low-skilled-labour-augmenting technologies. As the different growth rates of high-skilled and low-skilled labour productivity are totally passed through to real wages at the steady state, it is technical change that acts as a mediating factor between labour market institutions and income distribution. Thus, changes in the institutional framework governing the distributive conflict are the primary cause of changes in wage inequality.

We show that, in the presence of a high level of wage inequality, an increase in the bargaining power of the high-skilled workers, as compared to the low-skilled workers, or an exogenous increase in the mark-up allow both capitalists and high-skilled workers to raise their income shares at the expense of the low-skilled workers. Moreover, in contrast to both the conventional wisdom and the Goodwin model with induced technical change and homogenous labour force, no necessary trade-offs arise between labour market regulation and employment in the long run. An increase in the bargaining power of a fraction of the working class needs not imply employment losses, particularly in the presence of a high level of wage inequality.

The remainder of this paper is organized as follows. Section 2 provides an extensive discussion of the related literature and the main contributions of this paper. Section 3 proposes a theoretical model and derives the basic equations for the analysis. Section 4 discusses the characteristics of the dynamical system and the steady state. Section 5 derives the necessary and sufficient conditions for the local stability of the equilibrium. Section 6 details the main results of comparative statics analysis. Section 7 then concludes.

2. Related literature

The present paper relates to different strands of literature. First, the goods market is formalized along classical-Marxian lines. A distinctive feature of this approach is the close connection between capital accumulation and the conflict over income distribution among social classes. Capitalists own the capital stock of the economy and are supposed to have a larger propensity to save than workers, as a large fraction of profits is retained for investment purposes. Class-based saving behaviour implies that changes in functional income distribution affect capital accumulation. In its simplest formulation, i.e. the case of an exogenous real wage rate and constant technical coefficients of production, a classical-Marxian growth model consists of a system of four equations in four variables: (i) an inverse relationship between profit rate and real wage rate, for given labour productivity and output-capital ratio; (ii) an inverse relationship between capital accumulation and consumption per employed worker; (iii) a positive relationship between capital accumulation and profit rate, for a given propensity to save; (iv) a distributional closure stating that the real wage rate is set at the (socially and historically determined) subsistence level. The profit rate, that is, what is left after workers are paid their subsistence real wage, determines the equilibrium capital accumulation and hence the equilibrium consumption per worker. Thus, the validity of Say's law in its classical version is assumed: all savings are invested to increase the capital stock of the economy, so that no problems of lack of effective demand arise in the long run.[2] However, the assumption of a fixed-coefficients production function implies that even in a one-sector economy there is no spontaneous tendency towards full employment of labour (Kurz and Salvadori, 1995; 2003; Blecker and Setterfield, 2019).[3]

In this paper, I modify the basic classical-Marxian model in order to include endogenous technical change, a Kaleckian mark-up pricing, and heterogeneity in skill levels across workers. The model economy includes three distinct social classes with different saving behaviour: capitalists, high-skilled workers and low-skilled workers. The high-skilled labour real wage rate is supposed to be greater than the low-skilled labour real wage rate, since the acquisition of skills allow high-skilled workers to have both higher productivity and stronger bargaining power than low-skilled workers. Only the growth rate of the low-skilled workers' nominal wage is fully exogenous, whereas the growth rate of the high-skilled workers' nominal wage is made to depend on the high-skilled employment rate. The assumption that firms set the price by charging a mark-up over unit labour cost implies that the income shares of the three classes in the economy are anchored to the mark-up and to the relative unit labour cost. Thus, the Kaleckian mark-up pricing provides a link between the micro level of the firm's price-setting decisions and the macro level of income distribution. A rise in the mark-up affects functional income distribution, since it implies income redistribution from wages to profits, whereas an increase in the relative unit labour cost only worsens the intra-working-class distribution of wages. The endogenization of technical change gives back a steady-state growth path

[2] However, the relation between the role of effective demand and the classical-Marxian approach to economic growth is more problematic than it appears in the simplified theoretical framework presented here. It has been argued that if one allows aggregate demand to affect the short-run equilibrium of an economy, it is only in special cases that the long-run equilibrium can be taken as totally independent of effective demand in classical growth models (Dutt, 2011).

[3] Post-Keynesian growth models reverse the causality direction between profit rate and capital accumulation predicted by the classical authors. With an independent investment function, the profit rate is determined by capital accumulation, as well as by the exogenous propensity to save out of profits. In the Kaleckian approach, that was adopted to formalize the short-run equilibrium of the economy in Chapter I, the assumption of an endogenous rate of capacity utilization allows the profit rate and the profit share to move in opposite directions. Thus, Kaleckian models can generate different demand and growth regimes, whereas classical-Marxian models only allow for a "profit-led" growth regime. This implies that the classical-Marxian approach and the post-Keynesian theories of distribution and growth can be considered as different model closures of the same class-based framework for analyzing the issue of economic growth. For a survey of the heterodox models in this sense, see Hein (2017) or Dutt (2018).

characterized by high-skilled- and low-skilled-labour-augmenting technical change, along with a constant output-capital ratio.

The classical-Marxian tradition has investigated the implications of two alternative distributional closures: (i) a closure with exogenous income distribution, in which an infinitely elastic labour supply always accommodates labour demand at a constant real wage rate or a constant wage share; (ii) a closure with endogenous income distribution, in which the distributive variable adjusts so as to maintain a constant employment rate in the long run. Closure (i) is considered a realistic assumption for both a dual economy in the sense of Lewis (1954), in which a rising industrial sector can always draw workers from the substantially unlimited reserve of labour of the rural sector, and a mature economy with a loose immigration policy, in which the traditional sector has depleted its pool of labour but foreign labour inflows preserve the economy from labour scarcity. Closure (ii) is typically adopted for a mature industrialized economy in which foreign labour inflows are not available to accommodate labour demand, and capital accumulation responds to signals from both goods and labour markets. This closure corresponds to the case of a labour-constrained economy, where the supply side imposes a binding constraint to the demand side of the labour market, and economic growth is constrained by the growth rate of effective labour supply (Skott, 2010; Tavani and Zamparelli, 2016; 2018; Foley, *et al.*, 2019).[4]

In this paper, I adopt a slightly modified version of both closures (i) and (ii). The growth rate of the low-skilled workers' nominal wage is supposed to be exogenously determined by the institutional and political factors that affect the low-skilled workers' bargaining strength. Thus, low-skilled labour supply is perfectly elastic and always accommodates low-skilled labour demand, irrespective of the real wage rate or the income share that low-skilled workers are able to attain in the distributive conflict. Conversely, the mechanism of wage formation of the high-skilled workers is assumed to be described by a nominal Phillips curve, that relates the growth rate of the high-skilled workers' nominal wage to the high-skilled employment rate. A constant high-skilled employment rate in the long run implies that the economy is high-skilled-labour constrained: capital accumulation is constrained by the growth rate of the high-skilled effective labour supply. The rationale for this assumption is that the acquisition of high skills involves some costly activity, either for the individual or for the government, that does not make high-skilled labour supply be immediately available to accommodate high-skilled labour demand. Thus, the growth rate of high-skilled labour supply imposes a binding constraint to the demand side of the labour market. Conversely, individuals can always acquire low skills costlessly, so that not even an advanced economy faces a supply-side constraint in the low segment of the labour market. However, in contrast to closure (ii) with constant technical coefficients of production, and like all classical growth models with induced technical change, it is the output-capital ratio, rather than the distributive variable, that adjusts so as to keep the employment rate constant in the long run.

Second, this paper relates to the induced innovation literature. The core idea of the induced innovation theory is that technical change is cost-driven, that is, the direction of technical change is determined by the relative size of the labour and capital shares in total costs. An increase in unit labour cost is then supposed to foster labour productivity growth.

Neoclassical authors have interpreted the concept of induced innovation as technical change being driven by relative factor endowments (Brugger and Gehrke, 2017). This interpretation dates back to Hicks's (1932) claim that a change in relative input prices stimulates innovations that use more of the factor that has become relatively more scarce. An increase in the capital stock of the economy, by raising the wage-interest ratio, would then induce a labour-saving direction of technical change. The concept of induced technical change has been formalized by Kennedy (1964) and

[4] This does not imply that the economy will achieve full employment of labour, but only that the economy will grow at the full-employment growth rate, i.e. the growth rate compatible with a constant employment rate in the long run.

Samuelson (1965) by means of a decreasing and concave "innovation possibility frontier", that represents the set of feasible combinations of factor-augmenting technologies. A profit-maximizing firm will choose the direction of technical change so as to maximize the rate of unit cost reduction given the constraint of the innovation possibility frontier. Thus, labour productivity growth turns out to be an increasing function of the wage share. However, the induced innovation theory has been proved inconsistent with the neoclassical approach to factor-pricing in a perfectly competitive framework.[5] If all factors are paid to their marginal productivities, a change in relative factor prices will not induce a particular direction of technical change (Salter, 1960).

Within the classical-Marxian tradition, induced technical change is regarded as an instrument in the hands of capitalists in the class conflict. By replacing workers with machines, capitalists actively search for innovations that allow them to reduce the bargaining power of the working class or a fraction of it (Brugger and Gehrke, 2018). As capital and labour are not treated as symmetric productive factors, the induced innovation theory is not affected by the conceptual criticisms raised by neoclassical authors. Moreover, a microfoundation of technical change based on the innovation possibility frontier has been widely adopted by the classical-Marxian literature, as the maximization of the rate of unit cost reduction is equivalent to the maximization of the rate of change in the profit rate, and hence is consistent with the Okishio (1961) rule for viable innovations of the classical analysis of the choice of techniques (Shah and Desai, 1981; van der Ploeg, 1987; Foley, 2003; Julius, 2005; Rada, 2012; Tavani, 2012; 2013; Zamparelli, 2015).[6] If the induced innovation hypothesis is integrated into a balanced growth model, income distribution is determined only by the shape of the innovation possibility frontier, and income shares adjust in order to ensure a Harrod-neutral direction of technical change in the long run (Tavani and Zamparelli, 2018; Foley, *et al.*, 2019).

In this paper, I modify the standard innovation possibility frontier in order to allow firms to choose among high-skilled-labour-, low-skilled-labour- and capital-augmenting technologies. The solution of the firm's maximization problem implies that a fall in the mark-up positively affects both high-skilled- and low-skilled-labour-saving innovations, while an increase in wage inequality favours high-skilled- over low-skilled-labour-saving technologies. In contrast to the basic classical growth model with induced innovation, the long-run value of the distributive variable is not determined only by the dynamic equation of the output-capital ratio, and both the distributive variable and the (high-skilled) employment rate adjust in order to stabilize the output-capital ratio in the long run. Moreover, the steady-state growth path is characterized by both high-skilled- and low-skilled-labour-augmenting technical change.

Third, this paper relates to the Goodwin (1967) model of growth cycle. As is well known, this model provides a formalization of Marx's account of the class conflict over income shares, based on the Lotka-Volterra equations for predator-prey population dynamics. It consists of two dynamic equations for the labour share and the employment rate, which describe closed orbits around the equilibrium values of the two variables. The non-trivial equilibrium solution corresponds to the long-

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[5] The more recent literature on directed technical change can be considered as a neoclassical attempt to overcome these criticisms, by combining an endogenous direction of technical change with production of capital goods under monopolistic competition (Acemoglu, 2003; 2015). According to this literature, the direction of technical change responds to the profitability incentives of capital goods producers. As intermediate and final goods producers use both capital and (high-skilled and low-skilled) labour inputs, the decision of a profit-maximizing firm producing capital goods will be affected by the relative price and the relative endowment of high-skilled labour in the economy. The implication is that the development of high-skilled labour complementary technologies is induced by the rising supply of high-skilled labour itself. Thus, when the directed technical change approach is applied to skill-biased technical change, neoclassical authors conclude that, in contrast to the induced innovation hypothesis, technical change will be biased towards the relatively more abundant factor (Acemoglu, 2002a; 2002b).

[6] Duménil and Lévy (1995; 2003) frame the firm's choice of techniques in a stochastic set-up. Other authors simply postulate a positive dependence of labour productivity growth on the wage share at a macro level, and the output-capital ratio is assumed to be constant even along the transition path. See, for instance, Dutt (2013).

run values of income distribution and employment in a classical-Marxian model of a labour-constrained economy with exogenous labour productivity growth and exogenous labour supply growth. Thus, the Goodwin model can be interpreted as a description of the short-run cyclical dynamics of the wage share and the employment rate around a long-run trend which is mainly the product of structural and institutional changes (Veneziani and Mohun, 2006; Mohun and Veneziani, 2008; Fiorio, *et al.*, 2013).

The original model has been extended in many directions. Most notably, some authors have explored the dynamic and steady-state implications for the growth cycle of the introduction of the induced innovation hypothesis. As emphasized by Shah and Desai (1981) and van der Ploeg (1987), induced technical change gives capitalists an additional weapon in the class conflict, other than reducing investment, to regenerate the reserve army of labour and restore profitability, thus making the equilibrium be locally stable. As a result, the labour share and the employment rate converge towards the steady state with oscillations of decreasing amplitude (Foley, 2003). The integration of the induced innovation hypothesis into the Goodwin model implies that the steady-state employment rate adjusts to the level consistent with the labour share determined by the shape of the innovation possibility frontier at the intercept. Therefore, as Tavani and Zamparelli (2015) and Zamparelli (2015) point out, by introducing an explicit policy variable into the model, it can be shown that an increase in workers' bargaining strength only reduces the employment rate, while leaving income distribution, capital accumulation and labour productivity growth unaffected.

Some recent contributions have explored the channels through which labour market institutions may affect long-run income distribution, employment, capital accumulation, and labour productivity growth in the Goodwin model of growth cycle with induced technical change. Julius (2005) finds that if labour market institutions allow for a partial pass-through of labour productivity growth to the real wage, and the wage-setting process is internalized by the firm in its choice of techniques, the workers' bargaining power has a positive effect on the long-run wage share. Tavani (2012; 2013) find that if the wage-bargaining process takes the form of a strategic interaction *à la* Nash, labour market institutions have a positive effect on labour productivity growth, but no effect on steady-state income distribution and a negative effect on long-run employment. Tavani and Zamparelli (2015) show that if firms face a trade-off between investing in capital accumulation and investing in R&D expenditure for labour-saving innovations, and the position of the innovation possibility frontier is endogenous to the amount of R&D investment, an increase in workers' bargaining strength leads to an increase in the long-run wage share at the expense of employment and capital accumulation. Cruz Luzuriaga and Tavani (2021) find that the steady-state wage share, capital accumulation, and labour productivity growth turns out to be increasing in the workers' bargaining power, and the steady-state employment rate may be positively related to the wage share, if labour market institutions are formalized as an exogenous parameter affecting both the innovation possibility frontier and the real Phillips curve. Zamparelli (2021) argues that labour market institutions may have long-run distributional effects only by changing the trade-off between capital- and labour-saving innovations, namely the slope of the innovation possibility frontier at the intercept.

In this paper, I address the issue of the steady-state effects of labour market institutions in an economy with a heterogenous labour force and a Goodwin-like dynamic interaction between labour market and income shares. The model includes two distributive variables: the mark-up, representing functional income distribution, and the relative unit labour cost, which is equivalent to the ratio of the high-skilled labour share to the low-skilled labour share. As the economy is high-skilled-labour constrained, the antagonistic relationship between capital and labour over income distribution is formalized by assuming a negative response of profitability to the high-skilled employment rate and a nominal Phillips curve for the wage formation of the high-skilled workers. The negative response of the mark-up to the high-skilled employment rate is internalized by the firm in its choice of techniques. The dynamics of wage inequality is affected by the growth rates of nominal wages of high-skilled and low-skilled workers. Thus, the dynamic equation for the wage share of the standard Goodwin model is replaced by a dynamic equation for wage inequality, whereas a dynamic equation for employment is defined only for the high-skilled workers. As in Nishi (2020), the gap between nominal wage growth and labour productivity growth is reflected in the inflation rate. I find that, in contrast to the standard Goodwin model with induced innovation, labour market institutions affect steady-state income distribution, capital accumulation and labour productivity growth. Moreover, an increase in the bargaining strength of a fraction of the working class needs not imply employment losses, particularly in the presence of a high level of wage inequality.

Finally, this paper relates to the more recent non-neoclassical research agenda on the interaction between wage inequality, personal income distribution and economic growth. The basic classical-Marxian and post-Keynesian models of distribution and growth have been extended in three directions. First, some authors have developed two-class models in which workers are allowed to own a share of the capital stock of the economy (Dutt, 2017; Palley, 2017a; 2017b), the propensity to save out of wages is affected by wage inequality (Carvalho and Rezai, 2015; Prante, 2018; Hein and Prante, 2020), or workers' saving behaviour is determined by relative consumption concerns (Kapeller and Schütz, 2014; 2015). These contributions show that even a profit-led economy may be equality-led, as the reduction in wage inequality or an increase in the workers' share of capital stock have an expansionary effect on output growth, and that the demand regime of an economy is endogenous to the level of wage or wealth inequality. Second, some authors have proposed three-class models that incorporate a middle class, in the form of managers or supervisory workers, that is located in between capitalists and ordinary workers (Lavoie, 2009; Tavani and Vasudevan, 2014; Palley, 2015a; 2015b). Building on the Marxian distinction between productive and unproductive labour,[7] managers are assumed to be rewarded according to their capability to extract surplus from ordinary workers. Thus, these models describe the additional dimensions of the conflict over income distribution in advanced economies, while maintaining the wage-profit divide as the main distinctive feature of the capitalist class structure. Third, some contributions, that are the closest references of this paper, have explicitly integrated the concept of "human capital" into Kaleckian and classical-Marxian growth models, often splitting the working class into high-skilled and low-skilled workers. Carvalho, *et al.* (2019), and Lima, *et al.* (2019), show that if growth is demand-led, the economy typically operates with excess "knowledge capacity". Then, the presence of overeducation in the labour market is the result of a lack of effective demand, and it cannot be ascribed to an occupational mismatch between demand and supply of skills. Dutt (2010), and Dutt and Veneziani (2011; 2019; 2020) find that, in contrast to the conventional wisdom, educational policies may have an expansionary effect on output growth only by altering income distribution among social classes, rather than by spurring technical change. Moreover, the effect on wage inequality is dependent on the qualitative properties of the education system: a regressive education may weaken intra-working-class solidarity and socialize workers into legitimate income inequality.

To the best of my knowledge, none of the recent contributions in classical-Marxian and post-Keynesian traditions expressly addresses the issue of the joint determination of wage inequality and direction of technical change. In Dutt (2010), and Dutt and Veneziani (2011; 2019; 2020), the productivity gap between high-skilled and low-skilled labour is exogenous, hence skill-biased technical change is ruled out by assumption. In Lima, *et al.* (2019), labour productivity growth is endogenous and linked to the government expenditure on education, but human capital is uniformly distributed across workers. Neto and Ribeiro (2019) develop a Kaleckian model of the process of technological catching-up in developing economies with skill-biased technical change, but limit themselves to assume that technical change raises productivity gaps. Other authors do not include

[7] On the notion of "unproductive labour" in the Marxian literature and for an empirical application to the US economy, see Mohun (2014) and Duménil and Lévy (2015).

technical change at all. The main contribution of this paper is to fill this gap in the literature, and to link the recent research agenda on wage inequality and personal income distribution to the induced innovation literature. Thus, while the line of research on human capital investigates the determinants and the macroeconomic effects of the supply of skills, this paper addresses the issue from the demand side, namely how demand for skills is affected by technical change and labour market institutions.

3. THE STRUCTURE OF THE MODEL

3.1. PRODUCTION, INCOME DISTRIBUTION, AND EMPLOYMENT

Consider a closed economy with no government, in which only one good is produced with three inputs, low-skilled labour, high-skilled labour and a non-depreciating capital. There are three social classes: capitalists, who own the economy's capital stock and receive profits; high-skilled workers, that inelastically supply one unit of high-skilled labour in each period and receive a high-skilled wage; low-skilled workers, that inelastically supply one unit of low-skilled labour in each period and receive a low-skilled wage. The relation between inputs and the homogenous output is represented by a Leontief production function:

$$Y = \min\{a_L L, a_H H, a_K K\} \tag{1}$$

where Y denotes actual output in real terms; L, low-skilled labour employed in production; H, high-skilled labour; K, capital; $a_L = Y/L$, low-skilled labour productivity; $a_H = Y/H$, high-skilled labour productivity, with $a_H > a_L$; and $a_K = Y/K$, the output-capital ratio. The assumption of a fixed-coefficients production function implies that demands for low-skilled labour, high-skilled labour and capital are inelastic to input prices, and one or more inputs may not be fully employed.

Denoting the low-skilled nominal wage by w_L, the high-skilled nominal wage by w_H, the profit rate on capital stock by $r = \pi a_K$, where π is the profit share, the price by p, national income in real terms is given by:

$$Y = \frac{w_L}{p} L + \frac{w_H}{p} H + rK \tag{2}$$

We assume that $w_H > w_L$, which is consistent with the evidence that the higher labour productivity of high-skilled workers translates into a higher nominal wage.

National income accrues to the three social classes in the economy. We assume that capitalists save all their income, high-skilled workers have propensity to save $s \in (0,1)$, low-skilled workers devote all their income to consumption. In line with the classical tradition, capitalists have a higher propensity to save than workers, as the functional nature of profits implies that a large fraction of profits is retained for investment purposes. High-skilled workers have a higher propensity to save than low-skilled workers, consistently with the absolute income hypothesis that the propensity to save of high income individuals exceeds the propensity to save of low income earners (Keynes, 1936).

Firms set the price by charging a fixed mark-up (μ) over unit labour cost:

$$p = \left(\frac{w_H}{a_H} + \frac{w_L}{a_L}\right)(1 + \mu) = \frac{w_L}{a_L}(1 + z)(1 + \mu) \tag{3}$$

where the relative unit labour cost z is defined by:

$$z \equiv \frac{w_H a_L}{w_L a_H} \tag{4}$$

The mark-up pricing allows anchoring the macro level of income distribution to the micro level of the firm's price-setting decisions. From equations (2) and (3), we can define income distribution as follows:

$$\omega_H = \frac{w_H}{pa_H} = \frac{z}{(1+\mu)(1+z)} \tag{5}$$

$$\omega_L = \frac{w_L}{pa_L} = \frac{1}{(1+\mu)(1+z)} \tag{6}$$

$$\pi = 1 - \frac{w_L}{pa_L} - \frac{w_H}{pa_H} = \frac{\mu}{1+\mu} \tag{7}$$

where ω_H, ω_L and π are the income shares of high-skilled workers, low-skilled workers and capitalists, respectively.

The mark-up μ and the relative unit labour cost z are the key distributive variables of the model. From equation (4), or equations (5) and (6), we have $z = \omega_H/\omega_L$. Thus, an increase in μ only affects functional income distribution, as it implies an increase in the profit share, while leaving wage inequality unaltered. An increase in z only affects the distribution of wages, as it implies an increase in the high-skilled workers' wage share at the expense of the low-skilled workers, while leaving functional distribution unchanged.

Along classical-Marxian lines, we assume that savings are identically equal to investment. Thus, the growth rate of the capital stock is identically equal to the ratio of savings to the capital stock:

$$g \equiv \frac{I}{K} \equiv \frac{S}{K} = \frac{1}{1+\mu}\left(\mu + \frac{sz}{1+z}\right) a_K \tag{8}$$

The actual output is then assumed to be at its potential level, determined by the full utilization of the productive capacity of the economy. However, the assumption of a fixed-coefficients production function (equation (1)) still allows for unemployment of high-skilled and low-skilled labour.

At each point in time, high-skilled labour supply is $N = N_0 e^{nt}$, where N_0 denotes the initial value of high-skilled labour supply and $n > 0$ denotes the exogenous growth rate of N. Low-skilled labour supply is supposed to be infinitely elastic. The rationale for these assumptions is that the acquisition of a high level of skills requires some costs, either for the individual or for the government, so that the growth rate of high-skilled labour supply imposes a constraint to the growth rate of high-skilled labour demand. Conversely, an individual can always acquire the minimum level of skills required by the labour market with no costs, so that an economy with a pool of unemployed workers does not face a supply-side constraint in the low segment of the labour market.

From equation (1), the high-skilled employment rate e is given by:

$$e = \frac{a_K K}{a_H N} \tag{9}$$

The growth rate of the high-skilled workers' nominal wage is assumed to be an increasing function of the high-skilled employment rate e and an exogenous variable α:[8]

$$\hat{w}_H = h(e, \alpha), \quad h'_e > 0, \; h'_\alpha > 0 \tag{10}$$

[8] For any variable x, $\dot{x} = dx/dt$ and $\hat{x} = \dot{x}/x$.

Equation (10) formalizes the Marxian profit-squeeze mechanism with a nominal Phillips curve, as in Desai (1973), limited to the high-skilled workers. We interpret the exogenous variable α in a broad sense as a parameter that captures all institutional factors favouring the high-skilled workers' bargaining power.

The growth rate of the low-skilled workers' nominal wage is equal to an exogenous variable β:

$$\hat{w}_L = \beta, \qquad \beta > 0 \tag{11}$$

The exogenous variable β represents all institutional factors that positively affects the low-skilled workers' bargaining strength in the conflict over income distribution.

The mark-up set by the firm is supposed to be a decreasing function of the high-skilled employment rate e and an increasing function of an exogenous variable γ:

$$\mu = \mu(e, \gamma), \qquad \mu'_e < 0, \mu'_\gamma > 0 \tag{12}$$

Equation (12) postulates that an increase in labour market tightness, which is measured by the employment rate of the high-skilled workers, has a negative effect on profitability. The exogenous variable γ is an institutional parameter representing an exogenous measure of product market concentration.

3.2. Direction of technical change

We generalize the induced innovation hypothesis (Kennedy, 1964; Samuelson, 1965; Foley, 2003) in order to consider a heterogeneous labour force, and consequently technical change directed towards high-skilled or low-skilled labour. As firms face a trade-off in their choice of techniques, the set of feasible combination of factor-augmenting technologies can be summarized by a continuous, decreasing and concave innovation possibility frontier in a three-dimensional space:

$$\hat{a}_K = \phi(\hat{a}_H, \hat{a}_L, \tau), \qquad \phi'_{\hat{a}_H} < 0,\ \phi'_{\hat{a}_L} < 0,\ \phi''_{\hat{a}_H\hat{a}_H} < 0,\ \phi''_{\hat{a}_L\hat{a}_L} < 0,\ \phi''_{\hat{a}_H\hat{a}_L} = 0,\ \phi'_\tau = 1 \tag{13}$$

where the assumption of a null cross derivative is made for the sake of simplicity and without loss of generality.

Firms maximize the rate of unit cost reduction, or equivalently the rate of change in the profit rate (Julius, 2005), given the constraint of the innovation possibility frontier, taking into account the negative response of profitability to labour market tightness:

$$\max_{\hat{a}_K, \hat{a}_H, \hat{a}_L} \frac{\mu(e,\gamma)}{1+\mu(e,\gamma)}\hat{a}_K + \frac{z}{[1+\mu(e,\gamma)](1+z)}\hat{a}_H + \frac{1}{[1+\mu(e,\gamma)](1+z)}\hat{a}_L \tag{14}$$
$$s.t.\ \hat{a}_K = \phi(\hat{a}_H, \hat{a}_L, \tau)$$

The solution to this problem yields the two first-order conditions:

$$\phi'_{\hat{a}_H}(\hat{a}_H, \hat{a}_L) = -\frac{z}{\mu(e,\gamma)(1+z)} \tag{15}$$

$$\phi'_{\hat{a}_L}(\hat{a}_H, \hat{a}_L) = -\frac{1}{\mu(e,\gamma)(1+z)} \tag{16}$$

The optimal direction of technical change (equations (15) and (16)) identifies the growth rates of high-skilled labour productivity growth $\hat{a}_H$ and low-skilled labour productivity growth $\hat{a}_L$ as implicit functions of wage inequality z and high-skilled employment rate e:

$$\hat{a}_H = f^H[z, \mu(e,\gamma)], \quad f_z^{H\prime} > 0,\ f_\mu^{H\prime} < 0 \tag{17}$$

$$\hat{a}_L = f^L[z, \mu(e,\gamma)], \quad f_z^{L\prime} < 0,\ f_\mu^{L\prime} < 0 \tag{18}$$

From equations (17) and (18), we have that an increase in wage inequality favours the adoption of high-skilled- over low-skilled-labour saving innovations, whereas an increase in the high-skilled employment rate stimulates the adoption of both high-skilled- and low-skilled-labour-saving techniques.[9] The reason is that an increase in z implies a higher high-skilled labour share and a lower low-skilled labour share in total costs, hence a stronger incentive for firms to direct technical change towards the high-skilled labour, at the expense of the low-skilled labour; an increase in e reduces the capital share in total costs, thus inducing technological improvements of both high-skilled and low-skilled labour productivity growth.

4. Dynamical system and steady state

The dynamic behaviour of the system can be represented as a three-dimensional system of differential equations in the output-capital ratio a_K, the relative unit labour cost, i.e. wage inequality z, and the high-skilled employment rate e. From equations (4), (9), and (13), we have:

$$\frac{\dot{a}_K}{a_K} = \phi\left(\frac{\dot{a}_H}{a_H}, \frac{\dot{a}_L}{a_L}, \tau\right) \tag{19}$$

$$\frac{\dot{z}}{z} = \frac{\dot{w}_H}{w_H} + \frac{\dot{a}_L}{a_L} - \frac{\dot{w}_L}{w_L} - \frac{\dot{a}_H}{a_H} \tag{20}$$

$$\frac{\dot{e}}{e} = \frac{\dot{a}_K}{a_K} + g - \frac{\dot{a}_H}{a_H} - n \tag{21}$$

From equations (5), (6), and (20), it is immediate to check that, as in Nishi (2020), the gap between nominal wage growth and labour productivity growth is reflected in the inflation rate. Thus, at the steady state, real wage growth is equal to labour productivity growth. As the mark-up is dependent on the high-skilled employment rate (equation (12)), we have that $\dot{z}/z = \dot{e}/e = 0$ implies $\dot{\omega}_H/\omega_H = \dot{\omega}_L/\omega_L = \dot{\pi}/\pi = 0$ and $\dot{p}/p = \dot{w}_H/w_H - \dot{a}_H/a_H = \dot{w}_L/w_L - \dot{a}_L/a_L$.[10] Therefore, the inflation rate adjusts so as to stabilize the high-skilled and low-skilled labour shares and make them consistent with the mark-up (i.e. the profit share) set by the firm, for a given employment rate.

Substituting from equations (8) (along with equation (12)), (10), (11), (17), and (18), into equations (19), (20), and (21), we obtain the equations of motion for output-capital ratio, wage inequality, and high-skilled employment rate:

$$\frac{\dot{a}_K}{a_K} = \phi\{f^H[z, \mu(e,\gamma)], f^L[z, \mu(e,\gamma)], \tau\} \tag{22}$$

$$\frac{\dot{z}}{z} = h(e,\alpha) - \beta - f^H[z, \mu(e,\gamma)] + f^L[z, \mu(e,\gamma)] \tag{23}$$

[9] See Appendix A for the calculation of the expressions for $f_z^{H\prime}$, $f_\mu^{H\prime}$, $f_z^{L\prime}$, and $f_\mu^{L\prime}$.

[10] For a formal proof, see Appendix B.

$$\frac{\dot{e}}{e} = \frac{\dot{a}_K}{a_K} + \frac{1}{1+\mu(e,\gamma)}\left[\mu(e,\gamma) + \frac{sz}{1+z}\right] a_K - f^H[z, \mu(e,\gamma)] - n \tag{24}$$

The resulting dynamic interaction among the three variables is quite different from the Goodwin model with induced technical change and homogenous labour force. A dynamic equation for employment is defined only for high-skilled labour, as low-skilled labour is available in unlimited supply (equation (24)). Moreover, the dynamic equation for the wage share is replaced by a dynamic equation for wage inequality (equation (23)). Thus, the dynamic behaviour of the distributive variable captures the dynamics of intra-working-class income distribution, rather than the conflict over income distribution between workers and capitalists. The profit-squeeze effect of labour market tightness affects the dynamic behaviour of all variables, through the negative response of the mark-up to the high-skilled employment rate.

Equation (24) implies that, at the steady state, the economy will grow at the rate that ensures a constant high-skilled employment rate in the long run. Therefore, the economy is high-skilled-labour-constrained, namely economic growth is constrained by the growth rate of the high-skilled effective labour supply.

In the equilibrium, we have $\dot{a}_K = \dot{z} = \dot{e} = 0$. Thus, the steady-state values of output-capital ratio $a_K^*(\alpha, \beta, \gamma, \tau, s, n)$, wage inequality $z^*(\alpha, \beta, \gamma, \tau, s, n)$, and high-skilled employment rate $e^*(\alpha, \beta, \gamma, \tau, s, n)$ solve the following three equations:

$$\phi\{f^H[z, \mu(e,\gamma)], f^L[z, \mu(e,\gamma)], \tau\} = 0 \tag{25}$$

$$h(e,\alpha) - \beta - f^H[z, \mu(e,\gamma)] + f^L[z, \mu(e,\gamma)] = 0 \tag{26}$$

$$\frac{1}{1+\mu(e,\gamma)}\left[\mu(e,\gamma) + \frac{sz}{1+z}\right] a_K - f^H[z, \mu(e,\gamma)] - n = 0 \tag{27}$$

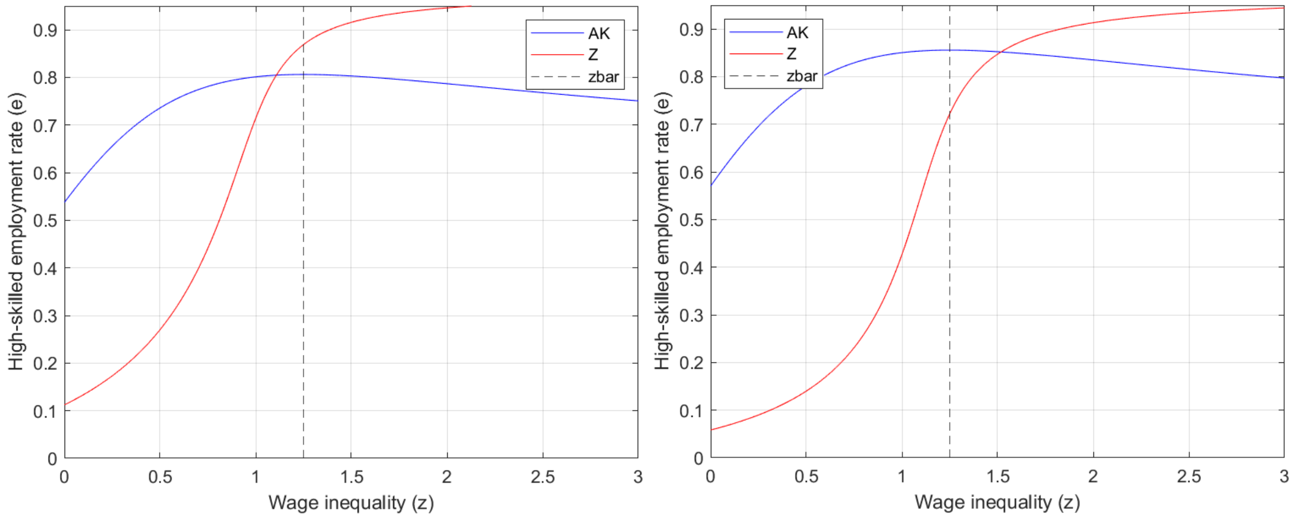
The dynamic equations of a_K and z evaluated at the steady state (equations (25) and (26)) give the conditions on z and e that keep output-capital ratio and wage inequality constant. As the dynamic equation of e only determines the equilibrium value of a_K (equation (27)), we can investigate the steady-state properties of the system by focusing only on the equations (25) and (26). We call the two isoclines AK and Z, respectively. The AK isocline represents the values of z and e that are consistent with the firm's technical choices and a constant output-capital ratio. The Z isocline gives the conditions on z and e that are consistent with the equilibrium in the labour market.

Let us define $\rho \equiv \phi''_{\hat{a}_L\hat{a}_L}/\phi''_{\hat{a}_H\hat{a}_H}$, $\bar{z} \equiv 1/\rho$, and $\Gamma_\mu \equiv (1-\rho z) f_\mu^{L'}$. $\Gamma_\mu > 0$ if, and only if, $z > \bar{z}$.

In the (z, e) plane, the AK isocline is depicted by an inverted U-shaped curve with a maximum point in $z = \bar{z}$ (Figure 1).[11] An increase in the high-skilled employment rate e always exerts downward pressure on the output-capital ratio, as a reduction in the capital share in income tends to stimulate both high-skilled- and low-skilled-labour-saving innovations at the expense of capital-saving techniques. Conversely, an increase in wage inequality z gives rise to two counteracting effects on the output-capital ratio: on the one hand, it induces a direction of technical change towards high-skilled labour, which puts downward pressure on the output-capital ratio; on the other hand, it induces less low-skilled-labour-saving innovations, thus exerting upward pressure on the output-capital ratio. As the first effect is non-linear and (in absolute value) increasing in z (equation (A1)), there is a critical value $\bar{z}$ such that if $z > \bar{z}$ the first effect will dominate over the second one. Thus, if $z > \bar{z}$, an increase in wage inequality has to be counteracted by a decrease in the employment rate in order to keep the economy on a steady-state growth path, whereas if $z < \bar{z}$ a constant output-capital ratio requires wage inequality and employment rate to go in the same direction.

[11] For the computation of the slopes of the AK and Z isoclines, see Appendix C.

Fig. 1. *The AK and Z isoclines in the baseline scenario*



a) Case I: $z^* < \bar{z}$ *b) Case II:* $z^* > \bar{z}$

Notes: In Case I, the long-run equilibrium values are $z^* = 1.1079$, $e^* = 0.8048$, $g^* = 0.0429$, $\hat{a}_H^* = 0.0329$, $\hat{a}_L^* = 0.0167$, $\hat{w}_H^* = 0.0562$, $\hat{w}_L^* = 0.04$, $\mu^* = 0.4287$, $\pi^* = 0.3$, $\omega_H^* = 0.3679$, $\omega_L^* = 0.3321$, $a_K^* = 0.1148$, and $\hat{p}^* = 0.0233$. In Case II, the long-run equilibrium values are $z^* = 1.5178$, $e^* = 0.8519$, $g^* = 0.0581$, $\hat{a}_H^* = 0.0531$, $\hat{a}_L^* = 0.0255$, $\hat{w}_H^* = 0.0676$, $\hat{w}_L^* = 0.04$, $\mu^* = 0.54$, $\pi^* = 0.3506$, $\omega_H^* = 0.3915$, $\omega_L^* = 0.2579$, $a_K^* = 0.1355$, and $\hat{p}^* = 0.0145$.

The Z isocline is upward (downward) sloping if $h'_e + \Gamma_\mu \mu'_e > (<)\ 0$. The effect of an increase in the employment rate e in the labour market is ambiguously signed: on the one hand, it strengthens the high-skilled workers' bargaining power, thus raising the growth rate of the high-skilled workers' nominal wage for given labour productivity growth; on the other hand, by reducing the capital share in income, it stimulates both high-skilled- and low-skilled-labour-saving innovations. While the direct effect of employment on wage inequality in the labour market is always positive, the indirect effect, resulting from the induced bias of technical change, is ambiguously signed. As the response of high-skilled labour productivity growth to the mark-up is non-linear and (in absolute value) increasing in z (equation (A5)), the indirect effect is positive if, and only if, $z < \bar{z}$. Accordingly, if $z < \bar{z}$, the Z isocline is unambiguously upward sloping, whereas if $z > \bar{z}$ the Z isocline is upward sloping if, and only if, the direct effect of employment on wage inequality offset the indirect one. Therefore, the equilibrium in the labour market requires wage inequality and employment to go in the same direction if an increase in the high-skilled employment rate results in an overall improvement of the bargaining position of the high-skilled workers, relative to the low-skilled workers, despite the negative impact of the induced high-skilled-labour-saving innovations on wage inequality. In the numerical simulations, the parameter values are such that the Z isocline is always upward sloping.[12] However, the results of comparative statics analysis are independent of the slope of the Z isocline.

In what follows, we assume that non-trivial equilibrium values (a_K^*, z^*, e^*) exist and are economically meaningful.

[12] For the details of the numerical simulations, see Appendix D.

5. LOCAL STABILITY ANALYSIS

Let us define $\theta_z \equiv (1-\rho z)f_z^{L'}$, $\theta_\mu \equiv (1+\rho z^2)f_\mu^{L'} < 0$, $\Gamma_z \equiv (1+\rho)f_z^{L'} < 0$. Remind that $\Gamma_\mu \equiv (1-\rho z)f_\mu^{L'}$. $\theta_z > 0$ and $\Gamma_\mu > 0$ if, and only if, $z > \bar{z}$.

We investigate the local stability of the equilibrium linearizing the system of differential equations (22), (23), and (24) around the equilibrium values (a_K^*, z^*, e^*):

$$\begin{bmatrix} \dot{a}_K \\ \dot{z} \\ \dot{e} \end{bmatrix} = \begin{bmatrix} 0 & J_{12} & J_{13} \\ 0 & J_{22} & J_{23} \\ J_{31} & J_{32} & J_{33} \end{bmatrix} \begin{bmatrix} a_K - a_K^* \\ z - z^* \\ e - e^* \end{bmatrix} \tag{28}$$

where the elements of the Jacobian matrix $\boldsymbol{J}$ evaluated at the steady-state values $a_K^*(\alpha,\beta,\gamma,\tau,s,n)$, $z^*(\alpha,\beta,\gamma,\tau,s,n)$, and $e^*(\alpha,\beta,\gamma,\tau,s,n)$ are given by:

$$J_{12} \equiv \left.\frac{\partial \dot{a}_K}{\partial z}\right|_{a_K=a_K^*,z=z^*,e=e^*} = \theta_z^* \phi'_{\hat{a}_L} a_K^* \tag{29}$$

$$J_{13} \equiv \left.\frac{\partial \dot{a}_K}{\partial e}\right|_{a_K=a_K^*,z=z^*,e=e^*} = \theta_\mu^* \phi'_{\hat{a}_L} \mu'_e a_K^* < 0 \tag{30}$$

$$J_{22} \equiv \left.\frac{\partial \dot{z}}{\partial z}\right|_{a_K=a_K^*,z=z^*,e=e^*} = \Gamma_z^* z^* < 0 \tag{31}$$

$$J_{23} \equiv \left.\frac{\partial \dot{z}}{\partial e}\right|_{a_K=a_K^*,z=z^*,e=e^*} = (h'_e + \Gamma_\mu^* \mu'_e) z^* \tag{32}$$

$$J_{31} \equiv \left.\frac{\partial \dot{e}}{\partial a_K}\right|_{a_K=a_K^*,z=z^*,e=e^*} = g'_{a_K} e^* > 0 \tag{33}$$

$$J_{32} \equiv \left.\frac{\partial \dot{e}}{\partial z}\right|_{a_K=a_K^*,z=z^*,e=e^*} = (\theta_z^* \phi'_{\hat{a}_L} + g'_z - f_z^{H\prime}) e^* \tag{34}$$

$$J_{33} \equiv \left.\frac{\partial \dot{e}}{\partial e}\right|_{a_K=a_K^*,z=z^*,e=e^*} = \left(\theta_\mu^* \phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right) \mu'_e e^* < 0 \tag{35}$$

Only partial derivatives (30), (31), (33), and (35) are unambiguously signed, whereas the signs of (29), (32) and (34) are crucially dependent on the level of wage inequality, on the effect of the high-skilled employment rate on the growth rate of the high-skilled nominal wage and the rates of high-skilled- and low-skilled-labour-saving innovations, and on the effect of wage inequality on capital accumulation and the rate of high-skilled-labour-saving techniques.

Equation (29) shows that an increase in wage inequality has a stabilizing effect on the dynamics of the output-capital ratio if and only if $z > z^*$. Indeed, an increase in z has two opposite effects on the rate of change of the output-capital ratio: on the one hand, it stimulates the development of high-skilled-labour-saving techniques, thus exerting downward pressure on the output-capital ratio; on the other hand, it reduces the adoption of low-skilled-labour-saving innovations, thus putting upward pressure on the output-capital ratio. Since the first effect is non-linear and (in absolute value) increasing in z (equation (A1)), the first effect will offset the second one if wage inequality exceeds the critical value $\bar{z}$.

Equation (32) shows that the effect of the high-skilled employment rate on the dynamics of wage inequality is mediated by its impact on the growth rate of the high-skilled workers' nominal wage and on the rates of adoption of high-skilled- and low-skilled-labour-saving innovations. An increase in e raises the growth rate of the high-skilled workers' nominal wage and, by reducing the profit share, stimulates both high-skilled- and low-skilled-labour-saving innovations. As the response of high-skilled labour productivity growth to profitability is non-linear and (in absolute value) increasing in z (equation (A5)), the overall effect of an increase in e is crucially dependent on the level of wage inequality: if $z < z^*$, an increase in e always has a destabilizing effect on the dynamics of wage inequality; if $z > z^*$, an increase in e has a stabilizing effect if and only if the stimulus to the development of high-skilled-labour-saving innovations offset the impact on the growth rates of high-skilled nominal wage and low-skilled labour productivity.

From equations (30) and (31), we have that the effect of the high-skilled employment rate on the dynamics of the output-capital ratio and the effect of wage inequality on its rate of change act as stabilization factors of the equilibrium. An increase in e lowers the capital share in total costs, putting downward pressure on the output-capital ratio. A rise in z has a negative feedback on itself, as it induces the development of high-skilled-labour-saving innovations at the expense of the low-skilled-labour-saving innovation, thus reducing wage inequality.

Equation (34) shows that an increase in wage inequality has a stabilizing effect on the dynamics of the high-skilled employment rate if $z > z^*$ and high-skilled labour productivity growth is more responsive than capital accumulation to wage inequality.

The characteristic equation of the Jacobian matrix $\boldsymbol{J}$ in (28) is given by:

$$\lambda^3 + a_1\lambda^2 + a_2\lambda + a_3 = 0 \tag{36}$$

where λ denotes a characteristic root. The coefficients of equation (36) are:

$$a_1 = -\mathrm{Tr}(\boldsymbol{J}) = -(J_{22} + J_{33}) = -\left[\Gamma_z^* z^* + \left(\theta_\mu^* \phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu'_e e^*\right] \tag{37}$$

$$\begin{aligned} a_2 = \begin{vmatrix} J_{22} & J_{23} \\ J_{32} & J_{33} \end{vmatrix} + \begin{vmatrix} 0 & J_{13} \\ J_{31} & J_{33} \end{vmatrix} &= \Gamma_z^*\left(\theta_\mu^* \phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu'_e e^* z^* - \theta_\mu^* \phi'_{\hat{a}_L} g'_{a_K} \mu'_e e^* a_K^* + \\ &- \theta_z^* \phi'_{\hat{a}_L}\left(h'_e + \Gamma_\mu^* \mu'_e\right) e^* z^* - \left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^* \mu'_e\right) e^* z^* \end{aligned} \tag{38}$$

$$a_3 = -\mathrm{Det}(\boldsymbol{J}) = J_{31}(J_{13}J_{22} - J_{12}J_{23}) = -g'_{a_K}\phi'_{\hat{a}_L}\left[\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) - \theta_\mu^*\Gamma_z^*\mu'_e\right] e^* z^* a_K^* \tag{39}$$

The necessary and sufficient condition for the local stability of the dynamic system is that all characteristic roots are negative or have a negative real part,[13] which occurs when:

$$a_1 > 0, \quad a_2 > 0, \quad a_3 > 0, \quad a_1 a_2 - a_3 > 0 \tag{40}$$

Proposition 1 The equilibrium is locally stable if $\left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$ and $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$, and only if $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) > \theta_\mu^*\Gamma_z^*\mu'_e$. Then, if $z^* < \bar{z}$, local stability requires $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) > \theta_\mu^*\Gamma_z^*\mu'_e$, whereas $g'_z < f_z^{H'}$ is sufficient for the equilibrium to be locally stable; if $z^* > \bar{z}$, a sufficient condition for the local stability is $g'_z > f_z^{H'}$ and $h'_e + \Gamma_\mu^*\mu'_e < 0$.

Proof The condition $a_1 > 0$ is always satisfied. The condition $a_3 > 0$ is satisfied if and only if $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) > \theta_\mu^*\Gamma_z^*\mu'_e$. After rearranging:

[13] See Gandolfo (2009).

$$a_2 = \underbrace{-\phi'_{\hat{a}_L}\left[\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) - \theta_\mu^*\Gamma_z^*\mu'_e\right]e^*z^*}_{\gtrless 0} \underbrace{+\Gamma_z^*\left(g'_\mu - f_\mu^{H'}\right)\mu'_e e^* z^*}_{>0} \underbrace{-\theta_\mu^*\phi'_{\hat{a}_L} g'_{a_K}\mu'_e e^* a_K^*}_{>0} + \underbrace{-\left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^*\mu'_e\right)e^*z^*}_{\gtrless 0} \quad (41)$$

If $a_3 > 0$, $\left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$ is a sufficient condition for $a_2 > 0$. After some algebra, we have:

$$\begin{aligned} a_1 a_2 - a_3 = {} & \underbrace{\phi'_{\hat{a}_L}\left[\Gamma_z^* z^* + \left(\theta_\mu^*\phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu'_e e^*\right]}_{>0} \underbrace{\left[\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) - \theta_\mu^*\Gamma_z^*\mu'_e\right]e^*z^*}_{\gtrless 0} + \\ & \underbrace{-\Gamma_z^*\left[\Gamma_z^* z^* + \left(\theta_\mu^*\phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu'_e e^*\right]}_{<0} \underbrace{\left(g'_\mu - f_\mu^{H'}\right)\mu'_e e^* z^*}_{<0} + \\ & \underbrace{+\theta_\mu^*\phi'_{\hat{a}_L} g'_{a_K}\left(\theta_\mu^*\phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu_e'^2 e^{*2} a_K^*}_{>0} + \\ & \underbrace{+g'_{a_K}\theta_z^*\phi'_{\hat{a}_L}\left(h'_e + \Gamma_\mu^*\mu'_e\right)e^*z^*a_K^*}_{\gtrless 0} + \\ & \underbrace{+\left[\Gamma_z^* z^* + \left(\theta_\mu^*\phi'_{\hat{a}_L} + g'_\mu - f_\mu^{H'}\right)\mu'_e e^*\right]}_{<0} \underbrace{\left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^*\mu'_e\right)e^*z^*}_{\gtrless 0} \end{aligned} \quad (42)$$

If $a_2 > 0$ and $a_3 > 0$, $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$ is a sufficient condition for $a_1 a_2 - a_3 > 0$. We have thus proved the first part of Proposition 1.
If $z^* < \bar{z}$, then $\theta_z^* < 0$ and $h'_e + \Gamma_\mu^*\mu'_e > 0$. Therefore, $g'_z < f_z^{H'}$ is sufficient for the equilibrium to be locally stable. If $z^* > \bar{z}$, we always have $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) > \theta_\mu^*\Gamma_z^*\mu'_e$, since $\theta_z^* > 0$ and $\theta_z^*\Gamma_\mu^* < \theta_\mu^*\Gamma_z^*$. Therefore, $g'_z > f_z^{H'}$ and $h'_e + \Gamma_\mu^*\mu'_e < 0$ are a sufficient condition for the local stability. We have thus proved the second part of Proposition 1.

The necessary condition $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) > \theta_\mu^*\Gamma_z^*\mu'_e$, or equivalently $\theta_z^*\phi'_{\hat{a}_L}\left(h'_e + \Gamma_\mu^*\mu'_e\right) < \theta_\mu^*\Gamma_z^*\phi'_{\hat{a}_L}\mu'_e$, prevents wage inequality z and employment e from causing an explosive growth of output-capital ratio and wage inequality. Indeed, the effect of employment on the growth of the output-capital ratio (equation (30)) and the effect of wage inequality on its growth rate (equation (31)) act as stabilizing forces of the equilibrium, whereas the effect of wage inequality on the growth of the output-capital ratio (equation (29)) and the effect of employment on the growth of wage inequality (equation (32)) are not unambiguously signed. The equilibrium will be locally stable only if the effect of the stabilizing forces offset the impact of the ambiguously signed effects – a condition which is always satisfied in the presence of a high level of wage inequality (i.e. if $z^* > \bar{z}$).

The sufficient condition $\left(g'_z - f_z^{H'}\right)\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$ and $\theta_z^*\left(h'_e + \Gamma_\mu^*\mu'_e\right) < 0$ implies that a system is locally stable in the presence of an equilibrium in the balance of power among social classes, in terms of dynamics of high-skilled employment and wage inequality (equations (31), (32), and (34)). Indeed, the system is stable if an imbalance in favour of the high-skilled workers in the dynamics of wage inequality (i.e. $h'_e + \Gamma_\mu^*\mu'_e > 0$) is counteracted by a negative effect of wage inequality on the growth rate of employment (i.e. $g'_z - f_z^{H'} < 0$) and a low level of wage inequality ($z^* < \bar{z}$), or alternatively, if an imbalance in favour of the high-skilled workers in the dynamics of employment (i.e. $g'_z - f_z^{H'} > 0$) and the level of wage inequality ($z^* > \bar{z}$) is compensated by a negative response of the growth rate of wage inequality to employment ($h'_e + \Gamma_\mu^*\mu'_e < 0$).

6. COMPARATIVE STATICS ANALYSIS

6.1. EFFECT OF LABOUR MARKET INSTITUTIONS AND PRODUCT MARKET CONCENTRATION

This section investigates the effects of changes in the institutional variables α, β, and γ on the steady-state values of wage inequality, high-skilled employment rate, capital accumulation, high-skilled labour productivity growth, low-skilled labour productivity growth, high-skilled nominal and real wages growth, low-skilled nominal and real wages growth, mark-up and income shares.

Let us define $\sigma \equiv \left[(1-\rho z)h_e' - \rho(1+z)^2 f_\mu^{L'} \mu_e'\right] f_z^{L'}$.[14] Since the implementation of a comparative statics analysis requires the stability of the equilibrium, we limit ourselves to the discussion of the case of $\sigma > 0$.[15]

Proposition 2 The equilibrium wage inequality, capital accumulation, high-skilled labour productivity growth, high-skilled nominal and real wages growth, and high-skilled wage share are increasing in α; the equilibrium low-skilled labour productivity growth, high-skilled real wages growth, and low-skilled wage share are decreasing in α; the equilibrium high-skilled employment rate is a positive function of α if and only if $z^* < \bar{z}$; the equilibrium values of mark-up and profit share are positive functions of α if and only if $z^* > \bar{z}$.

Proof Totally differentiating equations (25), (26), and (27) with respect to α yields:

$$\frac{dz^*}{d\alpha} = \frac{h_\alpha'(1+\rho z^2) f_\mu^{L'} \mu_e'}{\sigma} > 0 \tag{43}$$

$$\frac{de^*}{d\alpha} = -\frac{h_\alpha'(1-\rho z) f_z^{L'}}{\sigma} \tag{44}$$

Using equations (43), (44), and $g = \hat{a}_H - n$, total differentiation of equations (5) and (6), with (12), and (10), (12), (17), and (18) with respect to α yields:

$$\frac{d\mu^*}{d\alpha} = -\frac{h_\alpha'(1-\rho z) f_z^{L'} \mu_e'}{\sigma} \tag{45}$$

$$\frac{dg^*}{d\alpha} = \frac{d\hat{a}_H^*}{d\alpha} = -\frac{h_\alpha' \rho(1+z) f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} > 0 \tag{46}$$

$$\frac{d\hat{a}_L^*}{d\alpha} = \frac{h_\alpha' \rho z(1+z) f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} < 0 \tag{47}$$

$$\frac{d\hat{w}_H^*}{d\alpha} = -\frac{h_\alpha' \rho(1+z)^2 f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} > 0 \tag{48}$$

$$\frac{d\omega_H^*}{d\alpha} = \frac{h_\alpha'[1+\rho z^2 + \mu(1+z)]\mu_e'}{\mu^2(1+\mu)^2(1+z)^3 \phi_{\hat{a}_L\hat{a}_L}'' \sigma} > 0 \tag{49}$$

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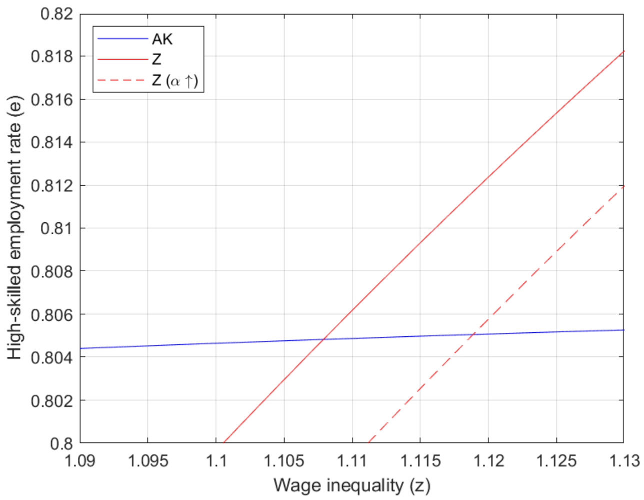
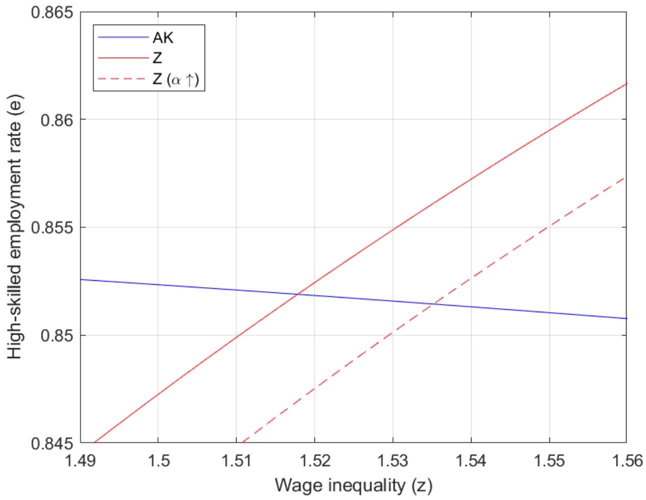
[14] We omit "$*$" to save notation.

[15] The coefficient a_3 of the Jacobian matrix is positive if and only if $\sigma > 0$.

Fig. 2. *The effect of an increase in the high-skilled workers' bargaining strength*



a) Case I: $z^* < \bar{z}$



b) Case II: $z^* > \bar{z}$

Notes: In Case I, the new equilibrium values are $z^* = 1.1189$, $e^* = 0.8051$, $g^* = 0.0478$, $\hat{a}_H^* = 0.0378$, $\hat{a}_L^* = 0.0113$, $\hat{w}_H^* = 0.0665$, $\hat{w}_L^* = 0.04$, $\mu^* = 0.4285$, $\pi^* = 0.3$, $\omega_H^* = 0.3696$, $\omega_L^* = 0.3304$, $a_K^* = 0.1277$, and $\hat{p}^* = 0.0287$. In Case II, the new equilibrium values are $z^* = 1.5352$, $e^* = 0.8514$, $g^* = 0.0617$, $\hat{a}_H^* = 0.0567$, $\hat{a}_L^* = 0.0201$, $\hat{w}_H^* = 0.0766$, $\hat{w}_L^* = 0.04$, $\mu^* = 0.5403$, $\pi^* = 0.3508$, $\omega_H^* = 0.3931$, $\omega_L^* = 0.2561$, $a_K^* = 0.1436$, and $\hat{p}^* = 0.0199$.

$$\frac{d\omega_L^*}{d\alpha} = -\frac{h'_\alpha[1 + \rho z^2 + \rho\mu z(1 + z)]\mu'_e}{\mu^2(1 + \mu)^2(1 + z)^3\phi''_{\hat{a}_L\hat{a}_L}\sigma} < 0 \tag{50}$$

An increase in the high-skilled workers' bargaining strength, as measured by the exogenous component of the high-skilled nominal wage growth (α), leads to a rightward shift in the Z isocline, while leaving the AK isocline unaffected (Figure 2).

Consider the case of an upward sloping Z isocline. The Z isocline shifts rightward, as an exogenous increase in the high-skilled workers' bargaining power allows them to attain a higher income share, for a given employment rate. The resulting increase in wage inequality induces the adoption of high-skilled-labour-saving innovations, at the expense of low-skilled-labour-saving techniques, putting pressure on the output-capital ratio. If $z^* < \bar{z}$, the increase in wage inequality exerts upward pressure on the output-capital ratio, thus leading to an increase in the employment rate up to the level that makes the profit share consistent with the firm's technical choices and a constant output-capital ratio (Figure 2a). Conversely, if $z^* > \bar{z}$, the increase in wage inequality put downward pressure on the output-capital ratio, that can only be stabilized by a lower long-run employment rate (Figure 2b).

The rise in wage inequality causes the long-run skill bias of technical change to increase. Indeed, the rise in the high-skilled labour share and the fall in the low-skilled labour share in total costs translate into a higher rate of high-skilled-labour-augmenting technical change and a lower rate of low-skilled-labour-augmenting technical change at the steady state. The high-skilled employment rate negatively affects profitability, as measured by the firm's mark-up. Thus, in the presence of a low level of steady-state wage inequality (i.e. $z^* < \bar{z}$), an increase in the high-skilled workers' bargaining strength reduces the mark-up and the capitalists' share of income, whereas with a high level of wage inequality (i.e. $z^* > \bar{z}$), both capitalists and high-skilled workers increase their income shares to the detriment of the low-skilled workers. A trade-off between income distribution and employment of the high-skilled workers arises only if $z^* > \bar{z}$. Conversely, if $z^* < \bar{z}$, an increase in the bargaining power of the high-skilled workers positively affects both their income share and their employment rate.

Proposition 3 The equilibrium wage inequality, capital accumulation, high-skilled labour productivity growth, high-skilled nominal and real wages growth, and high-skilled wage share are decreasing in β; the equilibrium low-skilled labour productivity growth, low-skilled nominal and real wages growth, and low-skilled wage share are increasing in β; the equilibrium high-skilled employment rate is a positive function of β if and only if $z^* > \bar{z}$; the equilibrium values of mark-up and profit share are positive functions of β if and only if $z^* < \bar{z}$.

Proof Totally differentiating equations (25), (26), and (27) with respect to β yields:

$$\frac{dz^*}{d\beta} = -\frac{(1+\rho z^2) f_\mu^{L'} \mu_e'}{\sigma} > 0 \tag{51}$$

$$\frac{de^*}{d\beta} = \frac{(1-\rho z) f_z^{L'}}{\sigma} \tag{52}$$

Using equations (51), (52), and $g = \hat{a}_H - n$, total differentiation of equations (5) and (6), with (12), and (10), (12), (17), and (18) with respect to β yields:

$$\frac{d\mu^*}{d\beta} = \frac{(1-\rho z) f_z^{L'} \mu_e'}{\sigma} \tag{53}$$

$$\frac{dg^*}{d\beta} = \frac{d\hat{a}_H^*}{d\beta} = \frac{\rho(1+z) f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} < 0 \tag{54}$$

$$\frac{d\hat{a}_L^*}{d\beta} = -\frac{\rho z(1+z) f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} > 0 \tag{55}$$

$$\frac{d\widehat{w}_H^*}{d\beta} = \frac{\rho(1+z)^2 f_z^{L'} f_\mu^{L'} \mu_e'}{\sigma} < 0 \tag{56}$$

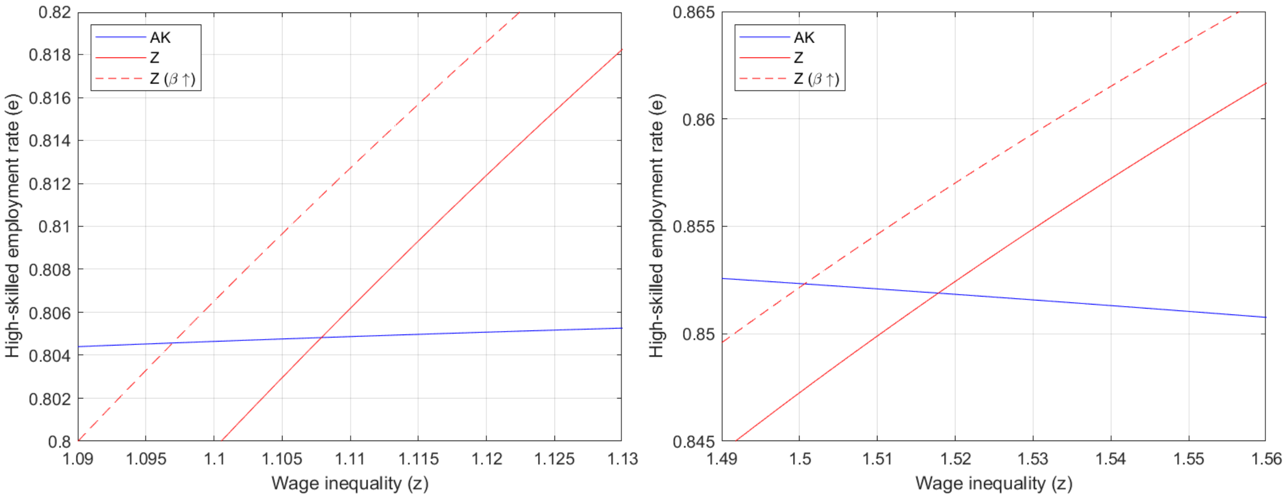
$$\frac{d\omega_H^*}{d\beta} = -\frac{[1+\rho z^2 + \mu(1+z)]\mu_e'}{\mu^2(1+\mu)^2(1+z)^3 \phi''_{\hat{a}_L\hat{a}_L}\sigma} < 0 \tag{57}$$

$$\frac{d\omega_L^*}{d\beta} = \frac{[1+\rho z^2 + \rho\mu z(1+z)]\mu_e'}{\mu^2(1+\mu)^2(1+z)^3 \phi''_{\hat{a}_L\hat{a}_L}\sigma} > 0 \tag{58}$$

An increase in the low-skilled workers' bargaining strength, as measured by the exogenous component of the low-skilled nominal wage growth (β), leads to a leftward shift in the Z isocline, while leaving the AK isocline unaffected (Figure 3).

The case of an increase in β is specular to the previous one. Let us consider again the case of an upward sloping Z isocline. Now, for a given high-skilled employment rate, the improved bargaining position of the low-skilled workers allow them to attain a higher income share. The resulting decrease

Fig. 3. *The effect of an increase in the low-skilled workers' bargaining strength*



a) Case I: $z^* < \bar{z}$ *b) Case II:* $z^* > \bar{z}$

Notes: In Case I, the new equilibrium values are $z^* = 1.097$, $e^* = 0.8046$, $g^* = 0.038$, $\hat{a}_H^* = 0.028$, $\hat{a}_L^* = 0.0221$, $\hat{w}_H^* = 0.0558$, $\hat{w}_L^* = 0.05$, $\mu^* = 0.4288$, $\pi^* = 0.3001$, $\omega_H^* = 0.3661$, $\omega_L^* = 0.3338$, $a_K^* = 0.1017$, and $\hat{p}^* = 0.0279$. In Case II, the new equilibrium values are $z^* = 1.5006$, $e^* = 0.8523$, $g^* = 0.0545$, $\hat{a}_H^* = 0.0495$, $\hat{a}_L^* = 0.031$, $\hat{w}_H^* = 0.0686$, $\hat{w}_L^* = 0.05$, $\mu^* = 0.5397$, $\pi^* = 0.3505$, $\omega_H^* = 0.3898$, $\omega_L^* = 0.2597$, $a_K^* = 0.1273$, and $\hat{p}^* = 0.019$.

in wage inequality induces a bias of technical change towards the low-skilled labour, at the expense of the high-skilled labour. If $z^* < \bar{z}$, the output-capital ratio must be stabilized by a decrease in the high-skilled employment rate (Figure 3a), whereas if $z^* > \bar{z}$, steady-state growth requires an increase in the high-skilled employment rate (Figure 3b).

The reduction in wage inequality, resulting from the fall in the high-skilled labour share and the increase in the high-skilled labour share, is associated with a lower skill bias of technical change at the steady state, namely with faster low-skilled labour productivity growth and slower high-skilled labour productivity growth. As the high-skilled employment rate is inversely related to the mark-up and the profit share, if $z^* > \bar{z}$ an increase in the low-skilled workers' bargaining power leads to income redistribution from profits to wages. Thus, in the presence of a high level of wage inequality, an increase in the low-skilled workers' bargaining strength is conducive to both higher employment and a lower capital share.

Proposition 4 The equilibrium wage inequality, high-skilled employment rate, capital accumulation, high-skilled labour productivity growth, high-skilled nominal and real wages growth, and high-skilled wage share are increasing in γ; the equilibrium low-skilled labour productivity growth, low-skilled real wages growth, and low-skilled wage share are decreasing in γ; the equilibrium values of mark-up and profit share are positive functions of γ if and only if $z^* > \bar{z}$.

Proof Totally differentiating equations (25), (26), and (27) with respect to γ yields:

$$\frac{dz^*}{d\gamma} = -\frac{h_e'(1+\rho z^2) f_\mu^{L'} \mu_\gamma'}{\sigma} > 0 \quad (59)$$

$$\frac{de^*}{d\gamma} = \frac{\rho(1+z)^2 f_z^{L'} f_\mu^{L'} \mu_\gamma'}{\sigma} > 0 \tag{60}$$

Using equations (59), (60), and $g = \hat{a}_H - n$, total differentiation of equations (5) and (6), with (12), and (10), (12), (17), and (18) with respect to γ yields:

$$\frac{d\mu^*}{d\gamma} = \frac{h_e'(1-\rho z) f_z^{L'} \mu_\gamma'}{\sigma} \tag{61}$$

$$\frac{dg^*}{d\gamma} = \frac{d\hat{a}_H^*}{d\gamma} = \frac{h_e' \rho(1+z) f_z^{L'} f_\mu^{L'} \mu_\gamma'}{\sigma} > 0 \tag{62}$$

$$\frac{d\hat{a}_L^*}{d\gamma} = -\frac{h_e' \rho z(1+z) f_z^{L'} f_\mu^{L'} \mu_\gamma'}{\sigma} < 0 \tag{63}$$

$$\frac{d\hat{w}_H^*}{d\gamma} = \frac{h_e' \rho(1+z)^2 f_z^{L'} f_\mu^{L'} \mu_\gamma'}{\sigma} > 0 \tag{64}$$

$$\frac{d\omega_H^*}{d\gamma} = -\frac{h_e'[1+\rho z^2 + \mu(1+z)]\mu_\gamma'}{\mu^2(1+\mu)^2(1+z)^3 \phi_{\hat{a}_L\hat{a}_L}'' \sigma} > 0 \tag{65}$$

$$\frac{d\omega_L^*}{d\gamma} = \frac{h_e'[1+\rho z^2 + \rho\mu z(1+z)]\mu_\gamma'}{\mu^2(1+\mu)^2(1+z)^3 \phi_{\hat{a}_L\hat{a}_L}'' \sigma} < 0 \tag{66}$$

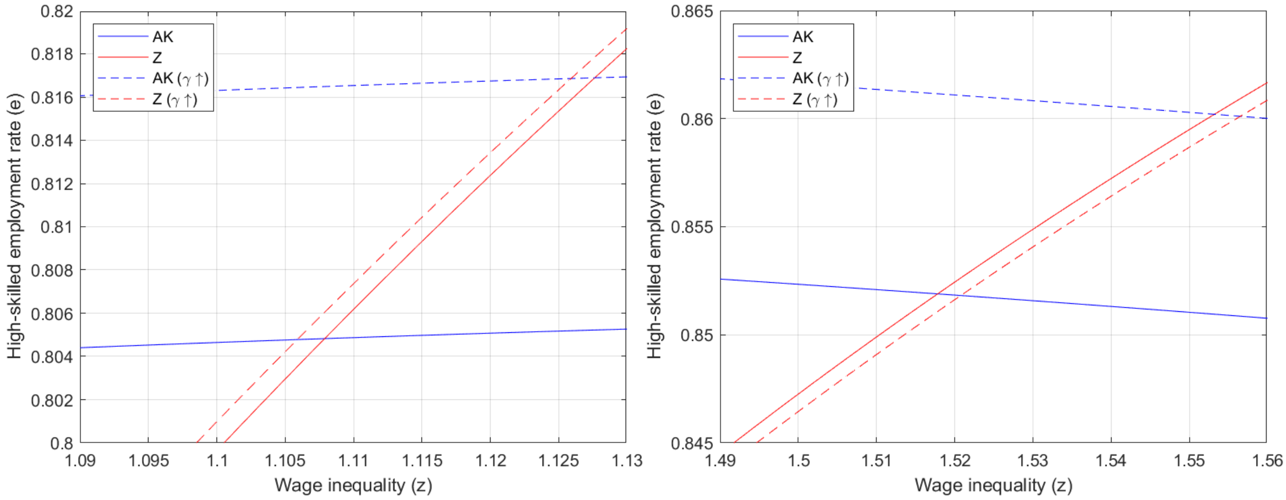
An increase in product market concentration, as measured by the exogenous component of the mark-up (γ), leads to an upward shift in the AK isocline; if downward sloping, the Z isocline always shifts upward; if upward sloping, the Z isocline rotates clockwise around the point $z = \bar{z}$ (Figure 4).[16]

As in the previous cases, we limit ourselves to discuss the case of an upward sloping Z isocline. An exogenous increase in the mark-up exerts upward pressure on the output-capital ratio, as the capital share in total costs increases. Therefore, the AK isocline shifts upward: for given wage inequality, the output-capital ratio must be stabilized by a higher employment rate. The increase in the high-skilled employment rate improves the bargaining position of the high-skilled workers in the labour market, thus leading to an increase in wage inequality. However, a rise in the exogenous component of the mark-up, by reducing the rates of adoption of high-skilled- and low-skilled-labour-saving innovations, also has a direct effect in the labour market. As the response of high-skilled labour productivity growth to the mark-up is non-linear and (in absolute value) increasing in z, the direct effect of γ depends on the level of wage inequality: for given employment, the equilibrium in the labour market requires a decrease in wage inequality if $z^* < \bar{z}$ (Figure 4a), and an increase in wage inequality if $z^* > \bar{z}$ (Figure 4b). However, both the analytical solutions and the numerical simulations show that the AK isocline is more responsive than the Z isocline to an increase in γ. Therefore, irrespective of the shift in the Z isocline, both wage inequality and employment increase at the steady state.

As in the case of an increase in the high-skilled workers' bargaining strength, the rise in wage inequality leads to faster high-skilled labour productivity growth and slower low-skilled labour productivity growth. In the presence of a high level of wage inequality (i.e. $z^* > \bar{z}$), the negative

[16] For a formal proof, see Appendix C.

Fig. 4. *The effect of an increase in product market concentration*



a) Case I: $z^* < \bar{z}$ *b) Case II:* $z^* > \bar{z}$

Notes: In Case I, the new equilibrium values are $z^* = 1.1259$, $e^* = 0.8169$, $g^* = 0.0508$, $\hat{a}_H^* = 0.0408$, $\hat{a}_L^* = 0.0078$, $\widehat{w}_H^* = 0.073$, $\widehat{w}_L^* = 0.04$, $\mu^* = 0.4285$, $\pi^* = 0.3$, $\omega_H^* = 0.3708$, $\omega_L^* = 0.3293$, $a_K^* = 0.1359$, and $\hat{p}^* = 0.0322$. In Case II, the new equilibrium values are $z^* = 1.5565$, $e^* = 0.8601$, $g^* = 0.0659$, $\hat{a}_H^* = 0.0609$, $\hat{a}_L^* = 0.0135$, $\widehat{w}_H^* = 0.0874$, $\widehat{w}_L^* = 0.04$, $\mu^* = 0.5406$, $\pi^* = 0.3509$, $\omega_H^* = 0.3952$, $\omega_L^* = 0.2539$, $a_K^* = 0.1534$, and $\hat{p}^* = 0.0265$.

effect of the increase in the high-skilled employment rate on profitability is offset by the positive effect of the exogenous increase in the mark-up. Thus, an increase in the degree of product market concentration also raises the capital share in income.

Table 1 summarizes the main results of comparative statics. As it turns out, labour market institutions and product market regulation affect both long-run income distribution and direction of technical change. Indeed, a fall in the low-skilled workers' bargaining strength or an exogenous increase in the mark-up lead to both an increase in wage inequality and an induced bias of technical change that disproportionately benefits high-skilled over low-skilled labour productivity growth. If wage inequality is high, namely if wage inequality exceeds a critical level, an increase in the bargaining power of the high-skilled workers, as compared to the low-skilled workers, or an exogenous increase in the mark-up also lead to income redistribution from wages to profits. Moreover, in contrast to both the conventional wisdom and the Goodwin model with homogenous labour force, no necessary trade-offs arise between labour market regulation and long-run employment. An increase in the high-skilled workers' bargaining strength reduces the high-skilled employment rate only if the current level of wage inequality is high. However, with a high level of wage inequality, an increase in the low-skilled workers' bargaining power leads to lower wage inequality, higher employment and income redistribution from profits to wages.

Tab. 1. *Results of comparative statics analysis*

	α		β		γ	
	$z^* < \bar{z}$	$z^* > \bar{z}$	$z^* < \bar{z}$	$z^* > \bar{z}$	$z^* < \bar{z}$	$z^* > \bar{z}$
z^*	$+$	$+$	$-$	$-$	$+$	$+$
e^*	$+$	$-$	$-$	$+$	$+$	$+$
$\hat{a}_H^*, g^*$	$+$	$+$	$-$	$-$	$+$	$+$
$\hat{a}_L^*$	$-$	$-$	$+$	$+$	$-$	$-$
π^*, μ^*	$-$	$+$	$+$	$-$	$-$	$+$
ω_H^*	$+$	$+$	$-$	$-$	$+$	$+$
ω_L^*	$-$	$-$	$+$	$+$	$-$	$-$
a_K^*	$+/-$	$+$	$+/-$	$-$	$+/-$	$+/-$
$\hat{p}^*$	$+$	$+$	$+/-$	$+$	$+$	$+$

Note: For the proof of the effects of a shift in parameters on a_K^* and $\hat{p}^*$, see Appendix E.

6.2. *Discussion: The role of labour market institutions in models of the growth cycle with induced innovation*

In this section, we provide a comparison between our model, the standard Goodwin model with induced technical change, and some recent contributions in the classical and Goodwinian literature concerned with the long-run effects of labour market institutions. Following the relevant literature, we introduce an explicit policy variable related to the workers' bargaining power into the classical model of growth cycle with induced technical change.

In our notation, the standard Goodwin model with induced innovation (Shah and Desai, 1981; van der Ploeg, 1987) can be represented as:

$$\frac{\dot{a}_K}{a_K} = \phi[f(\omega)] \tag{67}$$

$$\frac{\dot{\omega}}{\omega} = h(v, \delta) - f(\omega) \tag{68}$$

$$\frac{\dot{v}}{v} = \frac{\dot{a}_K}{a_K} + g(\omega, a_K) - f(\omega) - n \tag{69}$$

where δ denotes the workers' bargaining strength in the distributive conflict; ω, the wage share; and v, the employment rate. The usual assumptions hold: $\phi' < 0$, $f' > 0$, $h_v' > 0$, $h_\delta' > 0$, $g_\omega' < 0$, and $g_{a_K}' > 0$.

The steady-state income distribution and employment are $\omega^* = f^{-1}[\phi^{-1}(0)]$ and $v^* = h^{-1}[\phi^{-1}(0), \delta]$. The equilibrium capital accumulation and labour productivity growth are $g^* = \phi^{-1}(0) + n$ and $\hat{a}^* = \phi^{-1}(0)$, respectively. It is immediate to see that an increase in the workers' bargaining strength only reduces the employment rate, while leaving the long-run labour share, capital accumulation and labour productivity growth unaffected. The dynamic equation of the output-capital ratio (equation (67)) solves for the long-run value of the wage share, that does not depend on labour market institutions δ. Once the steady-state labour share is determined, the dynamic equation of the wage share (equation (68)) solves for the long-run value of the employment rate, that is dependent on labour market institutions δ. Thus, the dynamic equation of the labour share only determines the size of the reserve army of labour that makes the overall bargaining power of workers consistent with technology-determined income distribution. Capitalists react to any exogenous increase in workers' bargaining power by decreasing temporarily capital accumulation, so as to bring the labour share back to its original level. The size of the reserve army of labour then rises so as to make workers be "quiet" with their original share in income, whereas capital accumulation and labour productivity growth go back to their old steady-state values. Accordingly, labour market institutions do not affect permanently income distribution, capital accumulation and labour productivity growth.[17]

As balanced growth requires a constant output-capital ratio in the long run, steady-state labour productivity growth is determined by the intercept of the innovation possibility frontier. Therefore, long-run income distribution is uniquely determined by the shape of the frontier at the intercept, and the income shares change along the transitional dynamics in order to ensure a Harrod-neutral direction of technical change in the long run. As firm's technical choices are not affected by labour market institutions, an exogenous increase in the workers' bargaining power only affects income distribution along the transition path. At the new steady-state, the improved bargaining position of workers is fully neutralized by a decrease in the employment rate, that adjusts in order to make the wage share consistent with the firm's technical choices and a constant output-capital ratio.

Julius (2005) explores the steady-state implications of an increase in the workers' bargaining strength when labour market institutions allow for a partial pass-through of labour productivity growth to real wages, and wage bargaining is internalized by the firm in its choice of technique. Denoting the workers' bargaining power by the fraction of productivity pass-through $\delta \in (0,1)$, the solution to the firms' maximization problem yields the function for labour productivity growth $\hat{a} = f(\omega, \delta)$, where $f'_\omega > 0$ and $f'_\delta < 0$: the higher the fraction of productivity pass-through, the weaker the firms' incentive to bias technical change towards labour-saving innovations for a given labour share. The dynamic system is now represented as follows:

$$\frac{\dot{a}_K}{a_K} = \phi[f(\omega, \delta)] \tag{70}$$

$$\frac{\dot{\omega}}{\omega} = h(v) - (1 - \delta) f(\omega, \delta) \tag{71}$$

$$\frac{\dot{v}}{v} = \frac{\dot{a}_K}{a_K} + g(\omega, a_K) - f(\omega, \delta) - n \tag{72}$$

Once again, the dynamic equation of the output-capital ratio (equation (70)) solves for the steady-state labour share $\omega^* = f^{-1}[\phi^{-1}(0), \delta]$, but now long-run income distribution is increasing in the bargaining parameter δ (i.e. $d\omega^*/d\delta = -f'_\delta / f'_\omega > 0$). The economic intuition is that an increase in the partial pass-through of labour productivity to wages requires a higher share of wages in total costs to induce a Harrod-neutral direction of technical change. If productivity increases were not passed through (i.e. $\delta = 0$), the firm's maximization problem would reduce to a standard one and the dynamical system would reduce to equations (67)-(69), with no steady-state effects of the bargaining parameter. Thus, postulating a partial productivity pass-through and internalizing the wage-setting process allows labour market institutions to have long-run distributional effects.

However, labour productivity growth is still determined by the position of the innovation

[17] Labour market institutions do not have persistent effects on income distribution, capital accumulation and labour productivity growth, but only reduce the long-run employment rate, even in the original model with exogenous labour productivity growth and in the Goodwin model with non-microfounded induced technical change (see Chapter I).

possibility frontier (i.e. $\hat{a}^* = \phi^{-1}(0)$) and unaffected by labour market institutions. Thus, the equilibrium employment rate has to decline to make real wage growth consistent with technology-determined labour productivity growth (i.e. $dv^*/d\delta = -\hat{a}^*/h'_v < 0$). Long-run capital accumulation is anchored to labour productivity growth via the dynamic equation of the employment rate (i.e. $g^* = \phi^{-1}(0) + n$).

Tavani (2012) studies a model of growth cycle with induced innovation in which the wage-setting process takes the form of a strategic interaction *à la* Nash. Capitalists and workers are assumed to have preferences equal to their respective utility differentials between the case an agreement is struck and a fallback position. The weight attached to workers' preferences in the joint maximization problem is taken as a measure of workers' bargaining strength. The solution yields a function for the labour share $\omega = \varphi(v, \delta)$, with $\varphi'_v > 0$ and $\varphi'_\delta > 0$, which is in turn incorporated into the firm's choice of techniques. The optimal direction of technical change then identifies two functions for the rates of capital-saving innovations $\hat{a}_K = F^K(v, \delta)$ and labour-saving innovations $\hat{a} = F^L(v, \delta)$, with $F_v^{K\prime} < 0$, $F_\delta^{K\prime} < 0$, $F_v^{L\prime} > 0$, and $F_\delta^{L\prime} > 0$. As income distribution is set outside the dynamical system, the model can be represented in the two-dimensional state space:

$$\frac{\dot{a}_K}{a_K} = F^K(v, \delta) \tag{73}$$

$$\frac{\dot{v}}{v} = \frac{\dot{a}_K}{a_K} + g[\varphi(v, \delta), a_K] - F^L(v, \delta) - n \tag{74}$$

In contrast to the standard Goodwin model with induced innovation, the dynamic equation of the output-capital ratio (equation (73)) solves for the steady-state employment rate $v^* = F^{K^{-1}}(0, \delta)$. Thus, it is the employment rate, rather than the wage share, that adjusts so as to ensure a Harrod-neutral direction of technical change in the long run. The model then combines a technology-determined employment rate with a social determination of income distribution, which is formalized by the bargaining game *à la* Nash. However, the long-run employment rate is still negatively related to labour market regulation (i.e. $dv^*/d\delta = -F_\delta^{K\prime}/F_v^{K\prime} < 0$), as the downward pressure on the output-capital ratio arising from an increase in the workers' bargaining power has to be offset by a decline in the employment rate.

The solution proposed by Cruz Luzuriaga and Tavani (2021) allows labour market institutions to have long-run effects on income distribution, capital accumulation, and labour productivity growth and opens up the possibility of wage-led employment. They formalize labour market institutions as an exogenous shift parameter for both the innovation possibility frontier and the real Phillips curve. The dynamical system can be described as follows:[18]

$$\frac{\dot{a}_K}{a_K} = \phi[f(\omega), \delta] \tag{75}$$

$$\frac{\dot{\omega}}{\omega} = h(v, \delta) - f(\omega) \tag{76}$$

$$\frac{\dot{v}}{v} = \frac{\dot{a}_K}{a_K} + g(\omega, a_K) - f(\omega) - n \tag{77}$$

where $\phi'_\delta > 0$.

[18] In Cruz Luzuriaga and Tavani (2021), the institutional variable also enters into the function of labour productivity growth. However, the main comparative statics results are fundamentally unchanged if we adopt the simplified version represented by equations (75)-(77).

As in the standard Goodwin model, the dynamic equation of the output-capital ratio solves for the steady-state wage share $\omega^* = f^{-1}[\phi^{-1}(0, \delta)]$, which now positively responds to labour market institutions δ (i.e. $d\omega^*/d\delta = -\phi'_\delta/\phi'_{\hat{a}} f'_\omega > 0$). As the bargaining parameter is supposed to directly affect the innovation possibility frontier, labour productivity growth is increasing in the workers' bargaining power (i.e. $d\hat{a}^*/d\delta = -\phi'_\delta/\phi'_{\hat{a}} > 0$). Long-run capital accumulation, which is anchored to labour productivity growth via the dynamic equation of the employment rate (i.e. $g^* = \phi^{-1}(0, \delta) + n$), rises with labour market regulation as well. The output-capital ratio declines so as to restore a constant employment rate (equation (77)). Provided that the response of labour-saving innovations to labour market institutions is strong enough, as compared to the response of real wages (i.e. $d\hat{a}^*/d\delta > h'_v$), the employment rate is positively associated with the labour share in the long run. The overall picture then is one of a negative link between the labour share and economic activity at business cycle frequencies and a positive association between the labour share and capital accumulation in the long-run, where both income distribution and the rate of growth of the economy are endogenous to labour market institutions.

This paper follows a different path. In order to make the comparison easier, we rewrite our model as follows:

$$\frac{\dot{a}_K}{a_K} = \phi\{f^H[z, \mu(e)], f^L[z, \mu(e)]\} \tag{78}$$

$$\frac{\dot{z}}{z} = h(e, \alpha) - \beta - f^H[z, \mu(e)] + f^L[z, \mu(e)] \tag{79}$$

$$\frac{\dot{e}}{e} = \frac{\dot{a}_K}{a_K} + g[z, \mu(e), a_K] - f^H[z, \mu(e)] - n \tag{80}$$

The dynamic equation for the wage share of the Goodwin model is replaced by a dynamic equation for wage inequality, i.e. the relative unit labour costs (equation (79)), representing the dynamics of intra-working-class income distribution, rather than the conflict over income distribution between capital and labour. As the economy is high-skilled-labour constrained, a dynamic equation for employment is defined only for high-skilled labour (equation (80)), and the antagonistic relationship between capital and labour is represented by a negative response of profitability to the high-skilled employment rate – that affects the dynamic behaviour of all variables – and by a nominal Phillips curve for the wage formation of the high-skilled workers.

In contrast to the standard Goodwin model with induced innovation and homogenous labour force, the steady-state value of the distributive variable is not determined only by the dynamic equation of the output-capital ratio, and both the distributive variable and the employment rate adjust so as to stabilize the output-capital ratio and the distributive variable. Therefore, there are different combinations of wage inequality and employment that are consistent with the firm's optimal choice of techniques, a constant output-capital ratio, and a profile of technical change characterized by both high-skilled- and low-skilled-labour-augmenting technologies in the long run. The AK isocline is then represented by an inverted U-shaped curve, rather than a straight vertical line: due to the non-linearity of the effect of wage inequality, a constant output-capital ratio requires wage inequality and employment to go in the same direction if $z < \bar{z}$, in the opposite direction if $z > \bar{z}$.

In the Goodwin model, the steady-state value of the distributive variable is determined by technology, whereas the long-run employment rate is determined by the labour market. Thus, a trade-off arises between labour market regulation and long-run employment: any attempt by workers to increase their income share can but result in a fall in employment, since an exogenous increase in workers' bargaining strength has to be offset by an "endogenous" decrease in order to keep the overall bargaining power of workers consistent with technology-determined income distribution.

Strengthening labour market regulation results in an unambiguous loss for the working class, as the decrease in the employment rate is not compensated by any gain on the distributional ground in the long run. As capital accumulation and labour productivity growth are dependent on long-run income distribution, a change in the institutional framework governing the conflict over income distribution between capitalists and workers does not have other permanent effects on the outcomes of the economy.

In our model, firm's technical choices and the equilibrium in the labour market determine both the steady-state value of the distributive variable and long-run employment. As different combinations of wage inequality and employment are consistent with the equilibrium in the labour market and a constant output-capital ratio, our model restores a channel through which labour market institutions may affect long-run income distribution, capital accumulation and labour productivity growth.

An increase in the bargaining power of a fraction of the working class may have a positive effect on capital accumulation, high-skilled labour productivity growth and low-skilled labour productivity growth. Since, in a high-skilled-labour-constrained economy, capital accumulation is driven by high-skilled labour productivity growth, an improvement of the bargaining position of the high-skilled workers leads to faster capital accumulation, whereas an increase in the low-skilled workers' bargaining power leads to an increase in low-skilled labour productivity growth. As the direction of technical change is determined by the shares of capital, high-skilled and low-skilled labour in total costs, labour market institutions also affect long-run income distribution. An increase in the bargaining power of a fraction of the working of the working class always allows it to raise its income share. At some levels of wage inequality, the increase in the high-skilled or low-skilled labour share comes at the expense of capitalists. Therefore, as the profit share of income and long-run employment are inversely related, an improvement of the bargaining position of high-skilled or low-skilled workers needs not imply employment losses. A rise in the high-skilled workers' bargaining strength reduces the employment rate only in the presence of a high level of wage inequality. However, if the current level of wage inequality is high, an increase in the low-skilled workers' bargaining power improves both the distribution of wages and functional income distribution, while increasing employment in the long run.

7. CONCLUDING REMARKS

According to the conventional wisdom on skill-biased technical change, the increase in wage inequality experienced by many advanced economies over the last decades is the result of a purely technological process, that can only be counteracted by educational policies aiming to provide workers with the skills necessary to deal with technical change. The role of the institutions governing income distribution is explicitly neglected as a primary cause of changes in income distribution. By altering the effectiveness of union activity, labour market institutions may at most amplify the direct effect of skill-biased technical change on wage inequality.

This paper proposed an alternative framework for analyzing the interaction between labour market institutions, skill-biased technical change and income distribution. We extended the basic classical-Marxian growth model in order to include a heterogenous labour force, made up of high-skilled and low-skilled workers. Furthermore, we generalized the induced innovation hypothesis in order to admit technical change directed towards high-skilled or low-skilled labour. In a classical view, induced technical change is regarded as a weapon of capitalists for breaking the bargaining power of the working class or a fraction of it. The direction of technical change is then determined by the shares of capital, high-skilled labour and low-skilled labour in total costs.

We found that, in contrast to the neoclassical literature on skill-biased technical change, both wage inequality and the direction of technical change are determined by the institutional factors affecting the conflict over income distribution among social classes. The causality direction among skill-biased technical change, labour market institutions and wage inequality predicted by the neoclassical authors is then reversed. Institutional factors related to labour market regulation affect income inequality both directly, by altering the relative bargaining positions of the social classes in the labour market, and indirectly, by inducing different growth rates of high-skilled and low-skilled labour productivity growth, that are totally passed through to the real wages at the steady state. Thus, even if we assume that skill levels are the only source of heterogeneity across workers in the economy, and income distribution is affected by skill-biased technical change, the institutions that govern the distributive conflict are still a central determinant of both income distribution and the long-run macroeconomic outcomes. Institutional factors like the decline in unionization, the decentralization of the collective bargaining structure, the deterioration of the social protection system, and the liberalization of capital flows, that negatively affects the bargaining power of the working class, and particularly the bargaining power of the low-paid workers, lead to a rise in wage inequality and an increase in the skill bias of technical change. Furthermore, provided that the current level of wage inequality is high, an increase in the bargaining power of the high-skilled workers, as compared to the low-skilled workers, or an increase in the degree of product market concentration alter both functional income distribution in favour of the capitalist class and the distribution of wages in favour of the high-skilled workers. Finally, we proved that, in contrast to both the conventional view and the Goodwin model with induced innovation and a homogenous labour force, no necessary trade-offs arise between labour market regulation and employment even in a supply-side framework.

Even though the proposed framework is able to address some features of the relation between wage inequality and labour market regulation, more work is needed to provide a more complete view of the interaction between functional distribution, wage inequality, technical change and stagnation in labour productivity. Indeed, as in this model the steady-state growth path is characterized by high-skilled- and low-skilled-augmenting technical change, the economy does not evolve so as to achieve steady-state average labour productivity growth. Thus, the proposed framework does not allow examining the relation between labour market institutions and stagnation in labour productivity. Furthermore, while a classical-Marxian growth model provides some useful insights into the main issue of wage inequality and technical change, it does not incorporate effective demand. A more complete understanding can come from relaxing the assumption of full capacity utilization and postulating an independent investment function. Finally, education is not formalized. The model may be extended in terms of allowing low-skilled workers to acquire skills and convert themselves into high-skilled workers. This analysis is left for future research.

APPENDIX A

Remind that $\phi''_{\hat{a}_H\hat{a}_L} = 0$. Then, substituting equations (17) and (18) into equations (15) and (16), we find:

$$\phi'_{\hat{a}_H}\{f^H[z,\mu(e,\gamma)]\} = -\frac{z}{\mu(e,\gamma)(1+z)} \tag{A1}$$

$$\phi'_{\hat{a}_L}\{f^L[z,\mu(e,\gamma)]\} = -\frac{1}{\mu(e,\gamma)(1+z)} \tag{A2}$$

Totally differentiating equations (A1) and (A2) with respect to z and μ and rearranging, we have:

$$f_z^{H\prime} = -\frac{1}{\mu(e,\gamma)(1+z)^2}\frac{1}{\phi''_{\hat{a}_H\hat{a}_H}} > 0 \tag{A3}$$

$$f_z^{L\prime} = \frac{1}{\mu(e,\gamma)(1+z)^2}\frac{1}{\phi''_{\hat{a}_L\hat{a}_L}} < 0 \tag{A4}$$

$$f_\mu^{H\prime} = \frac{z}{[\mu(e,\gamma)]^2(1+z)}\frac{1}{\phi''_{\hat{a}_H\hat{a}_H}} < 0 \tag{A5}$$

$$f_\mu^{L\prime} = \frac{1}{[\mu(e,\gamma)]^2(1+z)}\frac{1}{\phi''_{\hat{a}_L\hat{a}_L}} < 0 \tag{A6}$$

It follows that:

$$\phi'_{\hat{a}_H} = z\phi'_{\hat{a}_L} \tag{A7}$$

$$f_z^{H\prime} = -\rho f_z^{L\prime} \tag{A8}$$

$$f_\mu^{H\prime} = \rho z f_\mu^{L\prime} \tag{A9}$$

where $\rho \equiv \phi''_{\hat{a}_L\hat{a}_L}/\phi''_{\hat{a}_H\hat{a}_H}$.

APPENDIX B

Taking logarithms of equation (5), after substituting from equation (12), and differentiating with respect to time, we find:

$$\frac{\dot{\omega}_H}{\omega_H}=\frac{\dot{z}}{z}-\frac{\mu_e'\dot{e}}{1+\mu}-\frac{\dot{z}}{1+z}=\frac{1}{1+z}\frac{\dot{z}}{z}-\frac{\mu_e'e}{1+\mu}\frac{\dot{e}}{e}=\omega_L\left[(1+\mu)\frac{\dot{z}}{z}-\mu_e'e(1+z)\frac{\dot{e}}{e}\right] \quad \text{(B1)}$$

Taking logarithms of equation (6), after substituting from equation (12), and differentiating with respect to time, we find:

$$\frac{\dot{\omega}_L}{\omega_L}=-\frac{\mu_e'\dot{e}}{1+\mu}-\frac{\dot{z}}{1+z}=-\left[\frac{\mu_e'e}{1+\mu}\frac{\dot{e}}{e}+\frac{z}{1+z}\frac{\dot{z}}{z}\right]=-\omega_L\left[z(1+\mu)\frac{\dot{z}}{z}+\mu_e'e(1+z)\frac{\dot{e}}{e}\right] \quad \text{(B2)}$$

Thus, $\dot{z}/z=\dot{e}/e=0$ implies $\dot{\omega}_H/\omega_H=\dot{\omega}_L/\omega_L=0$.
Taking logarithms of $\pi=1-\omega_H-\omega_L$ and differentiating with respect to time, we find:

$$\frac{\dot{\pi}}{\pi}=-\left(\frac{\dot{\omega}_H}{\pi}+\frac{\dot{\omega}_L}{\pi}\right)=-\left(\frac{\dot{\omega}_H}{\omega_H}\frac{\omega_H}{\pi}+\frac{\dot{\omega}_L}{\omega_L}\frac{\omega_L}{\pi}\right)=-\frac{\omega_L}{\pi}\left(z\frac{\dot{\omega}_H}{\omega_H}+\frac{\dot{\omega}_L}{\omega_L}\right) \quad \text{(B3)}$$

Thus, $\dot{\omega}_H/\omega_H=\dot{\omega}_L/\omega_L=0$ implies $\dot{\pi}/\pi=0$.
Taking logarithms of equation (5), after substituting from equation (12), and differentiating with respect to time, we find:

$$\begin{aligned}\frac{\dot{p}}{p}&=\frac{\mu_e'\dot{e}}{1+\mu}+\frac{\dot{w}_L}{w_L}-\frac{\dot{a}_L}{a_L}+\frac{\dot{z}}{1+z}=\frac{\dot{w}_L}{w_L}-\frac{\dot{a}_L}{a_L}+\frac{\mu_e'e}{1+\mu}\frac{\dot{e}}{e}+\frac{z}{1+z}\frac{\dot{z}}{z}=\\&=\frac{\dot{w}_L}{w_L}-\frac{\dot{a}_L}{a_L}+\omega_L\left[z(1+\mu)\frac{\dot{z}}{z}+\mu_e'e(1+z)\frac{\dot{e}}{e}\right]\end{aligned} \quad \text{(B4)}$$

Thus, $\dot{z}/z=\dot{e}/e=0$ implies $\dot{p}/p=\dot{w}_L/w_L-\dot{a}_L/a_L$.
Using equation (20), we have:

$$\begin{aligned}\frac{\dot{p}}{p}&=\frac{\mu_e'e}{1+\mu}\frac{\dot{e}}{e}+\frac{z}{1+z}\frac{\dot{z}}{z}+\frac{\dot{w}_H}{w_H}-\frac{\dot{a}_H}{a_H}-\frac{\dot{z}}{z}=\frac{\dot{w}_H}{w_H}-\frac{\dot{a}_H}{a_H}+\frac{\mu_e'e}{1+\mu}\frac{\dot{e}}{e}-\frac{1}{1+z}\frac{\dot{z}}{z}=\\&=\frac{\dot{w}_H}{w_H}-\frac{\dot{a}_H}{a_H}-\omega_L\left[(1+\mu)\frac{\dot{z}}{z}-\mu_e'e(1+z)\frac{\dot{e}}{e}\right]\end{aligned} \quad \text{(B5)}$$

Thus, $\dot{z}/z=\dot{e}/e=0$ implies $\dot{p}/p=\dot{w}_H/w_H-\dot{a}_H/a_H$.

APPENDIX C

Differentiating equations (25) and (26) with respect to z, we find:

$$\phi'_{\hat{a}_H} f_z^{H\prime} + \phi'_{\hat{a}_L} f_z^{L\prime} + \left(\phi'_{\hat{a}_H} f_\mu^{H'} + \phi'_{\hat{a}_L} f_\mu^{L'}\right)\mu'_e \left.\frac{de}{dz}\right|_{AK} = 0 \tag{C1}$$

$$-\left(f_z^{H'} - f_z^{L'}\right) + \left[h'_e - \left(f_\mu^{H'} - f_\mu^{L'}\right)\mu'_e\right]\left.\frac{de}{dz}\right|_Z = 0 \tag{C2}$$

After simplifying and rearranging, we have:

$$\left.\frac{de}{dz}\right|_{AK} = -\frac{(1-\rho z) f_z^{L'}}{(1+\rho z^2) f_\mu^{L'} \mu'_e} \tag{C3}$$

$$\left.\frac{de}{dz}\right|_Z = -\frac{(1+\rho z) f_z^{L'}}{h'_e + (1-\rho z) f_\mu^{L'} \mu'_e} \tag{C4}$$

Accordingly, $de/dz|_{AK} > 0$ if and only if $z < \bar{z}$, whereas $de/dz|_Z > 0$ if and only if $h'_e + \Gamma_\mu \mu'_e > 0$ (remind that $\Gamma_\mu \equiv (1-\rho z) f_\mu^{L'}$).
Differentiating equations (25) and (26) with respect to γ, we find:

$$\left(\phi'_{\hat{a}_H} f_\mu^{H'} + \phi'_{\hat{a}_L} f_\mu^{L'}\right)\mu'_\gamma + \left(\phi'_{\hat{a}_H} f_\mu^{H'} + \phi'_{\hat{a}_L} f_\mu^{L'}\right)\mu'_e \left.\frac{\partial e}{\partial \gamma}\right|_{AK} = 0 \tag{C5}$$

$$-\left(f_\mu^{H'} - f_\mu^{L'}\right)\mu'_\gamma + \left[h'_e - \left(f_\mu^{H'} - f_\mu^{L'}\right)\mu'_e\right]\left.\frac{\partial e}{\partial \gamma}\right|_Z = 0 \tag{C6}$$

After simplifying and rearranging, we have:

$$\left.\frac{\partial e}{\partial \gamma}\right|_{AK} = -\frac{\mu'_\gamma}{\mu'_e} > 0 \tag{C7}$$

$$\left.\frac{\partial e}{\partial \gamma}\right|_Z = -\frac{(1-\rho z) f_\mu^{L'} \mu'_\gamma}{h'_e + (1-\rho z) f_\mu^{L'} \mu'_e} \tag{C8}$$

Accordingly, $\partial e/\partial \gamma|_Z > 0$ if and only if $h'_e + \Gamma_\mu \mu'_e > 0$ (remind that $\Gamma_\mu \equiv (1-\rho z) f_\mu^{L'}$).

APPENDIX D

For the numerical simulation, we specify the functional forms of equations (10), (12), and (13), as follows:

$$\phi = -\frac{1}{2\rho}\hat{a}_H^2 - \frac{1}{2}\hat{a}_L^2 - a\hat{a}_H - b\hat{a}_L + \tau, \qquad a > 0,\ b > 0,\ \rho > 0,\ \tau > 0 \tag{D1}$$

$$\frac{\dot{w}_H}{w_H} = \alpha + \frac{\lambda}{1-e}, \qquad \alpha < 0,\ \lambda > 0 \tag{D2}$$

$$\mu = \frac{\gamma}{e}, \qquad \gamma > 0 \tag{D3}$$

Equation (D1) is a quadratic function for the innovation possibility frontier with $\phi''_{\hat{a}_L\hat{a}_L} = -1$. We assume a non-linear specification for the relation between wage and employment, as in Desai, *et al.* (2006), but we express it as a nominal Phillips curve (equation (D2)). Equation (D3) is a non-linear specification for the relation between mark-up and high-skilled employment rate, such that if $e \to 1$, then $\mu \to \gamma$ and $\pi \to \gamma/(1+\gamma)$, if $e \to 0$, then $\mu \to \infty$ and $\pi \to 1$.
In this case, $\hat{a}_H$ and $\hat{a}_L$ are given by:

$$\hat{a}_H = \left[-a + \frac{ez}{\gamma(1+z)}\right]\rho \tag{D4}$$

$$\hat{a}_L = -b + \frac{e}{\gamma(1+z)} \tag{D5}$$

Thus, the dynamical system becomes:

$$\frac{\dot{a}_K}{a_K} = \frac{1}{2}(a^2\rho + b^2 + 2\tau) - \frac{1}{2}\left[\frac{1+\rho z^2}{\gamma^2(1+z)^2}\right]e^2 \tag{D6}$$

$$\frac{\dot{z}}{z} = \alpha - \beta + a\rho - b + \frac{\lambda\gamma(1+z) + (1-\rho z)(1-e)e}{\gamma(1+z)(1-e)} \tag{D7}$$

$$\frac{\dot{e}}{e} = \frac{\dot{a}_K}{a_K} + \frac{e}{\gamma+e}\left[\frac{\gamma + (\gamma+se)z}{e(1+z)}\right]a_K - \left[-a + \frac{ez}{\gamma(1+z)}\right]\rho - n \tag{D8}$$

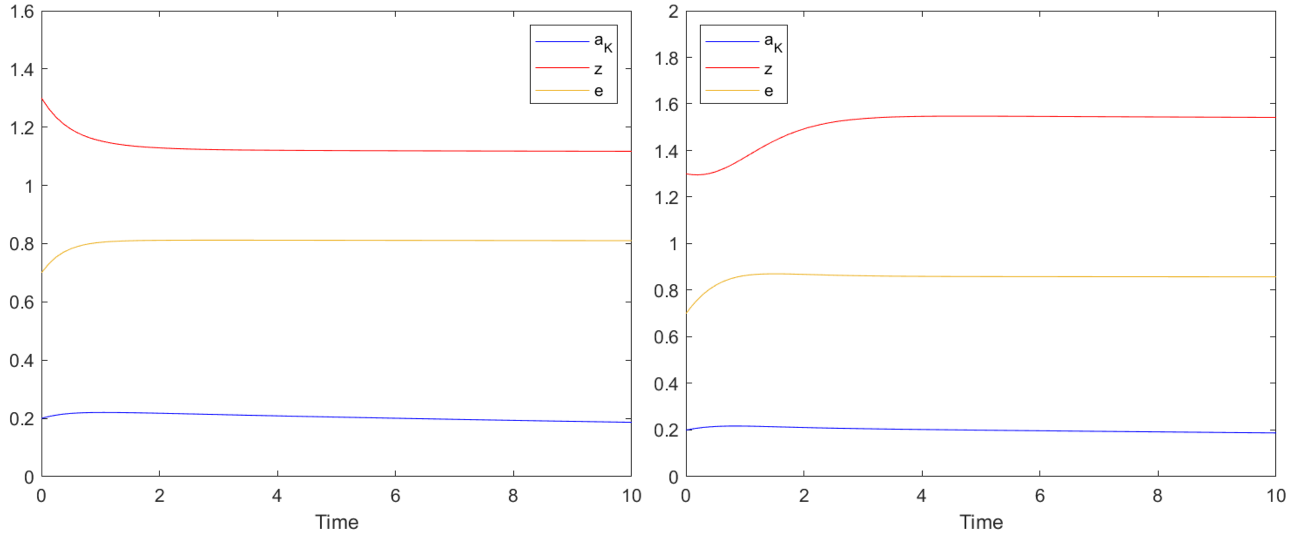
CASE 1: $z^* < \bar{z}$

In the baseline scenario (Figure 1a), we set the parameters as follows:

$$\begin{array}{ccccc} \tau = 0.058 & a = 1.185 & b = 1.09 & \rho = 0.8 & s = 0.2 \\ \alpha = -0.2 & \beta = 0.04 & \gamma = 0.345 & \lambda = 0.05 & n = 0.01 \end{array} \tag{D9}$$

Figures 2a, 3a, 4a display the long-run equilibrium values corresponding to a 1-percentage-point increase in α (i.e. $\alpha = -0.19$), a 1-percentage-point increase in β (i.e. $\beta = 0.05$), and a 0.5-percentage-points increase in γ (i.e. $\gamma = 0.35$), respectively.
Figure D1a shows that the dynamical system is locally stable in the baseline scenario. Small changes in the parameter values do not alter the stability properties of the system.

Fig. D1. *Convergence to the steady state in the baseline scenario*



a) Case I: $z^* < \bar{z}$ *b) Case II:* $z^* > \bar{z}$

Note: Time series of wage inequality (z), high-skilled employment rate (e), and output-capital ratio (a_K) in the baseline scenario. Initial values: $z(0) = 1.3$, $e(0) = 0.7$, $a_K(0) = 0.2$.

CASE 2: $z^* > \bar{z}$

In the baseline scenario (Figure 1b), we set the parameters as follows:

$$\begin{array}{lllll} \tau = 0.076 & a = 1.05 & b = 0.71 & \rho = 0.8 & s = 0.2 \\ \alpha = -0.27 & \beta = 0.04 & \gamma = 0.46 & \lambda = 0.05 & n = 0.005 \end{array} \quad \text{(D10)}$$

Figures 2b, 3b, 4b display the long-run equilibrium values corresponding to a 1-percentage-point increase in α (i.e. $\alpha = -0.26$), a 1-percentage-point increase in β (i.e. $\beta = 0.05$), and a 0.5-percentage-points increase in γ (i.e. $\gamma = 0.465$), respectively.
Figure D1b shows that the dynamical system is locally stable in the baseline scenario. Small changes in the parameter values do not alter the stability properties of the system.

APPENDIX E

Using equations (43), (44), (51), (52), (59) and (60), total differentiation of the dynamic equation of e evaluated at the equilibrium point with respect to α, β and γ yields:

$$\frac{da_K^*}{d\alpha} = \frac{h'_\alpha\left[(1-\rho z)g'_\mu - (1+\rho z^2)g'_z - \rho(1+z)f_z^{L'} f_\mu^{L'}\right]\mu'_e}{\sigma} \tag{E1}$$

$$\frac{da_K^*}{d\beta} = -\frac{\left[(1-\rho z)g'_\mu - (1+\rho z^2)g'_z - \rho(1+z)f_z^{L'} f_\mu^{L'}\right]\mu'_e}{\sigma} \tag{E2}$$

$$\frac{da_K^*}{d\gamma} = \frac{h'_e\left[(1+\rho z^2)g'_z f_\mu^{L'} - (1-\rho z)g'_\mu f_z^{L'} + \rho(1-z)f_z^{L'} f_\mu^{L'}\right]\mu'_\gamma}{\sigma} \tag{E3}$$

$z^* > \bar{z}$ implies $da_K^*/d\alpha > 0$ and $da_K^*/d\beta < 0$.
Using $\hat{p} = \widehat{w}_H - \hat{a}_H = \widehat{w}_L - \hat{a}_L$, we find:

$$\frac{d\hat{p}^*}{d\alpha} = -\frac{h'_\alpha \rho z(1+z)f_z^{L'} f_\mu^{L'} \mu'_e}{\sigma} > 0 \tag{E4}$$

$$\frac{d\hat{p}^*}{d\beta} = \frac{\left[(1-\rho z)h'_e - \rho(1+z)f_\mu^{L'} \mu'_e\right]f_z^{L'}}{\sigma} \tag{E5}$$

$$\frac{d\hat{p}^*}{d\gamma} = \frac{h'_e \rho z(1+z)f_z^{L'} f_\mu^{L'} \mu'_\gamma}{\sigma} > 0 \tag{E6}$$

$z^* > \bar{z}$ implies $d\hat{p}^*/d\beta > 0$.

Induced innovation, the distributive cycle, and the changing pattern of labour productivity cyclicality: a SVAR analysis for the US economy

Marco Stamegna*

Abstract The empirical literature on induced technical change has explored the long-run relationship between real wages and labour productivity but still lacks an explicit treatment of the implications of the wage-productivity nexus for the business cycle. The present paper aims to fill this gap. By employing a four-dimensional structural vector autoregressive (SVAR) model for the US economy (1948-2019), we test an extended version of the Goodwin model that includes aggregate demand and decomposes the labour share into real wages and labour productivity. This paper adds to the existing literature in some respects. First, it contributes to the induced innovation literature, by showing that wage shocks have positive and persistent effects on labour productivity at business cycle frequencies. Second, it adds to the debate and empirical evidence on the distributive cycle. Impulse response functions show that, even when decomposing the labour share, empirical evidence supports the Goodwin pattern, although the profit-led regime turns out to be driven more by technology than distributive shocks. Finally, we address two relevant cyclical stylized facts of the US economy: since the mid-1980s, the procyclical pattern of labour productivity has vanished, and real wages have no longer been correlated with employment over the business cycle. We explore the hypothesis that the two changes are linked. In light of the theory of induced innovation, we argue that the decline in the cyclical correlation between output and labour productivity can be explained by a lessened incentive to invest in labour-saving innovations due to missing wage growth in the upturn of the business cycle. Impulse response functions qualitatively support this intuition.

Keywords Labour productivity, endogenous technical change, income distribution, SVAR

JEL classification E12, E24, E25, E32

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1. INTRODUCTION

The procyclicality of labour productivity has conventionally been considered a defining feature of the business cycle in macroeconomic literature. Mainstream authors have long debated the source of this stylized fact. The New Keynesian explanation relies on labour hoarding, that is, variation in labour utilization over the business cycle, motivated by the presence of hiring and firing costs along the extensive margin of labour adjustment. By contrast, the proponents of the Real Business Cycle theory argue that procyclical labour productivity is the result of a business cycle driven by exogenous technology shocks. Thus, in mainstream economic literature, explaining the procyclical pattern of labour productivity has progressively become an empirical test for competing models of the business cycle (Basu, 1996; Basu and Kimball, 1997; Galí, 1999; Basu and Fernald, 2001; Basu, *et al.*, 2006).

More recently, the issue of procyclical labour productivity has also been addressed in non-orthodox economic literature. In this context, it has been invoked for its alleged implications for the relationship between income distribution and economic activity, namely for the demand and distributive regimes of the economy. Neo-Kaleckian authors argue that neo-Goodwinian findings of profit-led demand and profit-squeeze distribution regimes are the result of a failure to consider procyclical variations in labour productivity. On the empirical ground, they contend that if aggregative estimates of the demand regime were allowed to account for procyclical productivity, empirical evidence would not any longer support the Goodwin pattern (Lavoie, 2017; Cauvel, 2019; Fiebiger, 2022).

Since the mid-1980s, however, the procyclical pattern of US labour productivity has vanished, and output per worker and output per hour are no longer positively correlated with output or labour input. Productivity has shifted from strongly procyclical to roughly acyclical or weakly countercyclical relative to output, and from weakly procyclical to strongly countercyclical relative to employment and hours worked (Stiroh, 2009; Galí and Gambetti, 2009; Barnichon, 2010; Gordon, 2010; Fernald and Wang, 2016; Galí and van Rens, 2021). The changes in cyclical comovements among productivity, output, employment, and hours worked in the Euro area and other OECD countries have shown a similar pattern (Ohanian and Raffo, 2012; van Rens, 2012; Conti, *et al.*, 2019).

The decline in the cyclical correlation between output and labour productivity has been accompanied by another change in a key cyclical stylized fact: real wages appear to have become less responsive to fluctuations in economic activity and employment – namely, the real wage Phillips curve has become "flatter" (Roberts, 2006; Kuttner and Robinson, 2010; Galí and Gambetti, 2019). The transition of the US economy to the so-called Great Moderation period has indeed been marked by increasing labour market deregulation, in the form of deunionization, diffusion of part-time and temporary jobs, and reduction in workers' living standards, which have made it more difficult for workers to claim for higher wages in the upturn of the business cycle (Setterfield, 2005; 2021; Ratner and Sim, 2022).

This paper proposes a novel explanation for the change in the cyclical pattern of US labour productivity in light of the theory of distribution-induced technical change. It explores the hypothesis that the decline in the cyclical correlation between output and labour productivity is linked to the missing wage growth resulting from the flattening of the real wage Phillips curve. Thus, it argues that the reduced procyclicality of labour productivity is partially explained by a lessened incentive to invest in labour-saving innovations due to missing wage growth in the upturn of the business cycle. As real wages fail to sufficiently respond to labour market tightness, an increase in the level of economic activity does no longer raise labour productivity. The argument is briefly contrasted with competing explanations focusing on increasing labour market flexibility in the New Keynesian literature, which do not appear to be in line with some cyclical stylized facts of the US economy.

By employing a four-dimensional structural vector autoregressive (SVAR) model, I test an extended version of the Goodwin model that includes aggregate demand and decomposes the labour share into real wages and labour productivity. A non-recursive structure derived from Goodwinian theory is imposed on the matrix of contemporaneous effects. I consider two different periods, the post-war period (1948-1984) and the Great Moderation (1985-2019), in order to illustrate the changes in the properties of the US business cycle.

Thus, this paper adds to the existing literature in some respects. First, it contributes to the literature on induced technical change, by investigating the wage-productivity nexus at business cycle frequencies. Impulse response functions show that wage shocks have a positive and persistent effect on labour productivity in both periods, in accordance with the predictions of the theory.

Second, it adds to the debate and empirical evidence on the distributive cycle. I find that, even when decomposing the labour share into real wages and labour productivity, the US post-war period shows a profit-led demand and employment regime and a profit-squeeze distribution regime at business cycle frequencies. This result is robust to different measures of economic activity and labour market tightness. Moreover, controlling for procyclical productivity turns out to be irrelevant for evidence to support the existence of the distributive cycle, since allowing for a contemporaneous effect of demand on productivity does not fundamentally alter the main results. However, some theoretical questions remain open on the source of the profit-led regime, which appears to be largely driven by movements in labour productivity rather than in real wages.

Finally, this paper contributes to the literature on the change in the cyclical behaviour of US labour productivity. It claims that – together – the profit squeeze and induced technical change are an additional source of procyclicality in labour productivity. Differently from cyclical fluctuations in labour productivity implicit in Okun's Law, which are a mere artifact reflecting variable factor utilization, distribution-induced cyclicality in labour productivity reflects changes in the true state of technology of the economy over the business cycle. The stronger the decline in the profit share in the upturn of the business cycle, and the stronger the capitalists' incentive to preserve their profit margins by adopting labour-saving innovations, the more positive the cyclical comovements between output and labour productivity. Thus, this paper argues that the breakdown of the profit squeeze distribution regime in the Great Moderation, in the form of a flattening of the real wage Phillips curve, may account for part of the decline in the procyclicality of labour productivity. Impulse response functions qualitatively support this view.

The remainder of this paper is organized as follows. Section 2 provides an extensive discussion of the related literature and the main contributions of this paper. Section 3 documents some stylized facts about the US post-war period and the Great Moderation, with a special focus on the changing patterns of labour productivity cyclicality and employment-wage correlation. Section 4 derives the basic hypotheses that motivate this analysis. Section 5 describes data sources and the theoretical premises of our identification strategy. Section 6 discusses the main findings derived from impulse response functions, forecast error variance decomposition, and the estimated structural coefficients of the model. Section 7 shows that the main results are robust to different model specifications. Section 8 then concludes.

2. RELATED LITERATURE

This paper is related to the recent empirical literature on distribution-induced innovation. The theory of induced technical change states that an increase in real wages, relative to labour productivity, fosters the adoption of labour-augmenting innovations. In the classical and Marxian approach to induced innovation, labour-augmenting technical change is thought of as a weapon of the capitalist class in the capital-labour conflict, as it allows capitalists to defend their profit margins in the face of rising labour costs (Foley, 2003; Julius, 2005; Rada, 2012; Tavani, 2012; 2013; Zamparelli, 2015; Tavani and Zamparelli, 2018; Foley, *et al.*, 2019). This theory implies a classical narrative on secular stagnation relating the slowdown in capital accumulation and labour productivity growth in advanced economies to the decline in the labour share of income (Petach and Tavani, 2020; Barrales-Ruiz, *et al.*, 2021; Cruz Luzuriaga and Tavani, 2021; Rada, *et al.*, 2021).[1]

Some recent empirical works have tested the main predictions of the theory of induced innovation. Marquetti (2004) uses a vector error correction model to identify the long-run relationship between real wages and labour productivity in the US economy. He finds that the two series are cointegrated, with unidirectional Granger causality going from real wages to labour productivity. De Souza (2017) extends this methodology to a panel of industries and developed and developing countries and finds evidence of cointegration and bidirectional Granger causality between real wages and labour productivity, providing empirical support to distribution-induced innovation and long-run stationarity in the labour share. Dávila-Fernández (2020), by applying a panel vector autoregressive model to a sample of OECD countries, finds that positive shocks to the ratio of labour to capital share raise labour productivity growth, in line with the predictions of models of endogenous technical change based on an innovation possibility frontier (Kennedy, 1964; Samuelson, 1965).

Other studies, albeit not explicitly related to the theory of induced technical change, give empirical support to its central argument of a positive long-run association between the labour share and output growth. Charpe, *et al.* (2019) apply wavelet analysis to the UK, France, and the US economies in order to investigate the relationship between the labour share and economic growth across different time frequencies. They find that the labour share depresses growth at low frequencies but leads growth in the long run. Li and Mendieta-Muñoz (2020), by using a time-varying parameter model, provide evidence of a decline in the natural rate of growth in G7 countries that started much before the Great Recession and was mainly driven by a fall in the technical progress component – a result that can be consistent with the theory of induced innovation. Kiefer, *et al.* (2020) estimate the potential output rate of growth for the US economy conditional on the dynamic interaction between the labour share and economic activity at the business cycle level and, even without making a specific causal claim, conclude that the labour share and output gap have shared a downward trajectory over decades.

Second, this paper is related to the growing empirical literature on the distributive cycle. Building on the original Goodwin (1967) model of the growth cycle and the more flexible neo-Goodwinian model by Barbosa-Filho and Taylor (2006), the theory of the distributive cycle predicts counterclockwise cycles in the employment-labour share plane and the utilization-labour share plane, as a result of the combination of a profit-led demand and employment regime and a profit-squeeze distribution regime at business cycle frequencies. The original framework has been extended to incorporate a counterclockwise cycle in the utilization-employment plane of the kind observed in the US and other OECD countries (Zipperer and Skott, 2011; von Arnim and Barrales, 2015; Araujo, *et al.*, 2019).

While original empirical studies (e.g. Desai, 1984; Harvie, 2000) tried to find Goodwin cycles in the long-run waves of employment and distribution, the more recent empirical research looks at the short-run patterns in economic activity and distribution around a long-run trend determined by structural and institutional changes (Mohun and Veneziani, 2008) and makes extensive use of the vector autoregressive (VAR) methodology.[2]

Barbosa-Filho and Taylor (2006) employ a reduced-form VAR to estimate the slopes of the distributive curve and the effective demand curve for the US economy. Their findings – a positively sloped distributive curve and a negatively sloped effective demand curve – empirically support the

[1] See also Chapter I, in which I show that only a classical narrative on secular stagnation can arise from a Kaleckian growth model of a labour-constrained economy with induced innovation, conditional on institutional shocks.

[2] For an extensive review of the theoretical debate and empirical evidence on the distributive cycle, see Barrales-Ruiz, *et al.* (2021).

existence of the Goodwin pattern in the utilization-distribution plane. Kiefer and Rada (2015) estimate a panel VAR for some OECD countries and find evidence of a counterclockwise cycle in the utilization-labour share plane around a downward trend in both variables. Araujo, *et al.* (2019) show that empirical evidence in favour of the Goodwin pattern in the employment-distribution plane for the US economy is robust to the use of different filtering techniques.

Barrales-Ruiz, *et al.* (2021) claim that recursive VAR models based on classical-Keynesian theory should always allow the labour share to have a contemporaneous effect on the economic activity variable, but not the other way around, as this "standard ordering" reflects a rapidly adjusting goods market and a slowly adjusting labour share. These identifying restrictions support the Goodwin pattern for the US in both the employment-distribution plane and the utilization-distribution plane. However, they find that even the "reverse ordering" confirms the profit-squeeze distribution regime. Basu, *et al.* (2013) employ a three-dimensional VAR to test an extended version of the Goodwin model for the US including fixed investment and show that the finding of a cyclical profit squeeze does not depend on the ordering of the variables. The augmented six-dimensional VAR by Basu and Gautham (2019), who apply the recursive identification strategy proposed by Christiano, *et al.* (1999), confirms that adverse shocks to the labour share have a positive impact on utilization, employment, and capital accumulation at business cycle frequencies.

This paper adds to the more recent empirical research using SVAR methodology, in which a non-recursive structure derived from neo-Goodwnian theory is imposed on the matrix of contemporaneous effects. Santetti (n.d.) tests two extended versions of the Goodwin model, by imposing non-recursive restrictions on the A matrix of an AB-type SVAR model[3] and using the cyclical trajectories technique for impulse responses presented in Nikiforos, *et al.* (2021). The first model is a four-dimensional SVAR model including output, labour share, employment, and investment. The second model is a five-dimensional SVAR model splitting investment into its residential and nonresidential components. Cyclical trajectories derived from the two models support neo-Goodwinian findings of profit-led demand and employment, profit-squeeze distribution, and the leading role of investment over the business cycle. Mendieta-Muñoz, *et al.* (2020) estimate a four-dimensional SVAR in output, real wages, unemployment, and labour productivity with a non-recursive strategy to identify the structural innovations driving the labour share in the post-war era and in the neoliberal era of the US economy. Albeit not explicitly focusing on the demand and distributive regimes, they motivate the restrictions on the A matrix on the basis of neo-Goodwinian theory.

On a theoretical ground, some authors have integrated the induced innovation hypothesis into the Goodwin model and explored the implications for the dynamic stability properties of the growth cycle. The introduction of induced innovation makes the equilibrium point a stable focus (Shah and Desai, 1981; van der Ploeg, 1987; Foley, 2003). However, neither the literature on induced innovation nor the literature on the distributive cycle have explored the implications of the wage-productivity nexus for the business cycle on the empirical ground. The purpose of this paper is to fill this gap. By decomposing the labour share into real wages and labour productivity and apply filtering techniques, I show that the distribution-induced innovation mechanism starts operating at business cycle frequencies. Thus, part of the changes in labour productivity over the business cycle are in fact the result of wage-led technology shocks, reflecting the capitalists' incentive to invest in labour-saving innovations in response to rising real wages.

The decomposition of the labour share allows addressing the issue of the implications of cyclical variation in labour productivity for the demand, employment, and distributive regimes of the economy. Indeed, an increase in the labour share can be caused either by an increase in real wages or by a decrease in labour productivity. Thus, in the context of a decomposed labour share, a demand regime is profit-led if a distributive or technology shock raising the labour share has a negative effect

[3] See Lütkepohl (2005, Section 9.1).

on economic activity at business cycle frequencies,[4] and a distributive regime is profit-squeeze if a positive shock to the economic activity raises real wages and/or reduces labour productivity.

More recently, the issue of procyclical labour productivity has been invoked by supporters of wage-led growth to question the existence or the drivers of the Goodwin pattern. Fiebiger (2022) lists procyclical variation in labour productivity due to overhead labour (i.e. labour employed in proportion to productive capacity, as opposed to "direct labour" employed in proportion to actual output) among the six cyclical stylized facts for which neo-Goodwinian theory fails to offer a consistent explanation. Lavoie (2017) claims that the negative cyclical comovements between economic activity and labour share observed in the first phase of booms and recessions reflect procyclical productivity rather than profit-led demand. Thus, in his view, the Goodwin pattern is the result of a combination of procyclical profit share and external drivers of output rather than of cyclical fluctuations in the reserve army of labour driven by profit-led capital accumulation. His argument implies that empirical studies that fail to account for procyclicality in labour productivity could be biased towards finding profit-led demand and mistakenly be interpreted as supportive of the Marxian view of the business cycle. Cauvel (2019) estimates a three-dimensional recursive VAR in capacity utilization, real wages, and labour productivity for the US under different variable orderings. He finds that only the standard ordering confirms profit-led demand and profit-squeeze distribution. Results based on identifying restrictions that demand contemporaneously affects labour productivity no longer support the Goodwin pattern.

In the baseline model of this paper, demand only has a lagged effect on labour productivity, as in standard empirical works motivated on the basis of neo-Goodwinian theory. As a robustness check, I estimate an alternative model specification allowing for a contemporaneous effect of demand on productivity. Both models lead to qualitatively similar results, thus calling into question the relevance of procyclical labour productivity for empirical evidence to support the existence of the Goodwin pattern. However, irrespective of the chosen identification strategy, the profit-led regime appears to be largely driven by technology rather than distributive shocks – a result which opens relevant theoretical questions.

Finally, this paper relates to the debate on the decline in the cyclical correlation of US labour productivity with output and employment. New Keynesian authors have proposed several explanations for these changes, broadly falling into two categories: (i) changes in the volatility of demand shocks relative to technology shocks, and (ii) changes in the response of labour productivity to demand shocks, mainly (but not only) as a result of changes in firms' labour hoarding behaviour due to increasing labour market flexibility.[5]

The first explanation relies upon the argument that, in DSGE models with sticky prices and labour market frictions, demand shocks and technology shocks trigger opposite short-run comovements in employment and productivity. Positive demand shocks increase output, employment and – via Okun's Law – labour productivity. By contrast, following a positive technology shock, sticky prices prevent aggregate demand from increasing as much as productivity. As firms use less labour to produce the same amount of output, positive technology shocks generate negative cyclical

[4] The definition is similar to the one in Nikiforos and Foley (2012). However, in their analysis of the implications of a U-shaped distributive curve, distributive and technology shocks lead to exogenous shifts in the distributive curve, and their definition of profit-led economy refers to the steady-state effects of exogenous changes in income distribution. In this paper, the focus is on the impact of distributive and technology shocks on economic activity at business cycle frequencies, which determines the *slope* of the demand curve.

[5] A detailed discussion of New Keynesian explanations for the changes in the cyclical pattern of US labour productivity is beyond the scope of this paper. In this section, I limit myself to discuss the hypotheses that can be easily compared with the central argument of the paper. Other explanations include increased importance of reallocative shocks relative to aggregate shocks (Garin, *et al.*, 2018), changes in the structure of labour compensation (Nucci and Riggi, 2011), increased persistence of technology shocks, and shifts in the structure of the economy towards the service sector (Wang, 2014). For an extensive review of the evolution of the consensus on the cyclical behaviour of productivity, as well as the main hypotheses for the vanishing procyclicality in the New Keynesian literature and empirical evidence in favour and against each of them, see Fernald and Wang (2016).

comovements between employment and productivity (Basu, 1996; Galí and Gambetti, 1999). Thus, the decline in the procyclicality of labour productivity is ascribed by some New Keynesian authors to the diminished importance of demand shocks relative to technology shocks, with the former having become less volatile than the latter in the Great Moderation period (Galí and Gambetti, 2009; Barnichon, 2010; Daly, *et al*, 2015). This change in relative volatility is often attributed to the improved conduct of monetary policy, which is supposed to have become more effective in accommodating changes in potential output resulting from technology shocks (Galí, *et al.*, 2003; Galí and Gambetti, 2009).

The second explanation posits that labour productivity has become less procyclical conditional on demand shocks, mainly as a result of increased labour market flexibility, which has made it less costly for firms to hire and fire workers in response to fluctuations in demand. The labour market argument rests on the assumption that firms face a trade-off between adjusting the extensive margin (i.e. the number of employees) and adjusting the intensive margin (i.e. hours per worker or labour effort) in the upturn and downturn of the business cycle. Increased labour market flexibility, by reducing adjustment costs along the extensive margin, causes firms to rely more on adjusting the extensive margin relative to the intensive one in the face of changes in demand. As a result, the relative volatility of employment increases and observed labour productivity varies less positively over the cycle (Barnichon, 2010; Daly, *et al*, 2015; Galí and van Rens, 2021).

This explanation suffers from some shortcomings. Indeed, increased labour market flexibility may affect both the extensive and the intensive margins of adjustment. The labour market argument rests on the assumption that labour market reforms have made the cost of adjusting employment fall more than the cost of adjusting hours per worker, which is not clear a priori. An implication is that employment should have become more volatile relative to hours per worker in the Great Moderation period. However, empirical evidence on this point is at best inconclusive.[6] Wang (2014) examines the volatility of employment and hours per worker using industry-level data for the US. She finds that both margins of adjustment have become more volatile relative to output, but employment has become less, rather than more, volatile relative to hours per worker in most of the industries. Furthermore, the change in the cyclicality of labour productivity appears not to be correlated with the change in the relative volatility at the industry level. Van Rens (2012) investigates the importance of intensive and extensive margins of adjustment in European countries as compared to the US. He finds that, despite the evidence that labour market frictions are higher in European countries, adjustments along the intensive margin are not significantly more important in Europe than in the US. In the next session, I document some stylized facts about the US economy that do not appear to support the labour market argument along New Keynesian lines.

This paper proposes a novel explanation along induced innovation lines, linking the decline in the cyclical correlation of labour productivity with output and employment to the flattening of the real wage Phillips curve associated with labour market deregulation during the Great Moderation period.[7] As Setterfield (2005; 2021) claim, neoliberal institutional changes have created an environment in which perpetual worker insecurity has replaced unemployment as the key labour market discipline device. Thus, in the neoliberal institutional structure, labour market disciplines workers at any rate of unemployment and prevents the profit squeeze in economic upturns. Here, I

[6] It is perhaps not by chance that Galí and van Rens (2021) use the injury incidence rate, instead of the more commonly used hours per worker, as a proxy for labour effort to support the labour market argument. That the US economy did not exhibit a clear changing pattern in the relative volatility of employment to hours per worker is indeed implicit in Galí and van Rens (2021, Table 2).

[7] Notice that, in this context, the expression "labour market deregulation" has a more specific meaning than in previous chapters. In the theoretical models of Chapters I and II, labour market institutions were formalized as a generic bargaining parameter of the Phillips curve, with no distinction between slope and intercept. Thus, labour market deregulation meant an adverse shock to workers' bargaining power that could either shift the curve downward or make it flatter. In this context, I explicitly refer to the slope of the curve, as labour market deregulation is supposed to affect the response of real wages to changes in the unemployment rate.

find that empirical evidence confirms the disappearance of the profit squeeze in the Great Moderation, and I draw a further implication for the properties of the business cycle. If labour productivity responds to real wages, but the latter fail to rise in the face of a tighter labour market, then labour productivity comoves less positively with output and employment over the business cycle.

The induced innovation argument implies that labour market deregulation in fact plays a role in explaining the changing pattern of labour productivity cyclicality in the US, but in a way different from the one described by New Keynesian authors. In the New Keynesian story, the decline in the cyclical correlation of labour productivity only reflects procyclical measurement errors related to variable factor utilization. If labour input could be correctly measured along both margins of adjustment, there would have been no change in the cyclical behaviour of productivity. By contrast, the labour market argument along induced innovation lines implies that the changing cyclicality of productivity reflects changes in the true state of technology of the economy over the business cycle. Thus, the breakdown of the profit squeeze associated with labour market deregulation has both short-run effects on the cyclicality of wages and productivity and long-run effects on economic growth. This paper adds to the literature on induced technical change and the real Phillips curve by addressing the impact on the cyclical behaviour of labour productivity.

3. STYLIZED FACTS

This section documents some stylized facts about output, labour productivity, real wages, and the employment rate for the US economy. The main fact that motivates this empirical investigation is the change in the cyclical behaviour of output and labour productivity in the transition from the post-war period to the Great Moderation. To the best of my knowledge, this is the first paper to provide an explanation for this change in light of the classical approach to induced innovation theory.

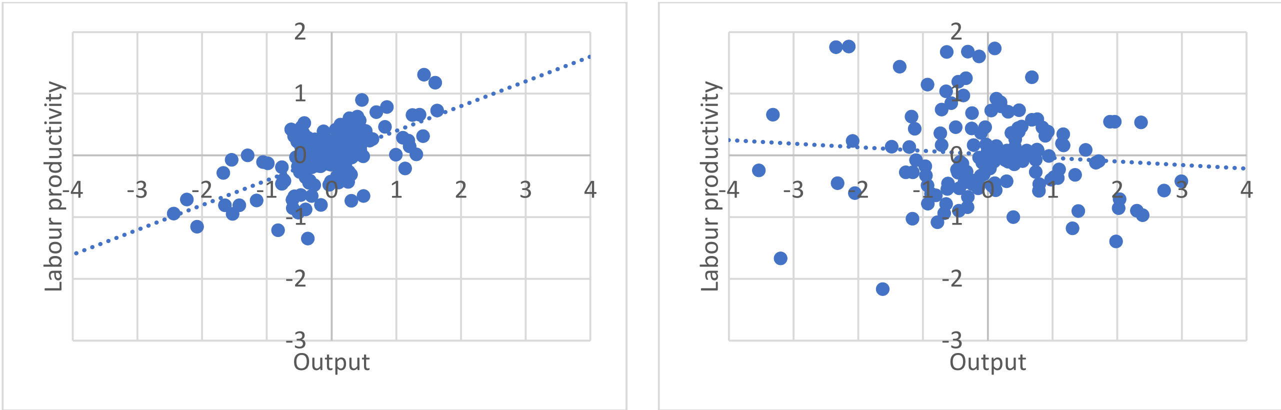
We use quarterly data for the US business and nonfarm business sectors over the period 1948Q1-2019Q4. We split the sample period into two subperiods, pre-1984 (1948Q1-1984Q4) and post-1984 (1985Q1-2019Q4), roughly corresponding to the post-war period and the Great Moderation. The break date we chose is in line with other empirical studies close in spirit to the present work, like Barnichon (2010), Mendieta-Muñoz, *et al.* (2020), and Galí and van Rens (2021). The employment rate is the complement of the civilian unemployment rate. Output, real wages, and labour productivity are computed as indices for the business and the nonfarm business sectors. The cyclical components of output, labour productivity, real wages, and employment rate in Figures 1-4 are obtained by applying the Hodrick-Prescott filter to the original series. Section 5.1 reports data description and data source of all variables of the baseline and robustness check SVAR models. Appendix A discusses further details. In this section, we limit ourselves to report the statistics of the main variables to introduce the central argument of the paper.

Figure 1 provides a graphical inspection of the change in the association between the cyclical components of output and labour productivity for the business sector in the transition from the post-war period to the Great Moderation. Figure 1a shows the scatter plot and the trend line of the relationship between output and labour productivity in the post-war period. Figure 1b displays the relationship between the two variables in the Great Moderation.[8]

As the two figures make clear, the positive association between the detrended components of output and labour productivity in the post-war period has turned into a slightly negative one in the Great Moderation. This is the first piece of evidence pointing to a change in the cyclical behaviour of

[8] For a more conventional representation of the cyclicality of the four variables in terms of time series plots, see Figure B1 in Appendix B.

Fig. 1. *Changes in the cyclical association between output and labour productivity*



a) Pre-1984 *b) Post-1984*

Notes: The series refer to the US business sector. Data are detrended using the HP filter with smoothing parameter λ=1600.

Tab. 1. *Changes in the relative volatility of labour productivity*

	Pre-1984	Post-1984
Raw series		
Business	1.090319	0.764879
Nonfarm business	1.010923	0.753470
HP filter		
Business	0.651620	0.622908
Nonfarm business	0.683534	0.602650

Note: The relative volatility of labour productivity is computed as the ratio of the standard deviation of labour productivity to the standard deviation of output.

output and productivity: since the mid-1980s, the pattern of the cyclicality of labour productivity has shifted from strongly procyclical to weakly countercyclical or acyclical relative to output.

The change in the cyclical association between output and labour productivity has been accompanied by a change in the volatility of labour productivity relative to the volatility of output. Table 1 summarises the evidence on relative volatility for the business and the nonfarm business sectors. Independently of whether we consider the original series or its detrended component, the relative volatility, measured as the ratio of the standard deviation of labour productivity to the standard deviation of output, has declined, consistently with our central hypothesis.

Table 2 provides evidence on changes in the volatility of two measures of labour input: employment rate and total hours worked. It displays absolute and relative standard deviations in the two subperiods for both the original and the HP-filtered series. The relative standard deviation is computed as the ratio of the standard deviation of hours to the standard deviation of employment.

Tab. 2. *Changes in the volatility of employment rate and hours worked*

	Absolute SD		SD relative to employment	
	Pre-1984	Post-1984	Pre-1984	Post-1984
<u>Raw series</u>				
Employment	1.752736	1.511437	–	–
Hours				
Business	7.579660	8.347409	4.324473	5.522829
Nonfarm business	9.346647	8.671981	5.332603	5.737574
<u>HP filter</u>				
Employment	0.934033	0.659006	–	–
Hours				
Business	1.264283	1.602440	1.353574	2.431602
Nonfarm business	1.252784	1.617608	1.341263	2.454618

Table B1 in Appendix B displays absolute and relative standard deviations of hours worked and employment levels for the business and the nonfarm business sectors.

The changes in absolute and relative standard deviations do not appear to support the labour market argument along New Keynesian lines. In the transition from the post-war period to Great Moderation, the US economy has faced a decline in the volatility of employment and – with the only exception of the raw series of hours in the nonfarm business sector – an increase in the volatility of hours. Independently of whether we consider the original or the transformed series, the relative volatility of total hours worked increased, suggesting growing importance of the intensive margin of adjustment (i.e. hours per worker) relative to the extensive one – a result in contrast with the basic New Keynesian argument.[9] By contrast, this piece of evidence does not affect the labour market argument along induced innovation lines.[10]

Figures 2-4 provide further evidence on the changes in the cyclical association among output, employment rate, real wages, and labour productivity for the business sector. As above, the left-hand figure shows the scatter plot and the trend line for the post-war period, the right-hand figure displays the corresponding scatter plot and trend line for the Great Moderation.

As the figures make clear, only the relationship between the employment rate and real wages has shown a significant change in the transition from the post-war period to the Great Moderation. By contrast, the patterns of association between output and employment rate, on the one hand, and real

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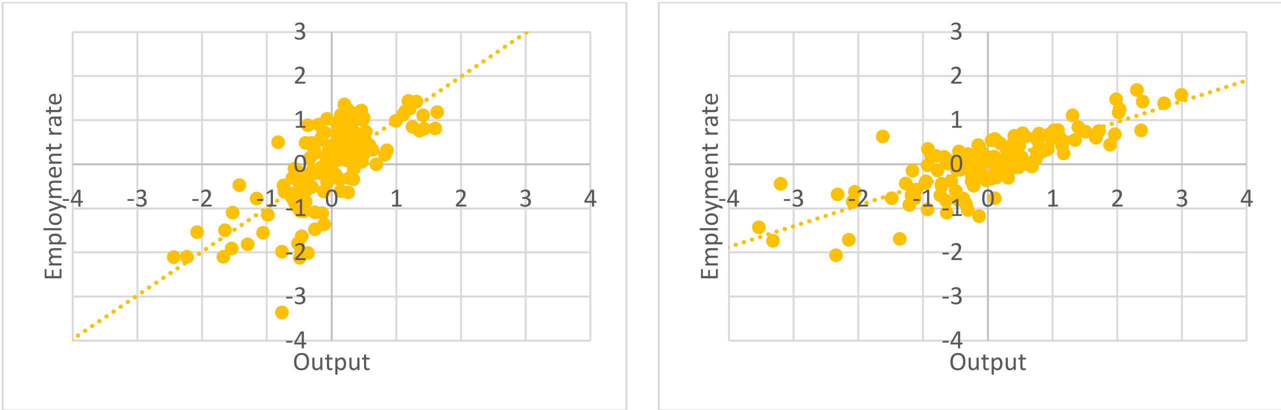
[9] Table B1 in Appendix B provides mixed evidence. The relative volatility of hours computed on the raw series increased – a result in contrast with the New Keynesian labour market argument. The relative volatility of hours computed on HP-filtered data indeed decreased, but the decline appears to be small, with the relative standard deviation falling between 5,3% and 5,9%.

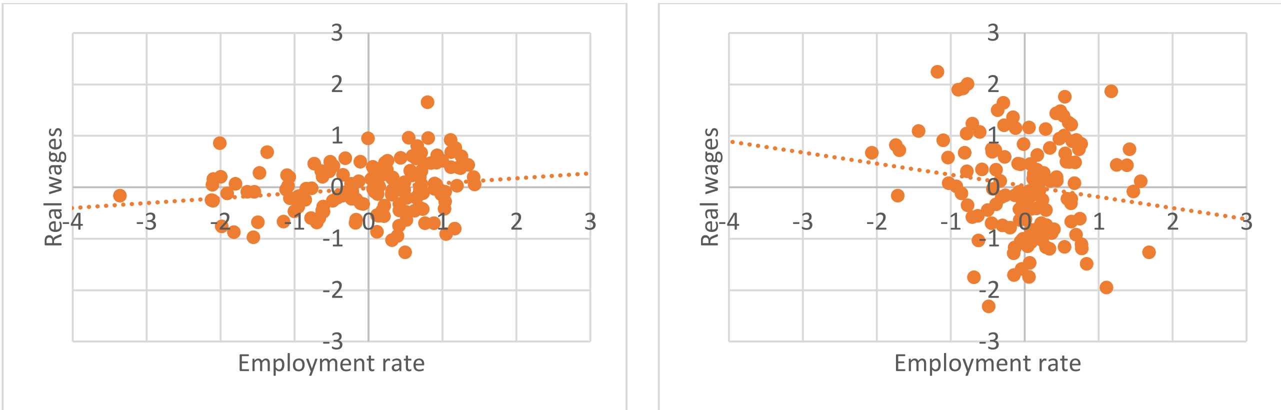
[10] Notice that this paper is silent on the factors behind the change in relative volatility of hours worked. We only want to stress that, while undermining the New Keynesian labour market argument, empirical evidence on the change in relative volatility of hours does not affect the core mechanism at play in the proposed explanation for the changing pattern of labour productivity cyclicality – induced innovation at business cycle frequencies. Moreover, Section 7 shows that the appearance of the induced innovation mechanism at business cycle frequencies is robust to the use of total hours worked as an alternative measure of labour market tightness. Thus, data support the induced innovation hypothesis – and the distributive cycle for the post-war period – irrespective of the chosen measure of labour input.

Fig. 2. *Changes in the cyclical association between output and employment rate*



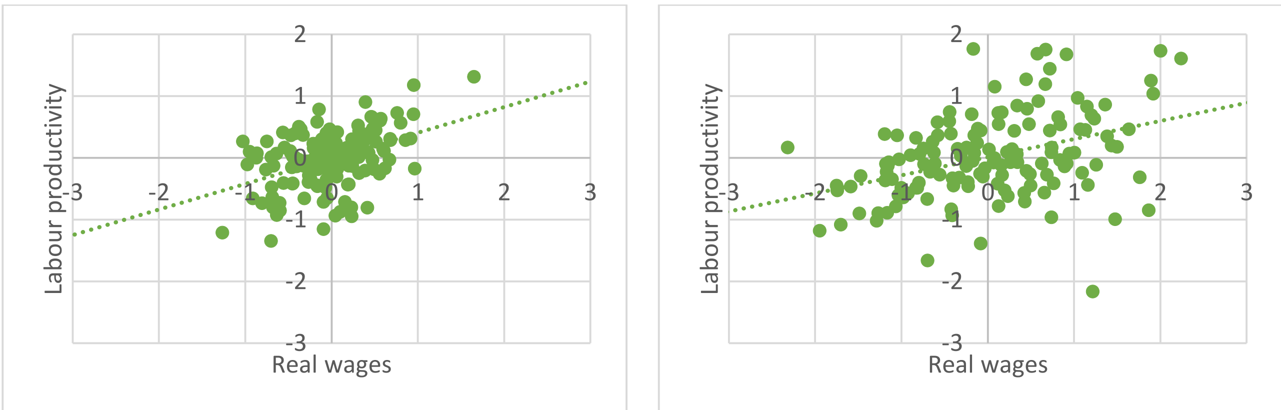
a) Pre-1984 *b) Post-1984*

Fig. 3. *Changes in the cyclical association between employment rate and real wages*



a) Pre-1984 *b) Post-1984*

Fig. 4. *Changes in the cyclical association between real wages and labour productivity*



a) Pre-1984 *b) Post-1984*

Notes: The series refer to the US business sector. Data are detrended using the HP filter with smoothing parameter λ=1600.

Tab. 3. *Changes in cyclical correlations among output, labour productivity, real wages, and employment rate*

	1948-2019	Pre-1984	Post-1984	Difference
Output and productivity				
Business	0.120604*	0.615566**	– 0.092602	– 0.708168**
Nonfarm business	0.144350*	0.644912**	– 0.102988	– 0.747900**
Output and employment				
Business	0.712182**	0.741029**	0.802749**	0.061720
Nonfarm business	0.718102**	0.740736**	0.807953**	0.067217
Employment and wages				
Business	– 0.003086	0.187372*	– 0.151279	– 0.338651**
Nonfarm business	– 0.014367	0.175681*	– 0.163206	– 0.338887**
Wages and productivity				
Business	0.403732**	0.437409**	0.394353**	– 0.043056
Nonfarm business	0.404737**	0.426605**	0.403346**	– 0.023259
Output and productivity (conditional on wages and employment)				
Business	0.342031**	0.696719**	0.802985**	0.106266*
Nonfarm business	0.360612**	0.736757**	0.789162**	0.052405

Note: * = significant at the 5% level, ** = significant at the 1% level.

wages and labour productivity, on the other hand, are qualitatively similar across the two subperiods. The employment rate comoved positively with output over the business cycle during both the post-war period and the Great Moderation, with only a modest decline in the slope of the trend line during the latter period (Figure 2). The slope of the trend line of employment rate and real wages has shifted from positive to negative since the mid-1980. Prior to 1985, real wages were weakly positively associated with the employment rate. Since 1985, however, the employment rate has become weakly negatively related to wages (Figure 3). The relationship between real wages and labour productivity is instead similar across the two subperiods, with labour productivity being strongly positively related to real wages at business cycle frequencies during both the post-war period and the Great Moderation (Figure 4).

Table 3 summarises the evidence on the changes in cyclical correlations among output, labour productivity, real wages, and the employment rate for the business and the nonfarm business sectors. For each pair of variables considered in Figures 1-4, Table 3 reports the computed correlation coefficients in the post-war period and the Great Moderation, as well as the subperiod difference. As above, data are detrended using the HP filter.

The first panel documents the strong decline in the cyclical correlation between output and labour productivity. Since the mid-1980s, both the business and the nonfarm business sectors have experienced a sign switch in the correlation between output and labour productivity over the cycle. Labour productivity has shifted from strongly procyclical in the post-war period to broadly acyclical in the Great Moderation. The subperiod difference is large and statistically significant at the 1% level in both sectors.

The second, third, and fourth panels show the changes in the correlation coefficients between output and employment rate, employment rate and real wages, and real wages and labour productivity, respectively. In both sectors, labour productivity is strongly positively correlated with real wages over the business cycle, with a correlation coefficient ranging from 0.40 in the post-war period to 0.43 in the Great Moderation. The subperiod difference is small and not statistically significant. The employment rate rises with output in both subperiods, and the difference is still small and not statistically significant. By contrast, both the business and the nonfarm business sectors exhibit a significant change in the cyclical correlation between the employment rate and real wages. The correlation coefficient ranged from 0.17 and 0.19 in the pre-1984 period, and became negative but not significant in the post-1984 period. The subperiod difference is large and statistically significant at the 1% level.

The last panel displays the cyclical correlation between output and labour productivity conditional on the employment rate and real wages. It shows that, after controlling for employment and wages, in the nonfarm business sector the correlation between output and productivity does not statistically differ across the two subperiods; in the business sector the difference, albeit still significant, is remarkably smaller.

Summarising, US labour productivity has become essentially uncorrelated with output at the business cycle level. The strong procyclicality of productivity of the postwar period has completely vanished. The volatility of labour productivity has also declined relative to the volatility of output. At the same time, real wages no longer rise with the employment rate. The positive correlation between the two variables in the postwar period has switched into a negative but not significant one in the Great Moderation. By contrast, the US economy has not experienced significant changes in the output-employment and wage-productivity correlations. Conditional on the employment rate and real wages, the change in the cyclical correlation between output and labour productivity turns out to be small or not significant.

Overall, we interpret these changes as prima facie evidence in favour of an induced innovation narrative on the changing pattern of labour productivity cyclicality. Our central argument posits that part of the positive cyclical comovements between output and labour productivity is induced by the profit squeeze in distribution that the economy faces in the upturn of the business cycle. This implies that the causality goes from output to labour productivity via employment and real wages. An increase in economic activity, by raising employment and wages, stimulates labour-saving innovations, thus making labour productivity more procyclical. If real wages fail to rise in response to an increase in economic activity, labour productivity comoves less positively with output at business cycle frequencies. A breakdown of the cyclical profit squeeze may then explain part of the vanished procyclicality of labour productivity in the Great Moderation. The next sections show that the results of our SVAR analysis qualitatively conform to this story.

4. Hypotheses

This section discloses the empirical hypotheses that motivate our analysis. All hypotheses reflect the purpose of (i) assessing the existence and the source of the Goodwin pattern, when the labour share is decomposed into real wages and labour productivity, (ii) testing the operation of induced innovation at business cycle frequencies, and (iii) evaluating if the effects of the structural innovations on output, employment, and real wages qualitatively conform to an induced innovation account of the diminished procyclicality of labour productivity. All hypotheses are phrased in terms of signs of the impulse responses to the structural shocks to output, employment, real wages, and labour productivity – the four variables included in our non-recursively identified SVAR model. Hypotheses 1-4 follow directly from a Goodwinian framework with induced innovation. Hypothesis 5 lists the sufficient conditions for the signs of the impulse responses to account for an induced innovation narrative on the vanishing procyclicality of labour productivity.

Denoting output by Y, the employment rate by e, and the labour share by $\omega = w/a$, where w is the real wage rate and a is labour productivity, we define our hypotheses as follows.

H1 – The economy exhibits a profit-led regime in both the (e, ω) and the (Y, ω) planes at business cycle frequencies, that is, an increase in the labour share lowers demand and employment in the short run.

H2 – The economy exhibits a profit-squeeze distribution regime in both the (e, ω) and the (Y, ω) planes at business cycle frequencies, that is, an increase in demand or employment raises the labour share in the short run.

Hypotheses 1 and 2 pertain to the *existence* of the Goodwin pattern, regardless of its source. The original Goodwin model and its subsequent developments predict counterclockwise cycles in the employment-labour share and the utilization-labour share planes, as a result of the combination of profit-led activity and profit-squeeze distribution. Economic activity leads the labour share, and the resulting profit squeeze generates a negative feedback on economic activity, giving rise to a cycle in the phase space. In a 3-D SVAR in output, employment, and labour share, this would imply a positive response of the labour share to shocks to output and employment and a negative response of employment and output to shocks to the labour share:

$$e \uparrow \; \Rightarrow \; \omega \uparrow \; \Rightarrow \; e \downarrow \tag{1}$$

$$Y \uparrow \; \Rightarrow \; \omega \uparrow \; \Rightarrow \; Y \downarrow \tag{2}$$

The standard story focuses on the Marxian mechanism of fluctuations of the reserve army of labour, resulting from the interaction of profit-constrained capital accumulation and rising wages in the face of a tightening labour market. Conditions for the recovery of profitability are restored via the labour market, as the slowdown in capital accumulation in the downturn of the business cycle replenishes the reserve army and puts downward pressure on wages. This story makes a precise statement about the *source* of the Goodwin pattern:

$$e \uparrow \; \Rightarrow \; w \uparrow \; \Rightarrow \; e \downarrow \tag{3}$$

$$Y \uparrow \; \Rightarrow \; w \uparrow \; \Rightarrow \; Y \downarrow \tag{4}$$

However, in the context of 4-D SVAR with a decomposed labour share, an increase in the labour share may be caused either by an increase in real wages or by a decrease in labour productivity. Thus, the Goodwin pattern may arise in principle either from the interaction between real wages and the employment rate (expressions (3) and (4)) or from the interaction between the employment rate and labour productivity:

$$e \uparrow \; \Rightarrow \; a \downarrow \; \Rightarrow \; e \downarrow \tag{5}$$

$$Y \uparrow \; \Rightarrow \; a \downarrow \; \Rightarrow \; Y \downarrow \tag{6}$$

or some combinations such that the overall effect is the one expressed by (1) and (2).

In this paper, we take a neutral theoretical stance on the overall causes of the Goodwin pattern. Hypotheses 1 and 2 concerns the *existence* of the Goodwin pattern, aiming to test (1) and (2) in the context of a decomposed labour share. Thus, for our purposes here, we limit ourselves to assess whether the economy exhibits profit-led activity and a profit squeeze in distribution at business cycle frequencies. A demand and employment regime is profit-led if a distributive or technology shock raising the labour share has a negative effect on output and employment, and a distributive regime is profit-squeeze if a positive shock to output and employment raises real wages and/or reduces labour productivity.[11]

H3 – A positive structural shock to the employment rate raises real wages.

Hypothesis 3 pertains to the *source* of the profit-squeeze distribution regime in the (ω, e) space. It states that at least part of the decline in the profit share in the upturn of the business cycle stems from real wage increases:

$$e \uparrow \Rightarrow w \uparrow \tag{7}$$

This hypothesis is in accordance with the conventional account of the source of the Goodwin pattern and with a real wage Phillips curve in mainstream economics.

H4 – A positive structural shock to the real wage raises labour productivity.

Hypothesis 4 is our empirical test for the induced innovation theory along classical-Marxian lines, that posits that an increase in labour costs acts as an incentive for firms to adopt labour-saving innovations. It is phrased in terms of response of labour productivity to real wages.

$$w \uparrow \Rightarrow a \uparrow \tag{8}$$

In the classical-Marxian view, labour-saving technical change is a weapon of the capitalist class in the distributive conflict, as it allows capitalists to counteract profit squeezing with increases in labour productivity.

H5 – If the following conditions are satisfied: (i) H4 holds in both the pre-1984 and the post-1984 periods, (ii) a demand shock raises employment in both the pre-1984 and the post-1984 periods, and (iii) H3 holds only in the pre-1984 period; then a failure of wages to sufficiently respond to employment accounts for part of the vanished procyclicality of labour productivity in the Great Moderation.

Hypothesis 5 summarises our induced innovation narrative on the changing pattern of cyclicality of US labour productivity. It posits that the real wage Phillips curve and induced technical change are an additional source of procyclicality in labour productivity. If the response of real wages to the employment rate is strong enough over the business cycle, and labour-saving innovations are driven by real wage increases, then labour productivity comoves more positively with output at business cycle frequencies:

$$Y \uparrow \Rightarrow e \uparrow \Rightarrow w \uparrow \Rightarrow a \uparrow \tag{9}$$

This hypothesis implies that, if distribution-induced technical change is a significant driver of labour productivity over the cycle, a vanishing real wage Phillips curve during the Great Moderation explains part of the reduced cyclicality of labour productivity. Thus, while in the post-war period an increase in economic activity led to an increase in labour productivity via employment and wages, as

[11] Of course, impulse response functions of our SVAR analysis give an additional piece of information on the source of the Goodwin pattern, but a theoretical investigation of the driving forces of the distributive cycle is not the main purpose of this paper. Thus, our findings in Sections 6-7 open theoretical questions for further research.

described by expression (9), in the Great Moderation labour productivity did not respond any longer to changes in economic activity via real Phillips curve:

$$Y \uparrow \;\Rightarrow\; e \uparrow \;\not\Rightarrow\; w \uparrow \;\Rightarrow\; a \uparrow \tag{10}$$

5. DATA AND EMPIRICAL METHODOLOGY

5.1. DATA

In the baseline model, we employ quarterly data for the US business sector coming from the Federal Reserve Bank of St. Louis Economic Database (FRED) and covering the period 1948Q1-2019Q4. We left out the post-2019 period due to the short time series available after the Covid-19 pandemic crisis. The employment rate is the reminder to 100 of the civilian unemployment rate. Time series of output, real wages, and labour productivity refer to the business sector. Real wages correspond to real hourly compensation. Labour productivity is defined as real output per hour. All variables except the employment rate are indexed as 2012 = 100. Appendix A reports further details on data description and data source of the variables used across all model specifications.

We chose 1984Q4 as a structural break date, in accordance with other empirical studies on the determinants of US income distribution in the spirit of neo-Goodwinian theory (Mendieta-Muñoz, *et al.*, 2020) or on the changes in the cyclical behaviour of US labour productivity (Barnichon, 2010; Galí and van Rens, 2021). Thus, we split the overall period into two subperiods: the post-war period (1948Q1-1984Q4) and the Great Moderation (1985Q1-2019Q4).

In the baseline and all robustness check models, data are detrended applying the Hodrick-Prescott filter, with smoothing parameter $\lambda = 1600$.

5.2. METHODOLOGY AND IDENTIFICATION STRATEGY

This paper uses a vector autoregressive (VAR) methodology to test the five hypotheses that motivate our analysis. Popularized by Sims (1980), VAR models have been widely used for multivariate time series analysis for their "atheoretical" structure, as they limit themselves to express each model variable in terms of its own lags and lags of the other model variables. However, a standard reduced-form VAR model cannot be given a causal interpretation, as it rules out contemporaneous correlations and its residuals are typically mutually correlated. Recovering the (mutually uncorrelated) structural shocks from the reduced-form representation of a VAR model requires imposing identifying restrictions on the data-generating process, motivated on the basis of economic theory.

In contrast to the more popular recursively identified models, our identification strategy orthogonalizes the reduced-form errors by imposing restrictions that do not constrain the matrix of contemporaneous effects to have a lower (or upper) triangular structure.[12] A non-recursive strategy is particularly appealing for high-dimensional VAR models in the spirit of classical-Keynesian theory, as it allows income distribution and economic activity to have contemporaneous effects on each other. In low-dimensional models including only one variable for economic activity (either output/utilization or employment) and one distributive variable, structural innovations can be

[12] For a similar non-recursive identification strategy in empirical studies on the distributive cycle, see Santetti (n.d.) and Mendieta-Muñoz, *et al.* (2021).

properly identified by means of a recursive strategy, as the "standard ordering" of variables can be easily motivated on a theoretical ground.[13] However, in the context of higher-dimensional VAR models, possibly including both demand and employment, a classical-Keynesian account of the business cycle cannot be immediately translated into a particular causal chain among variables. A non-recursive strategy is instead well-suited to identify structural innovations, allowing economic activity to feed back into income distribution via the labour market. Thus, differently from a recursive identification strategy, it can simultaneously allow for distribution-led demand, a demand-driven labour market, and income distribution determined by the state of the labour market, which constitute the basic "ingredients" of a classical-Keynesian theory of the business cycle.

Our four-dimensional dynamic system includes output (Y_t), employment (e_t), real wages (w_t), and labour productivity (a_t) and can be represented as a structural vector autoregressive (SVAR) model as follows:

$$\boldsymbol{A x_t} = \boldsymbol{\alpha} + \sum_{i=1}^{p} \boldsymbol{A_i x_{t-i}} + \boldsymbol{B \varepsilon_t} \tag{11}$$

where $\boldsymbol{x_t} = (Y_t, e_t, w_t, a_t)$ is a vector of endogenous variables, $\boldsymbol{\alpha}$ is a 4×1 vector of intercepts, $\boldsymbol{A}$ is a 4×4 matrix of contemporaneous effects among the endogenous variables, $\boldsymbol{A_i}$, with $i = 1, \dots, p$, are 4×4 matrices of structural slope coefficients, $\boldsymbol{B}$ is a 4×4 matrix of the correlation structure of the structural innovations, and $\boldsymbol{\varepsilon_t}$ is a 4×1 vector of mean zero and serially uncorrelated structural innovations.

Only the structural shocks may be given a causal interpretation and are suitable to build economically meaningful impulse response functions, but in general they are not directly observable. However, postulating that matrix $\boldsymbol{A}$ is invertible, the structural shocks may be recovered from the reduced-form representation of the model.

The corresponding reduced-form VAR model can be represented as follows:

$$\boldsymbol{x_t} = \boldsymbol{\gamma} + \sum_{i=1}^{p} \boldsymbol{C_i x_{t-i}} + \boldsymbol{u_t} \tag{12}$$

where $\boldsymbol{\gamma}$ is a 4×1 vector of reduced-form intercepts, $\boldsymbol{C_i}$, with $i = 1, \dots, p$, are 4×4 matrices of reduced-form slope coefficients, and $\boldsymbol{u_t} = \boldsymbol{A^{-1} B \varepsilon_t}$ is a 4×1 vector of mutually correlated reduced-form residuals.

Identification of the SVAR model (11) requires imposing some credible restrictions on the matrix $\boldsymbol{A}$ of the contemporaneous effects among variables and/or on the matrix $\boldsymbol{B}$ of the correlation structure of the structural shocks. In this paper, we only impose zero restrictions on the off-diagonal entries of $\boldsymbol{A}$, motivated on the basis of economic theory, while setting the diagonal elements of $\boldsymbol{A}$ to unity and leaving $\boldsymbol{B}$ as a diagonal matrix. Thus, since we have $n = 4$ variables, the order condition for a just-identified SVAR model requires the off-diagonal entries of $\boldsymbol{A}$ to have $n(n-1)/2 = 6$ restrictions.

We can illustrate the link between reduced-form residuals and structural innovations in terms of an AB-type model (Lütkepohl, 2005, Section 9.1):

$$\boldsymbol{A u_t} = \boldsymbol{B \varepsilon_t} \tag{13}$$

$$\begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} \\ a_{21} & 1 & a_{23} & a_{24} \\ a_{31} & a_{32} & 1 & a_{34} \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \begin{bmatrix} u_t^Y \\ u_t^e \\ u_t^w \\ u_t^a \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \tag{14}$$

[13] See Section 2.

Guided by classical-Keynesian growth theory, we do the following assumptions on the entries of matrix $\boldsymbol{A}$:

(i) $a_{12} = 0$, a_{13} and a_{14} unrestricted;
(ii) $a_{23} = 0$, a_{21} and a_{24} unrestricted;
(iii) $a_{31} = 0$, $a_{34} = 0$, a_{32} unrestricted;
(iv) $a_{41} = 0$, $a_{42} = 0$, a_{43} unrestricted.

Assumption (i) states that output is left free to respond contemporaneously to real wages and labour productivity, but is constrained to react only with a lag to employment. This assumption reflects standard post-Keynesian growth theory, in which the labour share affects economic activity and growth via both the Keynesian accelerator and cost-side profitability (Bhaduri and Marglin, 1990; Marglin and Bhaduri, 1990). In the context of a decomposed labour share, this implies contemporaneous links from both real wages and labour productivity to output. A positive sign for the estimated a_{13} implies that real wages have a negative contemporaneous impact on economic activity, in line with the conventional account of the source of a profit-led demand regime.[14]

Assumption (ii) allows employment to react to output and labour productivity, but not to real wages, within the same quarter. This assumption reflects the standard Keynesian view that employment is primarily driven by the level of economic activity and also allows productivity to feed back into employment. Together, assumptions (i) and (ii) imply that the labour market is contemporaneously affected by the state of the goods market, but the latter responds to the former only with a lag – which is again in line with a demand-side perspective on the drivers of the business cycle.

Assumption (iii) states that real wages contemporaneously react to employment, but have a lagged response to output and labour productivity. This assumption is in accordance with a real wage Phillips curve in mainstream economics and with the standard Goodwinian story of profit squeezing as a result of a tighter labour market. Thus, we expect the estimated a_{32} to have a negative sign.

Assumption (iv) implies that labour productivity is contemporaneously affected by real wages, but not by output and employment. This assumption summarizes the induced innovation hypothesis: rising real wages provide the incentive for capitalists to invest in labour-saving innovations, thus raising labour productivity.

Using assumptions (i)-(iv), our AB-type model can be represented as follows:

$$\begin{bmatrix} 1 & 0 & a_{13} & a_{14} \\ a_{21} & 1 & 0 & a_{24} \\ 0 & a_{32} & 1 & 0 \\ 0 & 0 & a_{43} & 1 \end{bmatrix} \begin{bmatrix} u_t^Y \\ u_t^e \\ u_t^w \\ u_t^a \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \tag{15}$$

Equation (15) summarizes our identifying restrictions for getting a just-identified SVAR model of the kind of (11). These restrictions are guided by classical-Keynesian economic theory and allow us to properly identify the mean zero and serially uncorrelated structural innovations we need to compute impulse response functions. Each element of vector $\boldsymbol{\varepsilon_t}$ can then be given a “distinct economic interpretation”, which is crucial for model (11) to be structural (Kilian and Lütkepohl, 2017, Section 7.6). Namely, the aggregate demand shock ε_{1t} is derived from the output equation u_t^Y, the employment shock ε_{2t} is derived from the employment equation u_t^e, the distributive shock is derived from the real wage equation u_t^w, and the technology shock ε_{4t} is derived from the labour productivity equation u_t^a. Thus, we can assess the causal effect of structural innovations on the endogenous

[14] Remind that, in the matrix notation of (13) and (14), all the reduced-form residuals appear on the left-hand side. Thus, the signs of contemporaneous effects are reversed.

variables of the system. Notice that an increase in the labour share may be caused either by a positive distributive shock or by an adverse technology shock. We then need to consider both distributive and technology shocks to assess the existence of the profit-led/profit-squeeze pattern in the two subperiods of the US economy.

6. RESULTS

In this section, we report and discuss the results based on impulse response functions (IRFs) and forecast error variance decomposition (FEVD) estimated for our baseline model. Our preferred specification is a SVAR model identified according to equation (15) and includes the employment rate, and output, real wages, and labour productivity of the business sector. All variables are transformed by means of a filtering technique (the HP filter), as the focus of this paper is on dynamic interactions at business cycle frequencies. The next section shows that the results of our baseline model are robust to the use of different measures of economic activity and labour market tightness and a different identification strategy allowing for a contemporaneous effect of demand on productivity.

We first estimated IRFs and FEVD for the whole period. Our findings confirm the induced innovation hypothesis, as real wages have a positive and persistent effect on labour productivity. Then, we estimated IRFs for both the post-war period (1948Q1-1984Q4) and the Great Moderation (1985Q1-2019Q4). Our results empirically support profit-led demand and employment regimes and the induced innovation hypothesis in both subperiods. The effect of employment on real wages turned from positive in the pre-1984 period to insignificant in the Great Moderation. In this section, we only reported the IRFs we need to empirically evaluate our five hypotheses. Complete results for the baseline and robustness check models are shown in Appendix D.

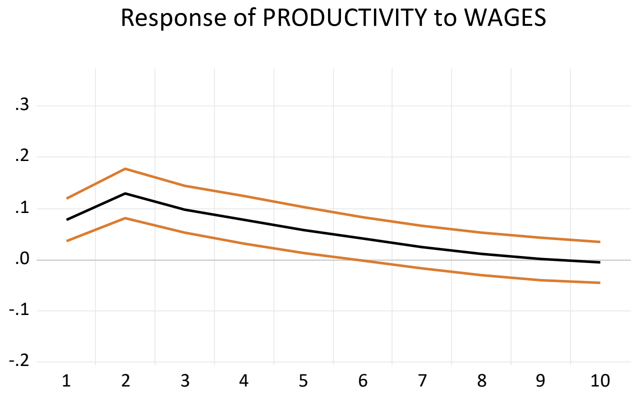
We performed an Augmented Dickey-Fuller (ADF) test to exclude the presence of unit roots, finding that all detrended series are indeed stationary. The baseline model includes 2 lags, as different information criteria indicated this is the optimal lag length for our VAR model and Lagrange Multiplier (LM) tests excluded the presence of serious autocorrelation problems. All real and imaginary roots of the characteristic polynomial lie inside the unit circle, which ensures the stability of the estimated VAR model (see Appendix C).

Figure 5 shows the response of labour productivity to real wages derived from the SVAR model for the whole period. A positive shock to wages has a positive and persistent effect on labour productivity, in line with the predictions of the theory of induced innovation. The effect is significant up to the fifth quarter. FEVD in Table 4 shows that, within a 1-2 year forecast horizon, wage shocks explain a consistent fraction of total variation in labour productivity (between 14% and 17,5%), suggesting that distributive shocks play an important role in determining changes in technology.

Figures 6-7 report selected IRFs for testing the profit-led and profit-squeeze pattern in the pre-1984 period. Figures 8-9 display the corresponding IRFs for the post-1984 period.

The US economy followed a profit-led and profit-squeeze pattern at the business cycle level during the post-war period, thus conforming to expressions (1) and (2). In the (e, ω) space, we found that a positive shock to employment raises real wages for one quarter and has a marginally negative effect on labour productivity in quarters 3-4, whereas a productivity shock has a strong positive effect on employment for five periods (quarters 3-7). However, we did not find evidence that distributive shocks affect the employment rate over a 10-quarter horizon. In the (Y, ω) plane, after a short-lived positive effect in quarter 2, a demand shock has a negative and persistent impact on labour productivity (quarters 5-9), whereas technology shocks strongly and positively affect output up to the 6th quarter. Again, distributive shocks appear to have no effects on economic activity. Moreover,

Fig. 5. *IRF for testing H3 (whole period)*



Notes: *IRFs are computed over a 10-quarter horizon. The black line gives the response of labour productivity to a distributive shock. The corresponding ±2 standard errors confidence interval, computed from the asymptotic analytic formula, is depicted by orange lines.*

Tab. 4. *Variance decomposition of labour productivity, 1948-2019*

Time horizon	Output	Employment	Wages	Productivity
1	0.006107	0.071037	4.778061	95.14480
2	0.208347	0.049957	12.70328	87.03842
3	0.795844	0.295040	16.02603	82.88309
4	4.540278	0.548085	17.53181	77.37983
5	11.44880	0.620525	17.38939	70.54129
6	19.19787	0.567490	16.31579	63.91885
7	25.74398	0.545140	15.04684	58.66404
8	30.34640	0.642234	13.99078	55.02059

wages do not respond to fluctuations in demand.

IRFs in Figures 6-7 support the existence of a distributive cycle in both the (e, ω) and the (Y, ω) spaces in the US post-war period, in line with our Hypotheses 1 and 2. Furthermore, the real wage Phillips curve is a driver of the profit-squeeze distribution regime in (e, ω), as shocks to employment have a positive, though not so persistent, effect on wages – a result that confirms Hypothesis 3 for the first subperiod. However, in our baseline estimates, the observed profit-led pattern in (e, ω) and (Y, ω) appears to be largely driven by movements in labour productivity, rather than in real wages, as the impact of distributive shocks on economic activity and employment is not significant.

During the Great Moderation, the US economy still exhibited profit-led demand and employment at business cycle frequencies, but the profit-squeeze distribution regime in the (e, ω) space appears to have vanished. Neither wages nor productivity significantly respond to changes in labour market tightness over a 10-quarter horizon. As above, positive technology shocks have a positive and persistent effect on employment (quarters 3-6). Moreover, a positive shock to wages now lowers the employment rate for one quarter. In the (Y, ω) plane, demand shocks significantly reduce labour productivity for eight periods (quarters 3-10), whereas productivity shocks have a positive effect on output for the first five quarters. As in the first subperiod, output does not react to shocks to real wages, and the latter does not respond to demand shocks.

Fig. 6. *IRFs for testing H1 (post-war period)*

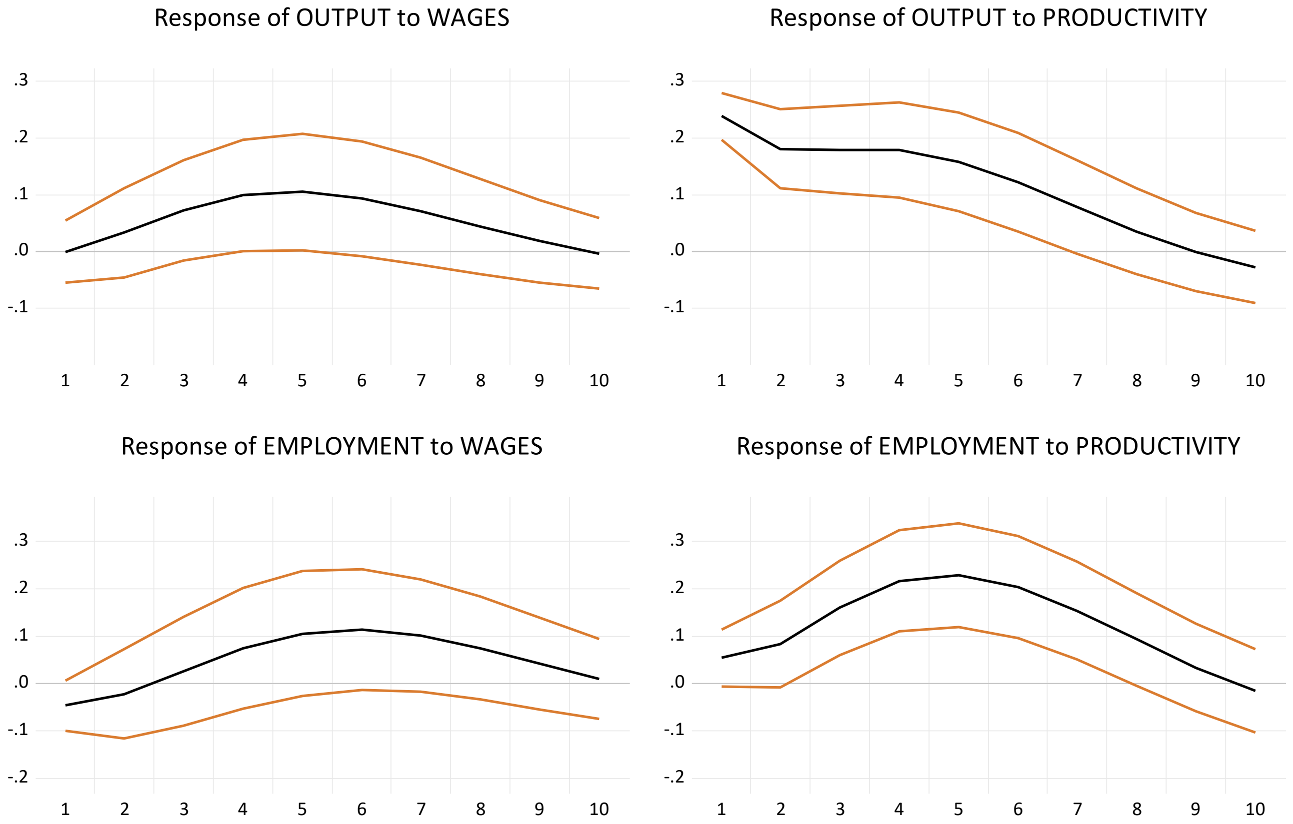


Fig. 7. *IRFs for testing H2-H3 (post-war period)*

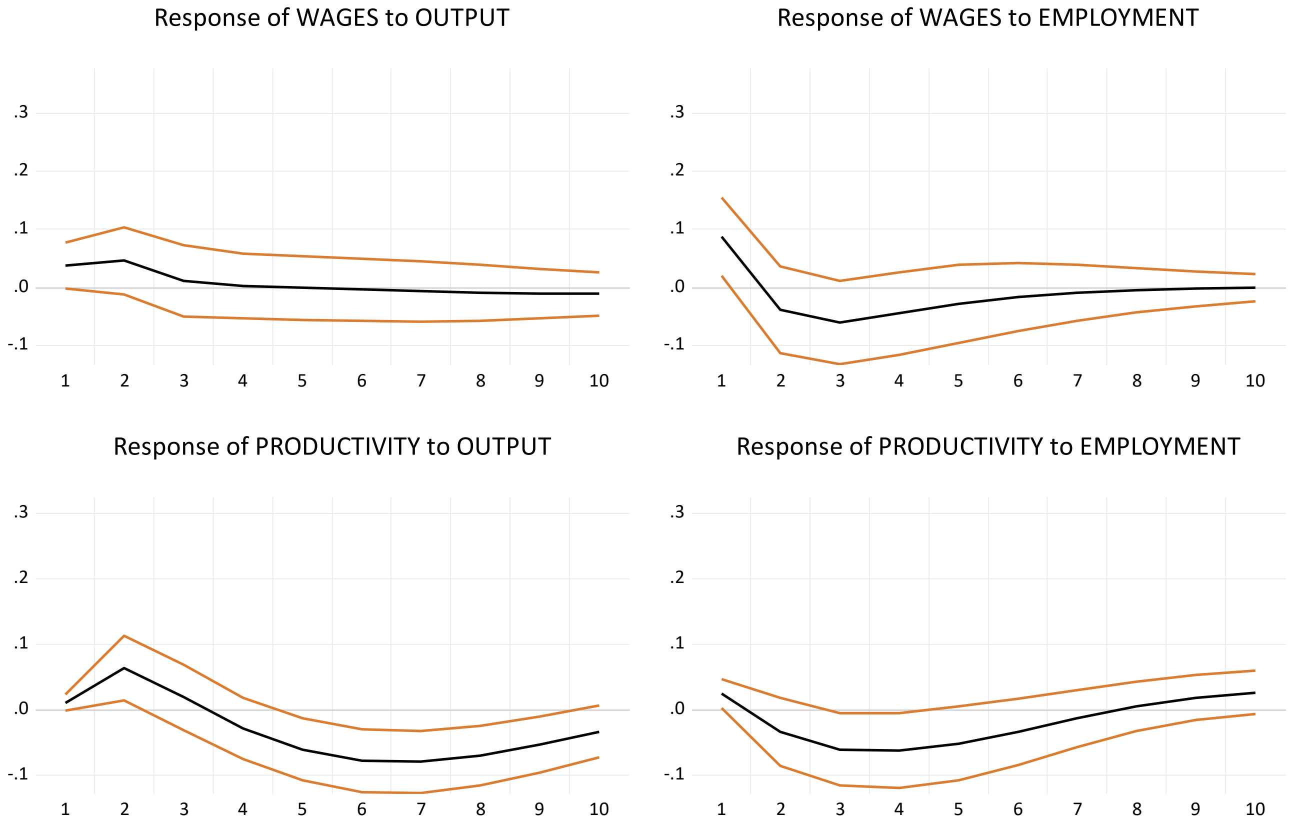


Fig. 8. *IRFs for testing H1 (Great Moderation)*

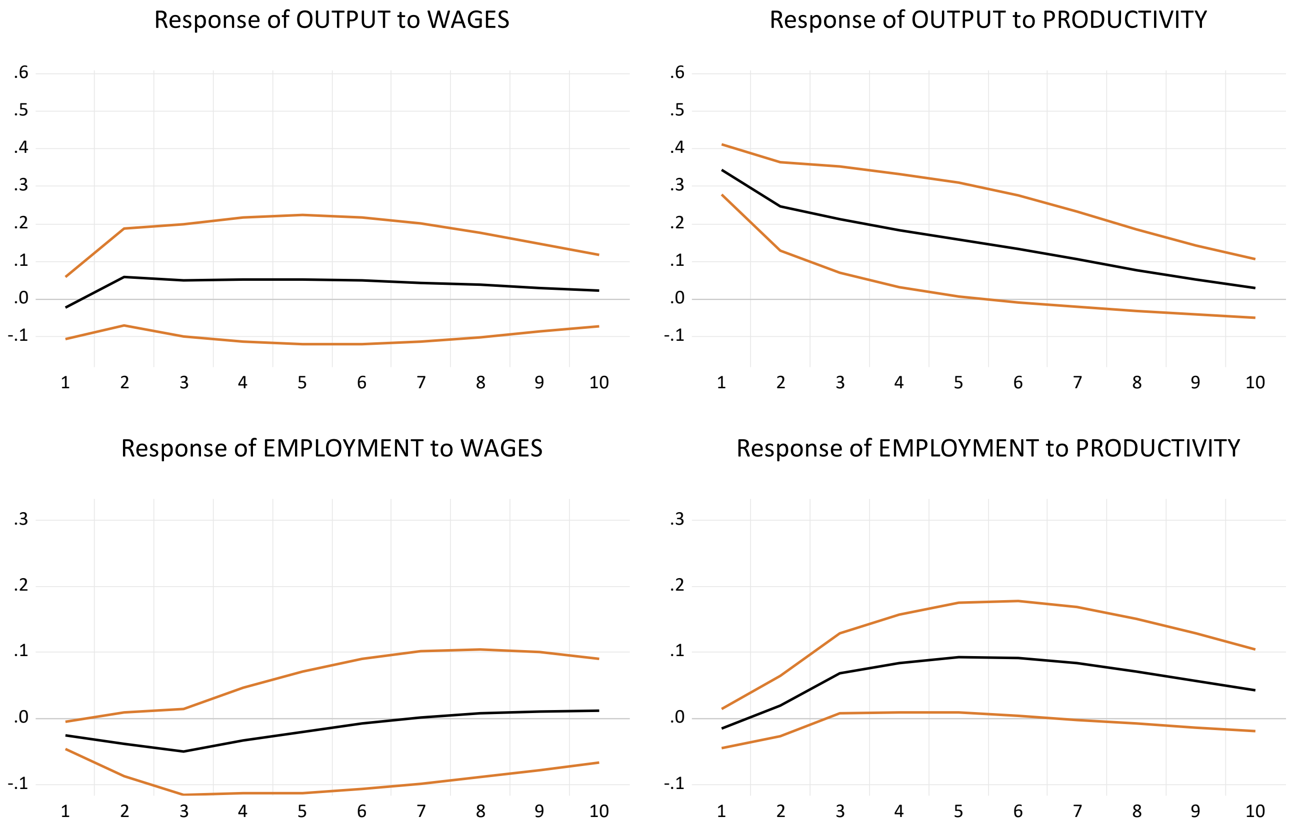


Fig. 9. *IRFs for testing H2-H3 (Great Moderation)*

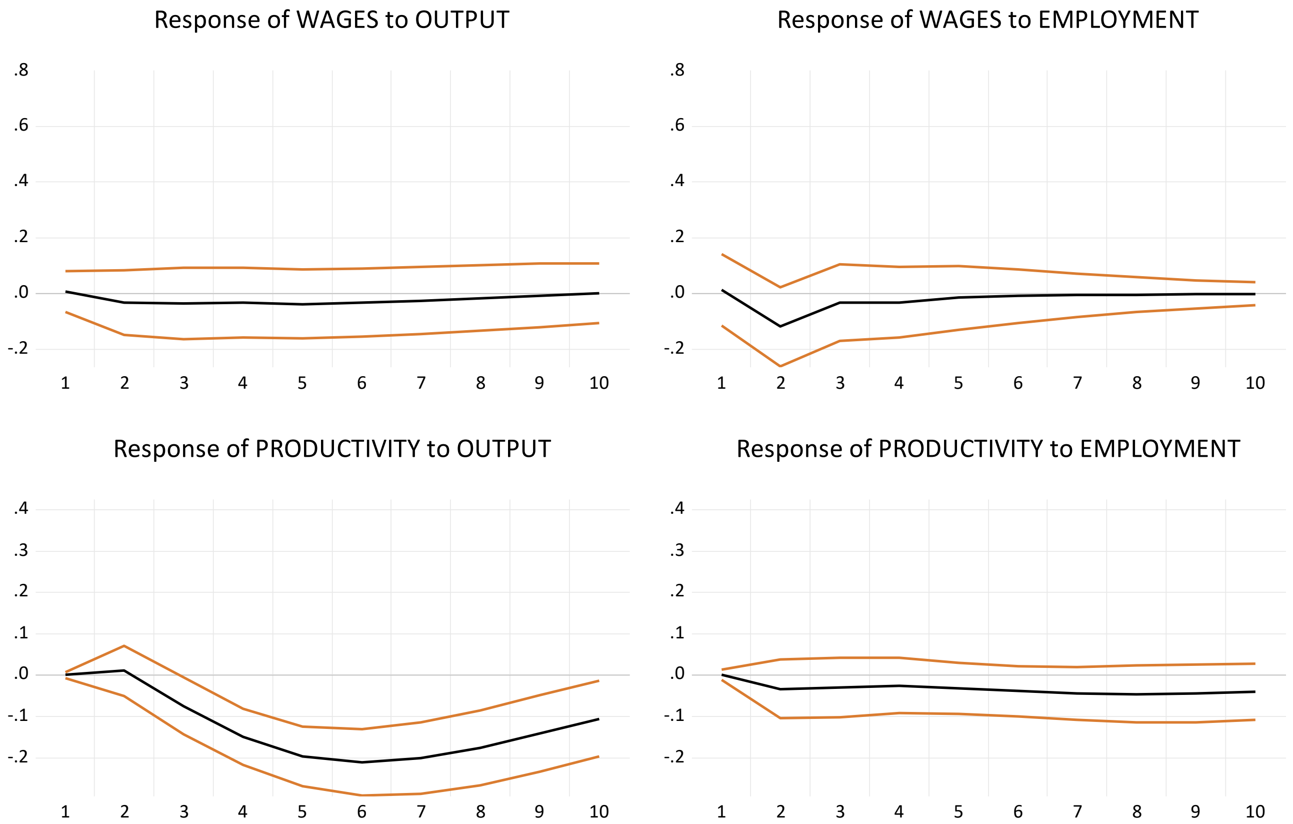
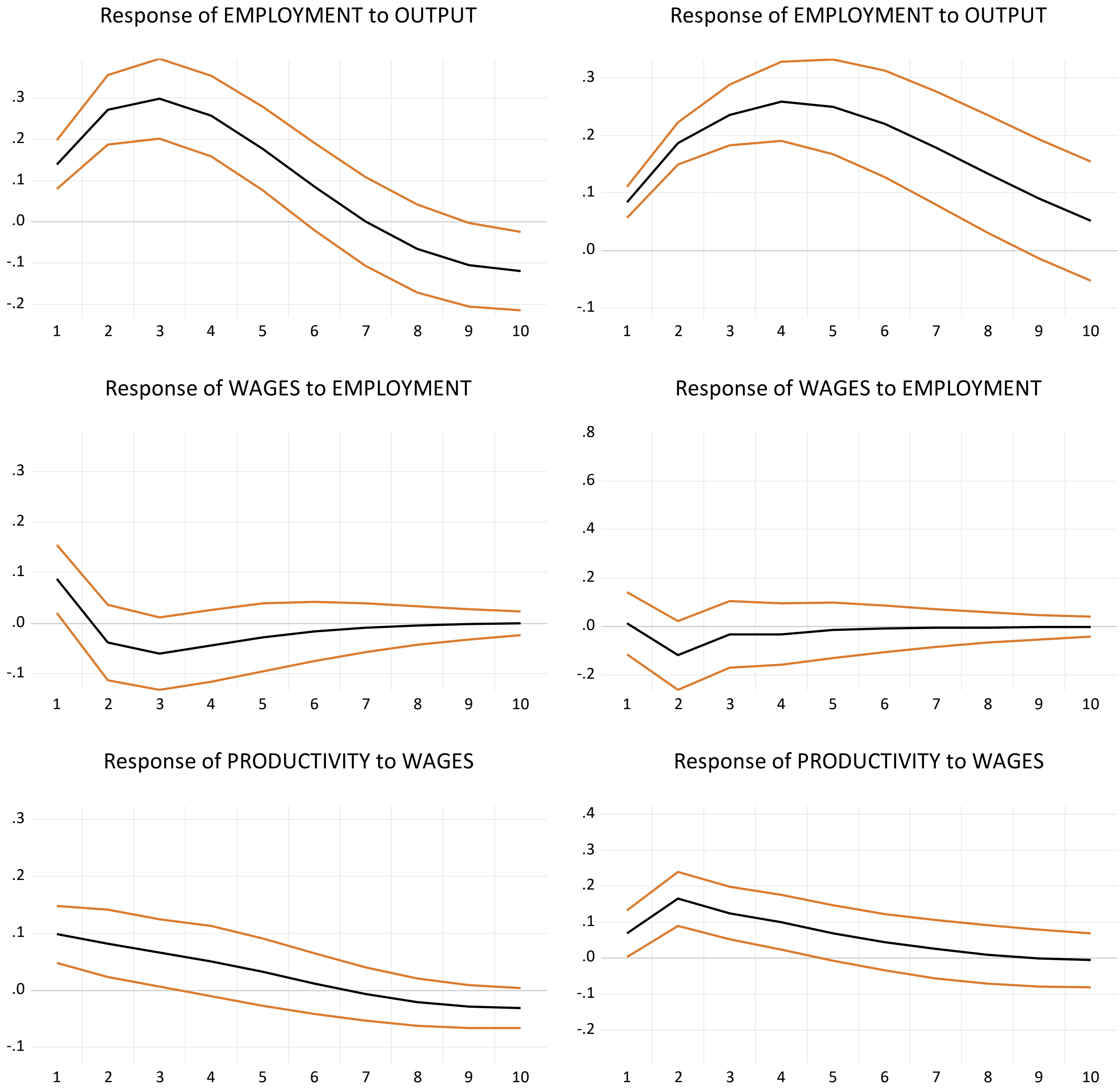


Fig. 10. *IRFs for testing H4-H5 (post-war period and Great Moderation)*



a) Pre-1984 *b) Post-1984*

Notes: *IRFs are computed over a 10-quarter horizon. The black lines give the responses of the variables of interest to structural innovations. The corresponding ±2 standard errors confidence intervals, computed from the asymptotic analytic formula, are depicted by orange lines.*

IRFs in Figures 8-9 are consistent with a distributive cycle in the (Y, ω) space, but not in (e, ω), where profit squeeze in distribution completely vanished. Thus, empirical evidence for the Great Moderation supports both Hypotheses 1 and 2 in (Y, ω), but only Hypothesis 1 in (e, ω). Moreover, differently from the post-war period, distributive shocks have a negative effect on employment, in line with the Marxian account of profit-constrained capital accumulation. Thus, an increase in the labour share, irrespective of whether is caused by a positive wage shock or by an adverse technology shock, always slows down employment at business cycle frequencies. In addition, real wages no longer rise with employment, that is, the real wage Phillips curve has become flat, in contrast with our Hypothesis 3. Labour productivity still decreases in response to demand shocks, a fact that explains the survival of profit-squeeze distribution in (Y, ω). This result could be due to the presence of reallocation effects in recessions, that is, reallocation of resources from low productive firms or sectors towards more productive ones following adverse demand shocks. Notice that this result needs not imply a rejection of the Kaldor-Verdoorn effect, which typically operates at higher frequencies than the ones captured by applying filtering techniques.[15]

Figure 10 reports the IRFs for testing our induced innovation account of the diminished procyclicality of labour productivity. Figure 10a displays the IRFs for the post-war period. Figure 10b shows the corresponding IRFs for the Great Moderation. Table 5 reports the estimated coefficients of matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ in the two subperiods.

The impact of structural innovations on output, employment, and real wages qualitatively conform to our narrative on the changing pattern of cyclicality of US labour productivity, in accordance with expression (9) for the post-war period and expression (10) for the Great Moderation. A wage shock significantly raises labour productivity up to the 3rd quarter in the pre-1984 period and up to the 4th quarter in the post-1984 period. A demand shock has a strong and positive effect on employment for five quarters in the first subperiod and for eight quarters in the second subperiod. The response of wages to employment has turned from positive in the post-war period to insignificant during the Great Moderation.

IRFs in Figure 10 support Hypotheses 4 and 5 on induced innovation and the cyclicality effects of the disappearance of the real wage Phillips curve. In the US post-war period, a highly regulated labour market allowed workers to have sufficient bargaining power to claim for higher wages in the expansionary phase of the business cycle. Upward wage pressures in booms forced capitalists to protect their profit margins by adopting more labour-saving innovations. Thus, labour productivity comoved more positively with output over the cycle. The transition to the Great Moderation brought about a flat real Phillips curve – real wages failed to rise in response to an increase in labour market tightness. Distribution-induced innovation was still an important driver of labour productivity, but missing wage growth in the upturn of the business cycle implies that labour productivity failed to respond to fluctuations in economic activity and employment. As a result, labour productivity comoved less positively with output at business cycle frequencies.

A comparison of the estimated coefficients of the matrix of contemporaneous effects in the two subperiods appears to support the intuition as well. The left-hand panel of Table 5 reports the estimated coefficients of matrices $\boldsymbol{A}$ and $\boldsymbol{B}$ for the post-war period. The right-hand panel displays the corresponding coefficients for the Great Moderation. As the table makes clear, in both subperiods real wages have a positive and significant contemporaneous impact on labour productivity. However, the contemporaneous effect of the employment rate on real wages has turned from positive and significant in the pre-1984 period to not significant during the Great Moderation.

Table 6 summarizes our findings. Impulse responses support both the induced innovation hypothesis and the existence of Goodwin cycles in the (e, ω) and (Y, ω) spaces for the post-war period, though the profit-led regime appears to be determined by technology rather than distributive shocks. During the Great Moderation, the profit-led regime in (e, ω) is determined by both technology and distributive shocks, but the profit-squeeze regime in (e, ω) is completely broken. However, income distribution is still a driver of labour-saving innovations, as structural innovations to wages raise labour productivity. Thus, part of the changes in economic activity and employment are the result of wage-led technology shocks, though the disappearance of the cyclical profit squeeze does not allow labour productivity to significantly react to fluctuations in economic activity through the

[15] For a SVAR analysis on the long-run effects of the growth rate of output on labour productivity, which empirically supports a technical progress function *à la* Kaldor-Verdoorn, see Antenucci, *et al.* (2020).

Tab. 5. *Estimated coefficients of matrices **A** and **B***

	Pre-1984		Post-1984	
	Coefficients	Prob.	Coefficients	Prob.
a_{13}	0.245257	0.0000	0.118021	0.0062
a_{14}	– 0.832982	0.0000	– 0.903600	0.0000
a_{21}	– 0.794165	0.0000	– 0.271560	0.0000
a_{24}	0.467261	0.0093	0.285146	0.0000
a_{32}	– 0.267887	0.0129	– 0.090623	0.8328
a_{43}	– 0.292383	0.0000	– 0.094706	0.0358
b_{11}	0.181057	0.0000	0.310678	0.0000
b_{22}	0.337397	0.0000	0.150088	0.0000
b_{33}	0.348290	0.0000	0.719778	0.0000
b_{44}	0.286451	0.0000	0.380614	0.0000

Tab. 6. *Summary of results*

		Pre-1984	Post-1984
H1 –	Profit-led pattern	Yes	Yes
H2 –	Profit-squeeze pattern	Yes	Yes, in (Y, ω); no, in (e, ω)
H3 –	Real Phillips curve	Yes	No
H4 –	Induced innovation hypothesis	Yes	Yes
H5 –	Induced innovation account of the changing cyclicality of productivity	Yes	

induced innovation channel. We then conclude that impulse responses in the two subperiods qualitatively support an induced innovation account of the vanishing procyclicality of US labour productivity.

7. Robustness checks

This section performs some robustness analyses. We show that the main findings of our baseline model identified according to equation (15) are robust to the use of different measures of economic activity (i.e. output gap or GDP instead of output for the business sector) and different measures of labour market tightness (i.e. employment levels or hours worked instead of the employment rate). As a further robustness check, we identify structural innovations with restrictions allowing demand to have a contemporaneous impact on productivity, as in Mendieta-Muñoz, *et al.* (2020). All model specifications provide empirical support to the existence of the Goodwin pattern, the weakening of the Phillips curve effect during the Great Moderation, and the induced innovation hypothesis. Only the impact of distributive shocks on output and employment appears to be sensitive to the chosen measure of labour market tightness. However, across almost all model specifications, the effect of technology shocks on output and employment is positive and persistent. IRFs for all estimates are reported in Appendix D.

As in the baseline specification, we preliminarily tested for the presence of unit roots, the optimal lag length, serial correlation, and VAR stability. A VAR model with 2 lags passed the relevant tests in all specifications except the one with hours worked, for which information criteria and LM tests suggested the inclusion of 3 lags.

First, we report IRFs obtained by a SVAR model identified according to equation (15) and in which output of the business sector is replaced by output gap for the total economy as a measure of economic activity (Figure D2 in Appendix D). In both subperiods, the economy exhibits profit-led demand and employment following a technology shock, as the response of output and employment to labour productivity is positive and persistent. As in the baseline model, a distributive shock in favour of the labour share hurts employment for one quarter in the post-1984 period. Wage shocks raise labor productivity for three quarters in the first subperiod and four quarters in the second one, which confirms the induced innovation hypothesis. The response of wages to an increase in labour market tightness supports our argument on the changing pattern of cyclicality along induced innovation lines, as it switched from positive in the pre-1984 period to not significant during the Great Moderation. However, positive shocks to employment appear to squeeze profits in both subperiods, through a strong and persistent negative impact on labour productivity.

Second, we estimated a model specification including the detrended component of GDP as an alternative measure of economic activity. IRFs reported in Figure D3 show that the effects of structural innovations in this specification are qualitatively similar to those found in the baseline model. In the pre-1984 period, profit-led demand and employment are entirely determined by technology shocks. After 1984, profit-led demand is still driven by technology shocks, which have a positive effect on output up to the 5th quarter, whereas profit-led employment is caused by a one-quarter negative effect of wage shocks. The cyclical profit squeeze in the (e, ω) plane appears to have vanished during the Great Moderation. This result, along with the induced innovation hypothesis, qualitatively supports our hypothesis about the changing cyclicality of productivity.

In order to test if our five hypotheses are robust to the chosen measure of labour market tightness, we estimated a model specification including data on employment levels for the business sector instead of the employment rate (Figure D4). Again, evidence supports the induced innovation hypothesis in both subperiods. A positive shock to wages raises labour productivity for three quarters in the pre-1984 period and four quarters during the Great Moderation. Furthermore, profit-squeeze distribution is observed in both the (Y, ω) and the (e, ω) spaces during the post-war period, but only in (Y, ω) during the Great Moderation. The disappearance of the real wage Phillips curve again supports the induced innovation argument on the cyclical behaviour of productivity.

For what concerns the effects of the labour share on output and employment, IRFs return a more complex picture. As before, technology shocks persistently raise output and employment in the pre-1984 period. However, the effect of wage shocks on employment switches from negative in the first two quarters to positive in quarters 8-10. An increase in wages also marginally raises output in quarters 7-8. Thus, the economy exhibits profit-led demand and employment up to quarters 6-7, but output and employment rise thereafter for about two quarters following a wage shock. This result could be supportive of the view that demand is more likely to be profit-led in the short run and more likely to be wage-led at longer time horizons (Blecker, 2016). During the Great Moderation, output and employment do not appear to respond to distributive shocks, whereas technology shocks against the labour share still raise output up to the 4th quarter.

As an additional robustness check, we estimated a model specification in which the employment rate is replaced by total hours worked, which implicitly considers both the extensive and the intensive margins of labour adjustment (Figure D5).[16] The response of output and hours worked to the labour share shows a similar pattern as before. In the pre-1984 period, technology shocks have a positive and persistent effect on output and hours, whereas wage shocks reduce hours in the first quarter but raise output and hours for three quarters after about two years. During the Great Moderation, technology shocks raise output for two quarters, but the response of output and hours to distributive shocks turns out to be insignificant. Furthermore, wage shocks raise labour productivity in both subperiods, in line with the induced innovation hypothesis. Wages positively react to increases in hours for two quarters before 1984 and for one quarter thereafter. Thus, the cyclical profit squeeze is still present, albeit weakened, in the Great Moderation period.

Finally, as VAR models motivated on the basis of neo-Goodwinian theory have been criticized by supporters of wage-led growth for their supposed failure to account for procyclical variation in labour productivity,[17] we estimated a further specification allowing demand to affect contemporaneously labour productivity. We adopted the identifying restrictions originally proposed by Mendieta-Muñoz, *et al.* (2020) in their study on the evolution of the drivers of the US labour share. This model specification is then estimated on HP-filtered data on the same variables as in our baseline model, but is identified as follows:

$$\begin{bmatrix} 1 & 0 & a_{13} & a_{14} \\ a_{21} & 1 & 0 & a_{24} \\ 0 & a_{32} & 1 & 0 \\ a_{41} & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u_t^Y \\ u_t^e \\ u_t^w \\ u_t^a \end{bmatrix} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \\ \varepsilon_{3t} \\ \varepsilon_{4t} \end{bmatrix} \quad (16)$$

Equation (16) leaves productivity free to respond to output within the same quarter but constrains labour productivity to react to wages with a lag.

Figure D6 displays the effects of structural innovations on output, employment rate, wages, and productivity in the two subperiods. As the IRFs make clear, our findings are qualitatively unchanged. Wage shocks raise productivity for three or four quarters in both subperiods. The transition to the Great Moderation is marked by a flattening of the real Phillips curve. Furthermore, the profit-led pattern appears to be even stronger than in the baseline model: technology shocks raise output up to the 6th quarter and raise employment up to the 7th quarter in the pre-1984 period, and have a positive effect on output and employment for seven quarters in the Great Moderation. In the latter, a wage shock also lowers employment in the first quarter. In addition, this model specification confirms the negative response of productivity to demand shocks at business cycle frequencies, probably due to the cleansing effects of recessions: in the pre-1984 period, productivity does not even show the one-quarter positive response to demand we found in the baseline model, and demand shocks lower productivity for five periods; after 1984, demand shocks harm productivity for seven quarters.

These results shed some doubt on the argument that the appearance of a profit-led/profit-squeeze pattern is the result of a failure to control for procyclical variation in labour productivity. Indeed, the effects of distributive and technology shocks on output and employment, as well as the distributional and productivity effects of changes in demand and employment, are broadly the same in both the baseline model, in which demand only has a lagged effect on labour productivity, and the robustness check model identified according to equation (16), in which productivity is contemporaneously affected by demand. Impulse responses support profit-led demand and employment in both subperiods and the disappearance of the cyclical profit squeeze in (e, ω) in the transition from the post-war period to the Great Moderation. Furthermore, the comovements of output and productivity are *negative* at business cycle frequencies conditional to demand shocks – a result which is fundamentally unaltered if we use the identification strategy in equation (16). However, differently

[16] We estimated this model using data for the US nonfarm business sector, as estimates for the business sector did not lead to reliable impulse response functions due to the high values of the standard errors of the structural coefficients.

[17] See Section 2 and Lavoie (2017).

from Mendieta-Muñoz, *et al.* (2020), we found that the profit-led pattern is largely driven by technology shocks, rather than distributive shocks, as the response of output and employment to increases in productivity is positive and persistent, whereas wage shocks have a one-quarter negative impact on employment. Thus, our results suggest that the negative comovements between economic activity and labour share in the initial phase of booms and recession do not reflect procyclical labour productivity, as in the argument of wage-led growth supporters, but still profit-led activity, although driven more by technology than distributive shocks.

8. CONCLUDING REMARKS

This paper empirically tested an extended version of the Goodwin model including aggregate demand and a decomposed labour share. It employed a structural vector autoregressive model identified by means of a non-recursive matrix of contemporaneous effects, with restrictions guided by classical-Keynesian and induced innovation theory. The whole period was split into two subperiods, the post-war period (1948-1984) and the Great Moderation (1985-2019), in order to illustrate the changes in the properties of the US business cycle. We then added to the debate and empirical evidence on the distributive cycle, induced innovation, and the changing pattern of cyclicality in the US labour productivity.

The Goodwin model and its subsequent developments predict counterclockwise cycles in the activity-labour share plane, as a result of the combination of profit-led activity and profit-squeeze distribution. The standard story focuses on the Marxian account of class conflict, resulting from the interaction of profit-constrained capital accumulation and employment-driven real wages. Our empirical findings confirm the existence of a profit-led/profit-squeeze pattern at business cycle frequencies during the post-war period. During the Great Moderation, the cyclical profit squeeze in the employment-distribution space appears to have been completely broken, in accordance with the view that neoliberal institutional changes succeeded in preventing wages from rising in economic upturns.

We have shown that the argument of procyclical labour productivity invoked by supporters of wage-led growth to question the existence or the source of the Goodwin pattern does not appear to be well-founded. Indeed, productivity comoves negatively with output at business cycle frequencies conditional to demand shocks, and the findings of profit-led demand and employment and profit-squeeze distribution are robust to allowing for a contemporaneous effect of demand on productivity. However, the profit-led pattern turned out to be largely driven by technology shocks, rather than distributive shocks, irrespective of the chosen identification strategy. Across almost all specifications, technology shocks had a positive and persistent effect on output and employment, whereas wage shocks only caused employment to fall for one or two quarters in the postwar period. The standard Marxian explanation of business cycle fluctuations then needs to be integrated with the consideration of the positive effects of technology on economic activity and employment.

The classical approach to induced innovation theory suggests that part of these economic fluctuations are the result of wage-led technology shocks, reflecting the capitalists' incentive to adopt labour-saving innovations in response to rising real wages. Our findings show that increases in real wages did indeed have a positive and persistent effect on labour productivity over the whole sample period, in line with the predictions of the theory.

Finally, we claimed that the changing pattern of cyclicality in the US labour productivity and the disappearance of the cyclical profit squeeze in the transition from the post-war period to the Great Moderation are consistent with the operation of distribution-induced technical change at business cycle frequencies. Our argument posits that distribution-induced innovation and the profit squeeze cause labour productivity to comove positively with output over the cycle. Causality goes from output to labour productivity via employment and real wages: in economic upturns, increases in labour market tightness allow workers to claim for higher real wages; capitalists try to counteract profit squeezing with higher investment in labour-saving innovations. The breakdown of the cyclical profit squeeze in the Great Moderation then accounts for part of the decline in the cyclical correlation between output and labour productivity. If labour-saving innovations are driven by increases in real wages, but the latter does not respond any longer to fluctuations in economic activity, labour productivity comoves less positively with output over the cycle. Impulse responses qualitatively support our story. The next advance in this line of investigation should quantify the contribution of the induced innovation channel relative to competing explanations of the changing cyclicality of productivity.

Our results appear to indicate a promising avenue for future research on the interaction between changes in labour market institutions, the business cycle, and induced innovation. Previous contributions have investigated the long-run association between labour share and economic growth via the induced innovation channel. In this paper, we have drawn a further implication of the induced innovation theory for the cyclical behaviour of wages and productivity. A promising research agenda is to link short-run and long-run effects of distributive shocks and jointly investigate the impact of institutional changes on the properties and the structural shifts of the business cycle. This analysis is left for future work.

Appendix A

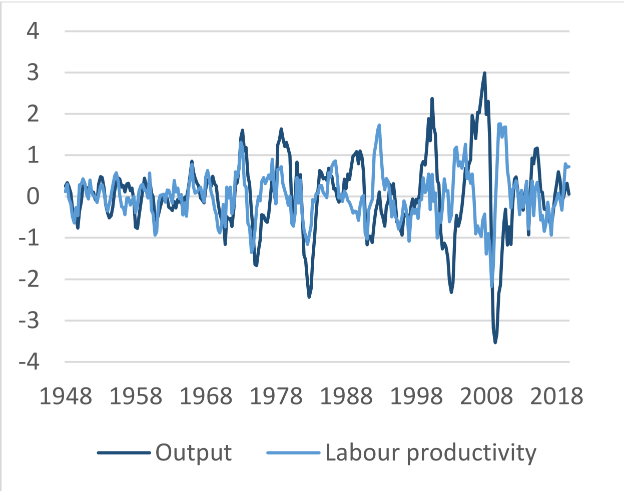
Tab. A1. *Data description and data source*

Y_t	Output of the business sector: "Business Sector: Output for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("OUTBS" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Output of the nonfarm business sector: "Nonfarm Business Sector: Output for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("OUTNFB" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). GDP: "Real Gross Domestic Product, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate" ("GDPC1" series), computed as index 2012=100 and retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Output gap, measured as the difference between actual GDP and potential GDP, where actual GDP is "Real Gross Domestic Product, Billions of Chained 2012 Dollars, Quarterly, Seasonally Adjusted Annual Rate" ("GDPC1" series) and potential GDP is "Real Potential Gross Domestic Product, Billions of Chained 2012 Dollars, Quarterly, Not Seasonally Adjusted" ("GDPPOT" series), both indexed relative to 2012 levels of potential GDP (index 2012 = 100) and retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). The potential GDP series starts from 1949.
e_t	Employment rate, measured as 100 minus "Unemployment Rate, Percent, Monthly, Seasonally Adjusted" ("UNRATE" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Employment levels in the business sector: "Business Sector: Employment for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("PRS84006013" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Hours worked in the nonfarm business sector: "Nonfarm Business Sector: Hours Worked for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("HOANBS" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED).
w_t	Real wages in the business sector: "Business Sector: Real Hourly Compensation for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("RCPHBS" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Real wages in the nonfarm business sector: "Nonfarm Business Sector: Real Hourly Compensation for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("COMPRNFB" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED).
a_t	Labour productivity in the business sector: "Business Sector: Labor Productivity (Output per Hour) for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("OPHPBS" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED). Labour productivity in the nonfarm business sector: "Nonfarm Business Sector: Labor Productivity (Output per Hour) for All Employed Persons, Index 2012=100, Quarterly, Seasonally Adjusted" ("OPHNFB" series), retrieved from Federal Reserve Bank of St. Louis Economic Database (FRED).

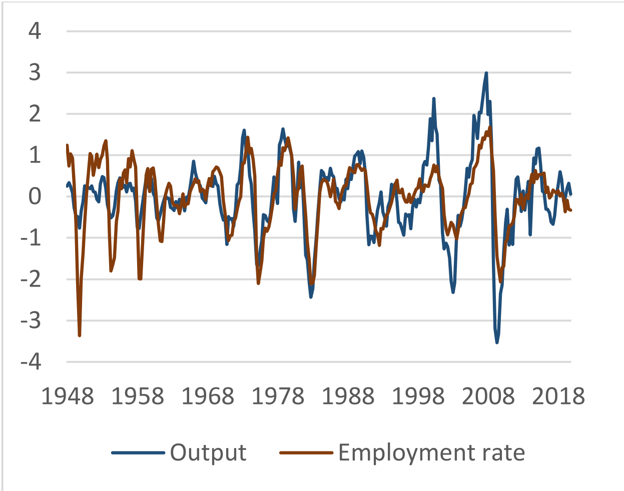
In the baseline and all robustness check models we used detrended data, applying the Hodrick-Prescott filter, with a standard smoothing parameter for quarterly data ($\lambda = 1600$). All HP-filtered series are $I(0)$.

Appendix B

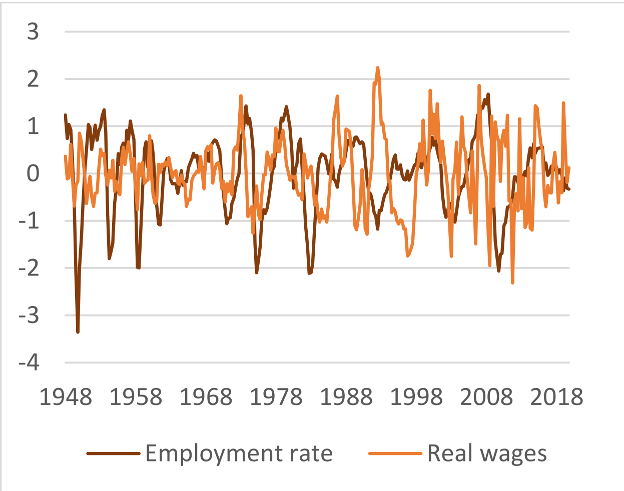
Fig. B1. *Cyclical fluctuations in output, labour productivity, real wages, and employment rate*



a) Output and labour productivity



b) Output and employment rate



c) Employment rate and real wages

d) Real wages and labour productivity

Notes: The series refer to the US business sector. Data are detrended using the HP filter with smoothing parameter λ=1600.

Tab. B1. *Changes in the volatility of employment levels and hours worked*

	Absolute SD		SD relative to employment	
	Pre-1984	Post-1984	Pre-1984	Post-1984
<u>Raw series</u>				
Employment				
Business	9.175317	9.246799	–	–
Nonfarm business	10.727918	9.647619	–	–
Hours				
Business	7.579660	8.347409	0.826092	0.902735
Nonfarm business	9.346647	8.671981	0.871245	0.898873
<u>HP filter</u>				
Employment				
Business	0.980436	1.320809	–	–
Nonfarm business	0.979008	1.335022	–	–
Hours				
Business	1.264283	1.602440	1.289511	1.213226
Nonfarm business	1.252784	1.617608	1.279646	1.211671

APPENDIX C

Tab. C1. *Augmented Dickey-Fuller unit root test statistics for the cyclical components of output, employment rate, real wages, and labour productivity (baseline model)*

	Intercept	Intercept and trend
Output (Y_t)	– 6.499597**	– 6.488036**
Employment rate (e_t)	– 8.092636**	– 8.081474**
Real wages (w_t)	– 6.861069**	– 6.848849**
Labour productivity (a_t)	– 6.815739**	– 6.801450**

*Notes: ** = significant at the 1% level. ADF tests include 2 lags.*

Tab. C2. *VAR lag length selection criteria (baseline model)*

Lag	FPE	AIC	SC	HQ
Pre-1984				
0	0.002695	5.435030	5.519077	5.469184
1	4.73e-05	1.391329	1.811563*	1.562100
2	3.47e-05*	1.082895*	1.839317	1.390282*
3	3.72e-05	1.149421	2.242031	1.593425
4	4.11e-05	1.247504	2.676302	1.828125
5	4.75e-05	1.387789	3.152775	2.105027
6	5.15e-05	1.461966	3.563139	2.315820
7	5.73e-05	1.559686	3.997046	2.550156
8	5.33e-05	1.476014	4.249563	2.603102
Post-1984				
0	0.014688	7.130766	7.214813	7.164920
1	0.000276	3.155894	3.576128*	3.326665
2	0.000208*	2.872910*	3.629333	3.180298*
3	0.000219	2.923781	4.016391	3.367785
4	0.000251	3.057613	4.486410	3.638233
5	0.000284	3.175610	4.940595	3.892847
6	0.000311	3.261685	5.362858	4.115568
7	0.000330	3.312166	5.749527	4.302636
8	0.000331	3.301221	6.074770	4.428308

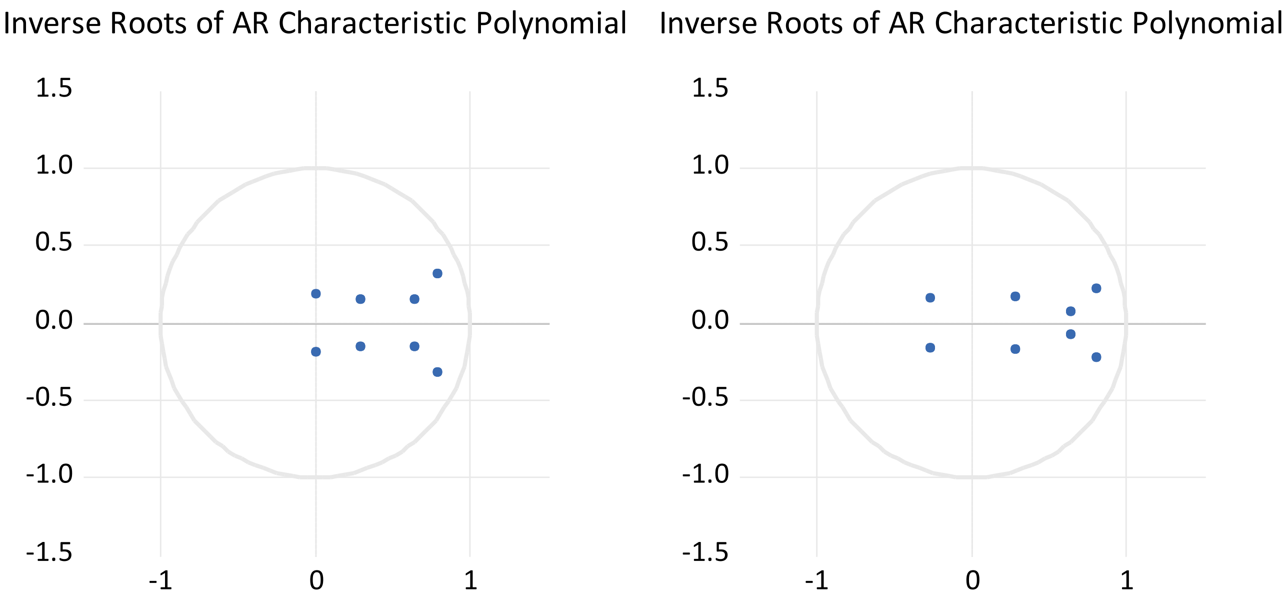
*Notes: * = lag order selected by the criterion. FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion.*

Tab. C3. *VAR residual serial correlation LM tests (baseline model)*

Lag	LRE stat	Prob.
Pre-1984		
1	15.62607	0.4793
2	17.90339	0.3296
3	15.02220	0.5230
4	16.36751	0.4276
5	9.427065	0.8948
6	8.896066	0.9176
7	9.049141	0.9114
8	38.19065	0.0014
Post-1984		
1	19.61934	0.2379
2	14.08253	0.5926
3	14.23156	0.5815
4	14.58374	0.5553
5	23.00201	0.1137
6	9.987885	0.8673
7	18.27798	0.3079
8	39.68883	0.0009

Note: LRE: Edgeworth expansion corrected likelihood ratio.

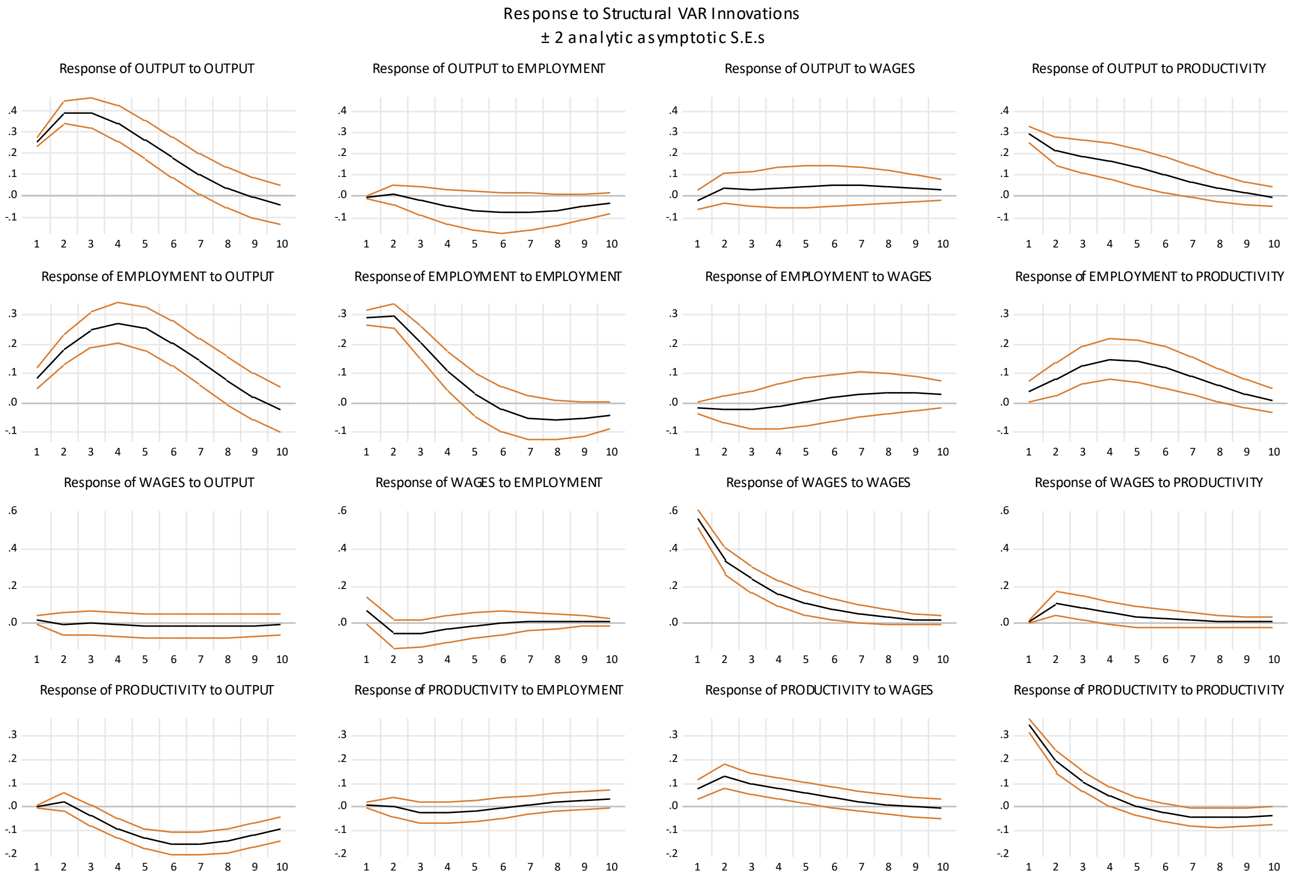
Fig. C1. *VAR stability conditions (baseline model)*



a) Pre-1984 *b) Post-1984*

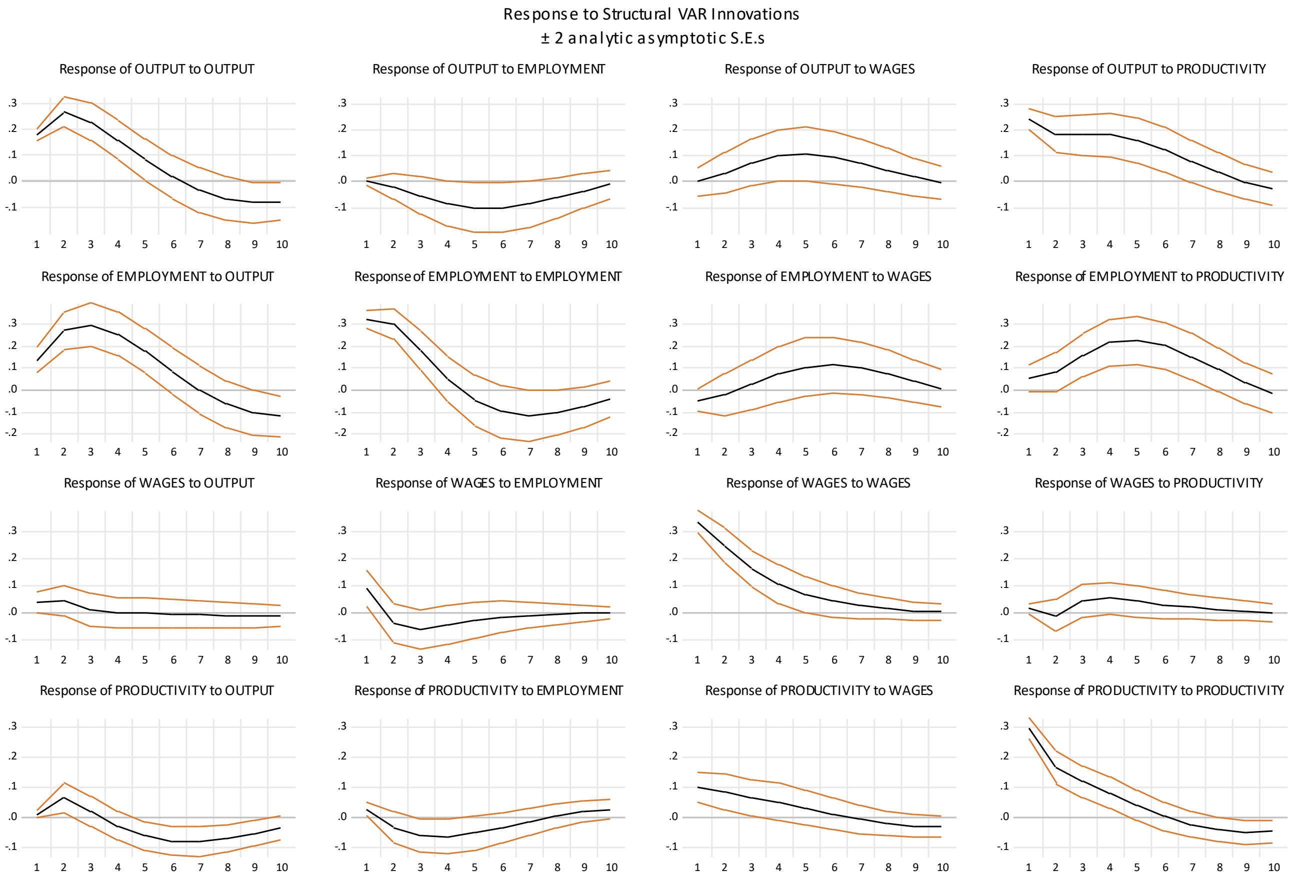
APPENDIX D

Fig. D1. *Impulse response functions, baseline model*

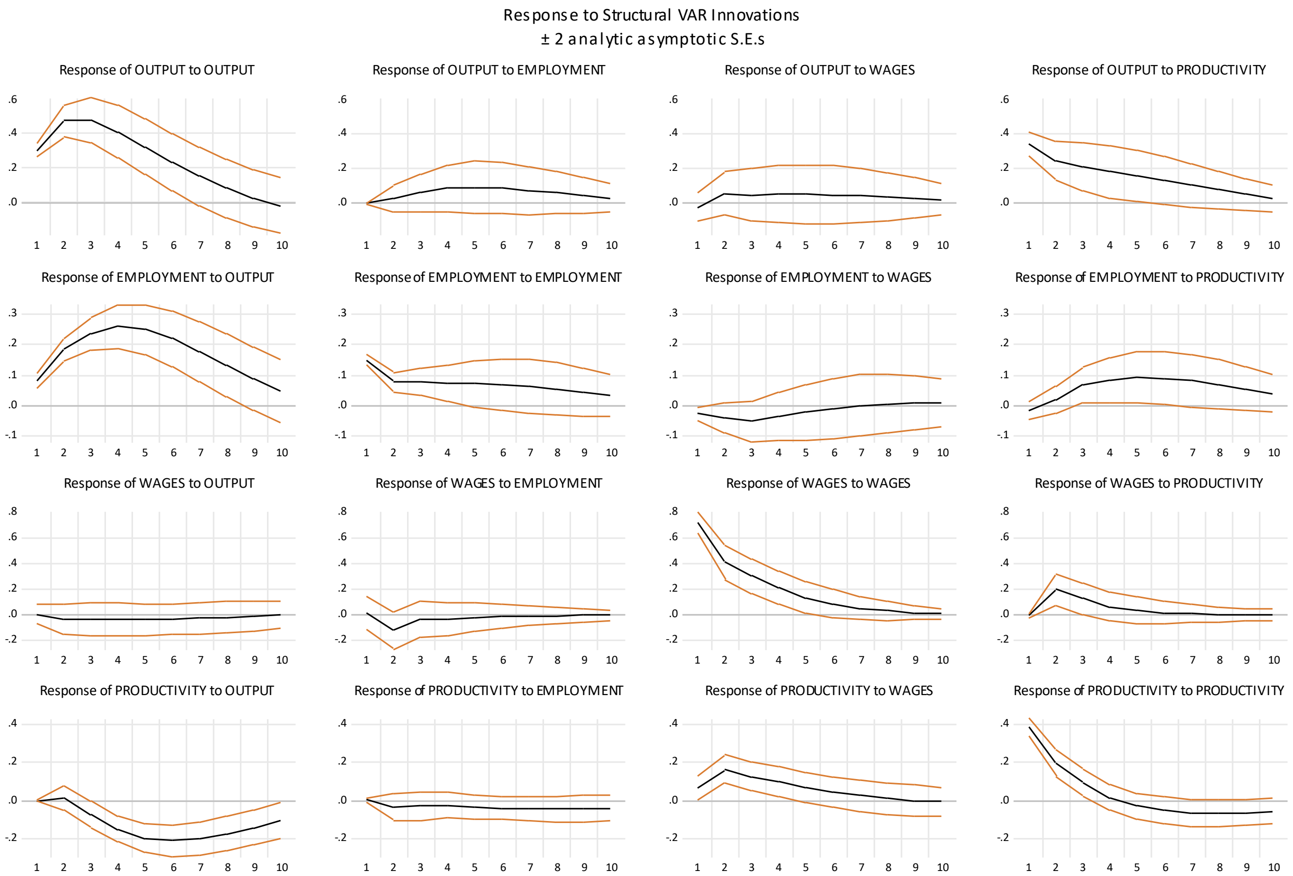


a) 1948-2019

Fig. D1. *(continued)*

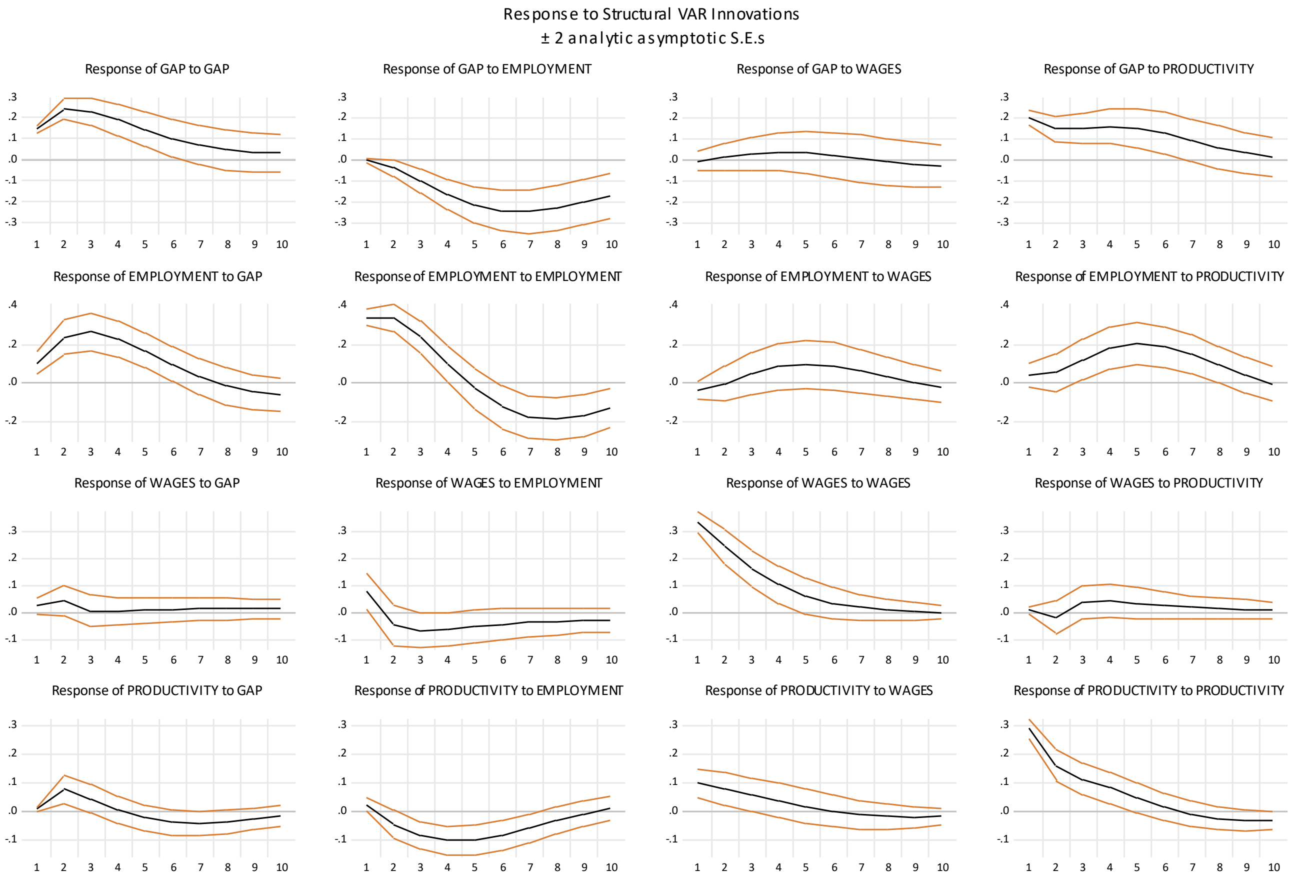


b) Pre-1984

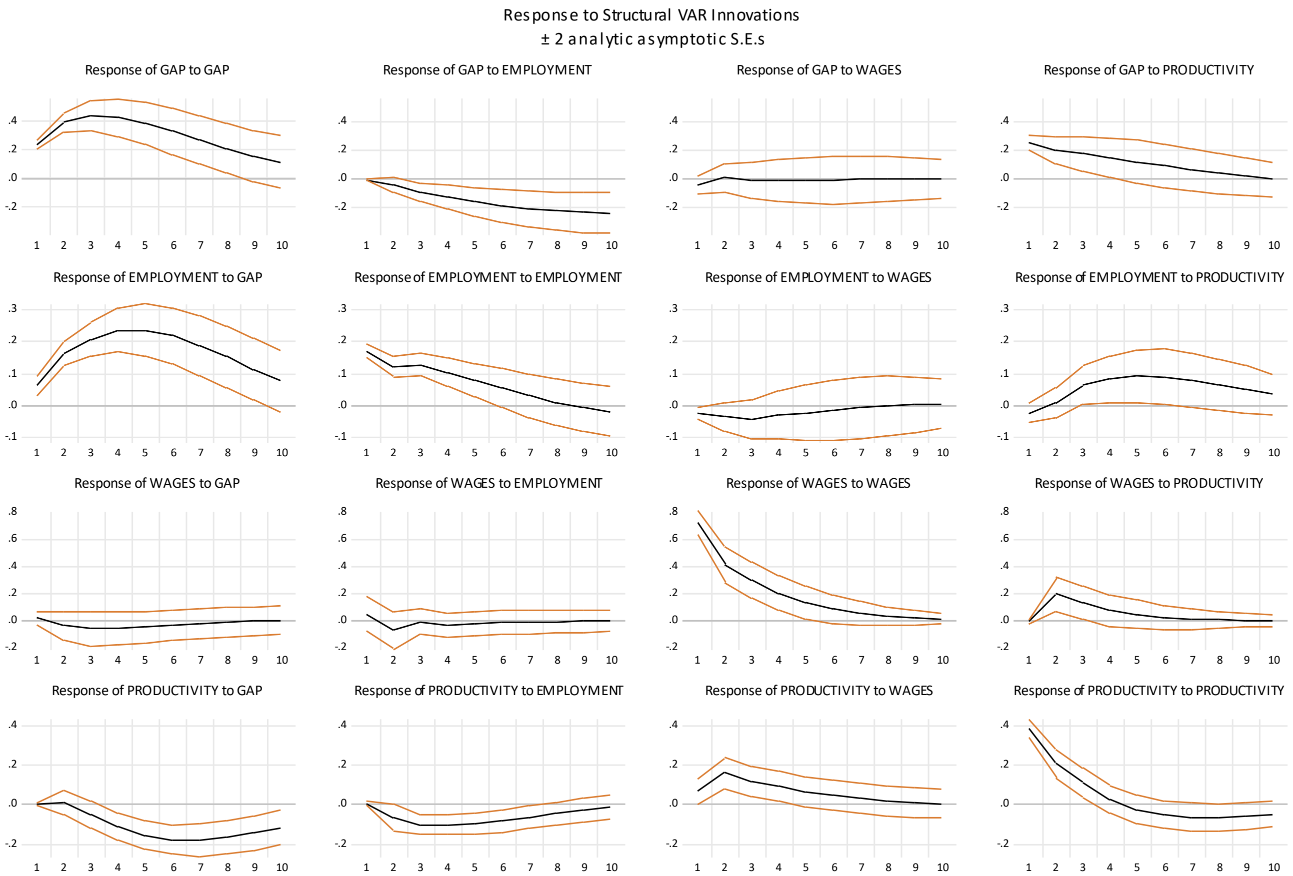


c) Post-1984

Fig. D2. *Impulse response functions, robustness check model 1 (output gap)*

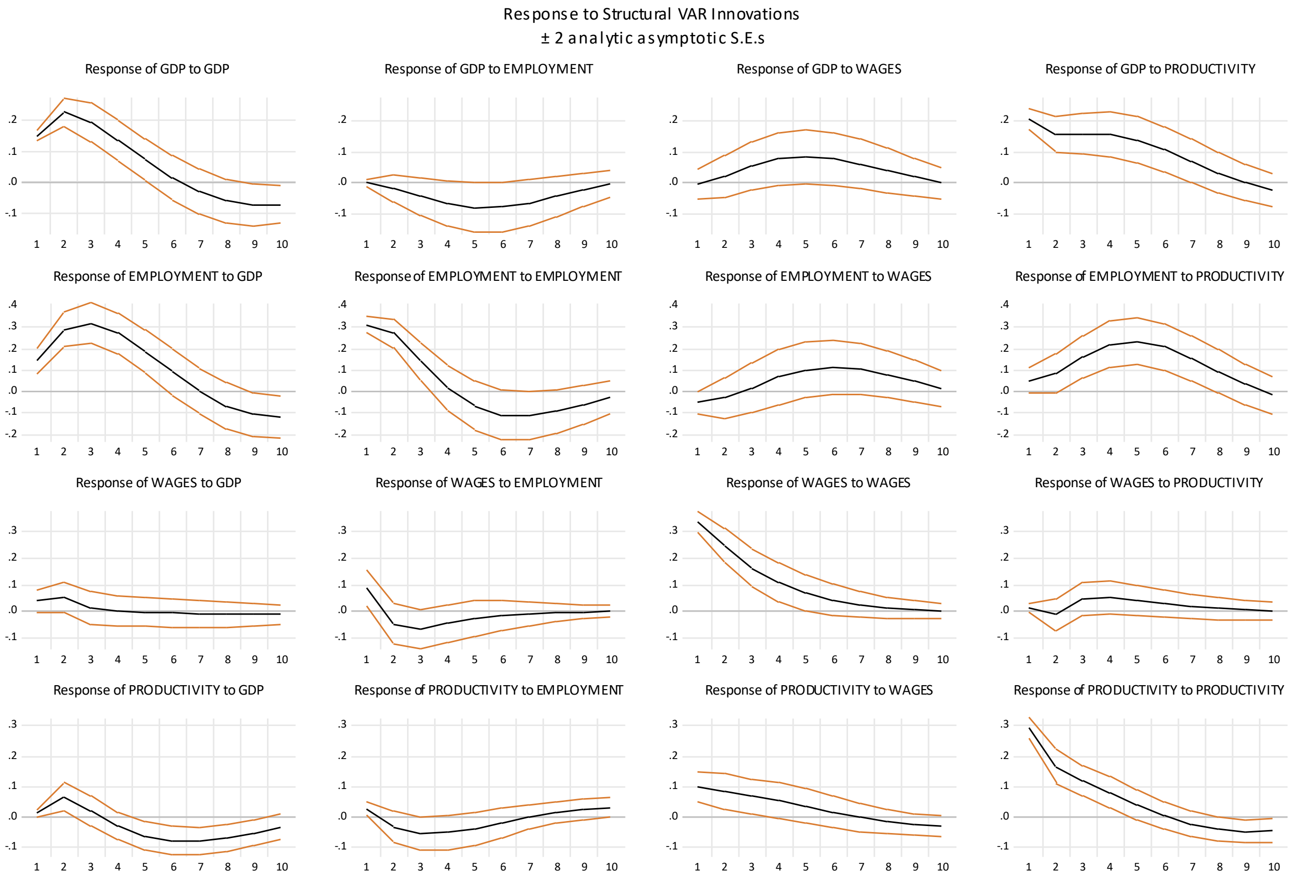


a) Pre-1984

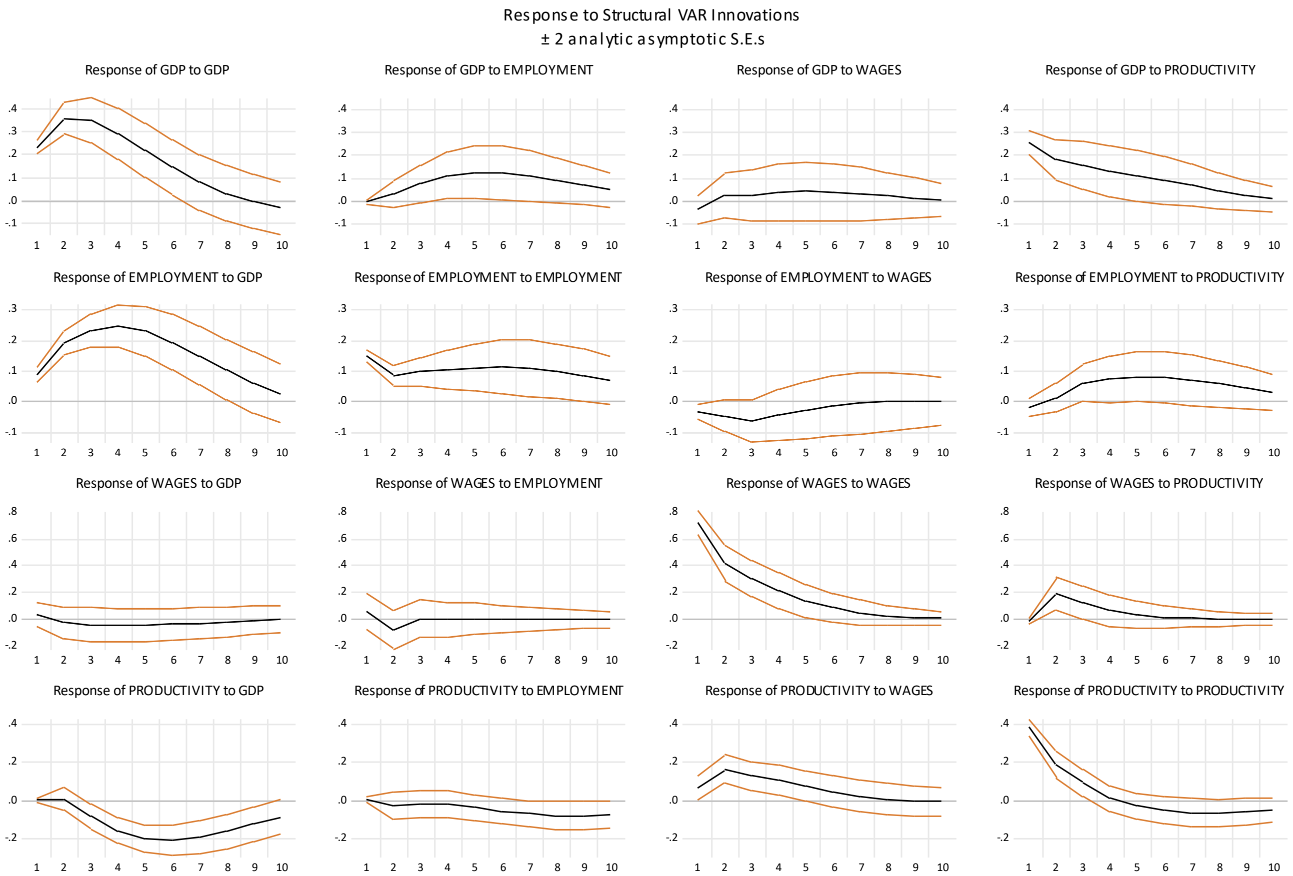


b) Post-1984

Fig. D3. *Impulse response functions, robustness check model 2 (GDP)*

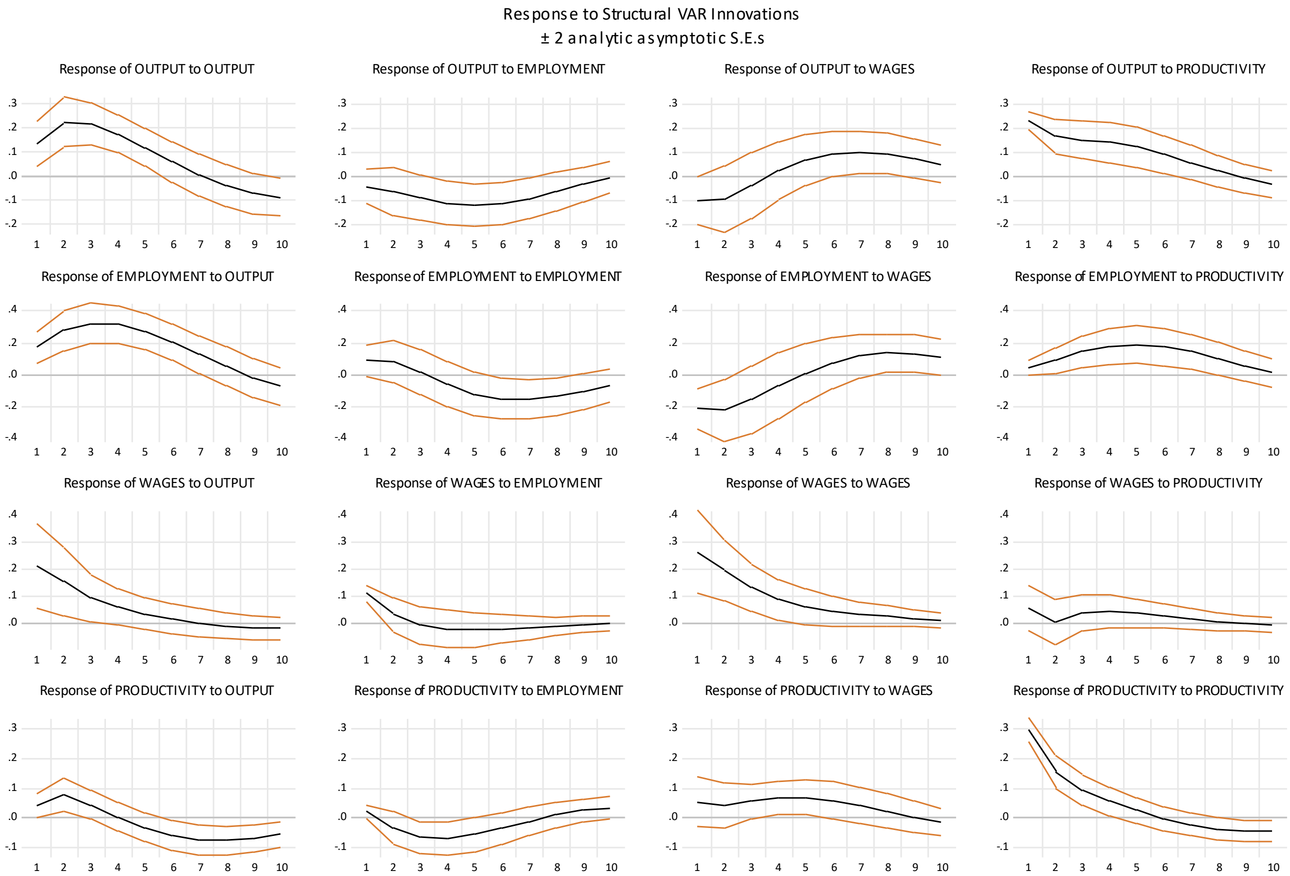


a) Pre-1984

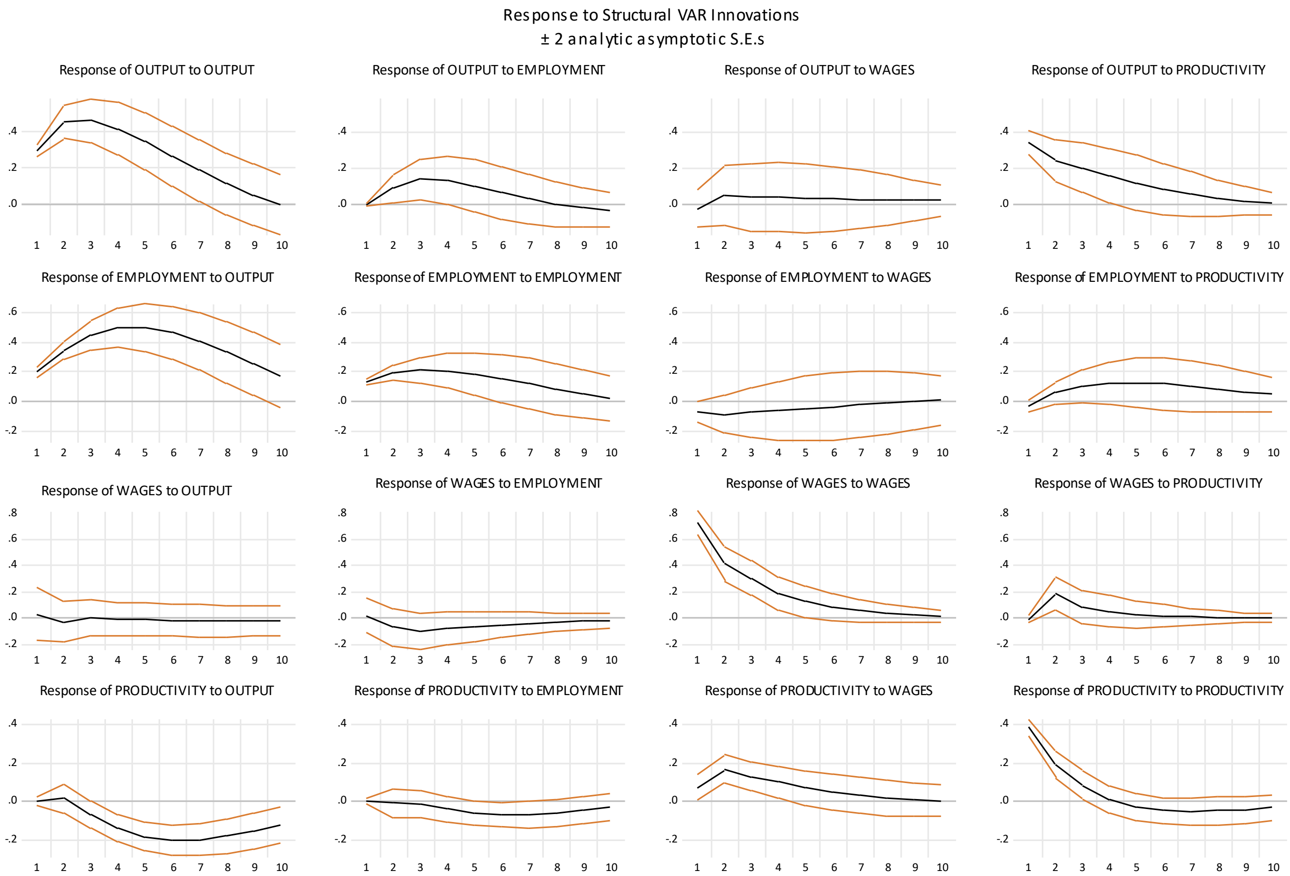


b) Post-1984

Fig. D4. *Impulse response functions, robustness check model 3 (employment level)*

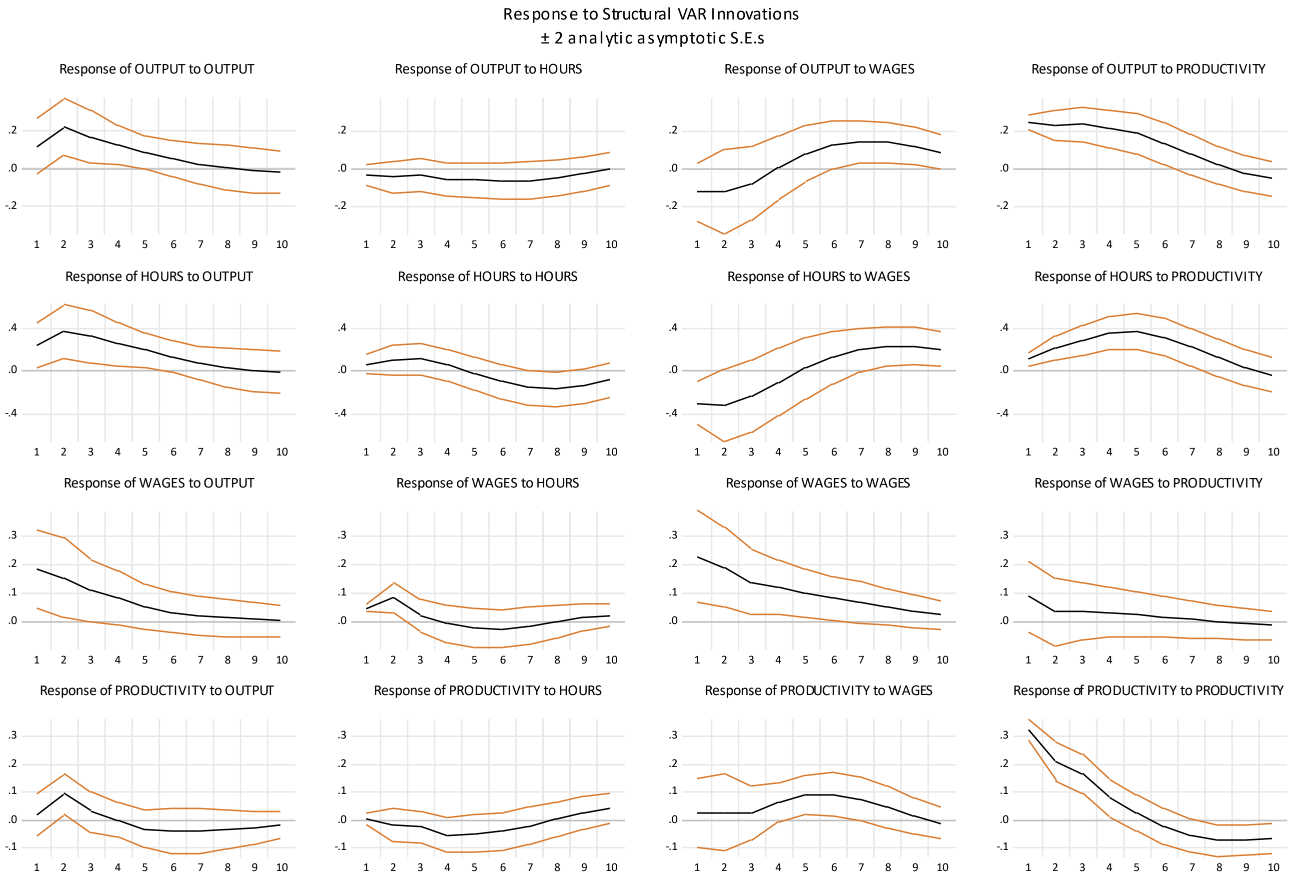


a) Pre-1984

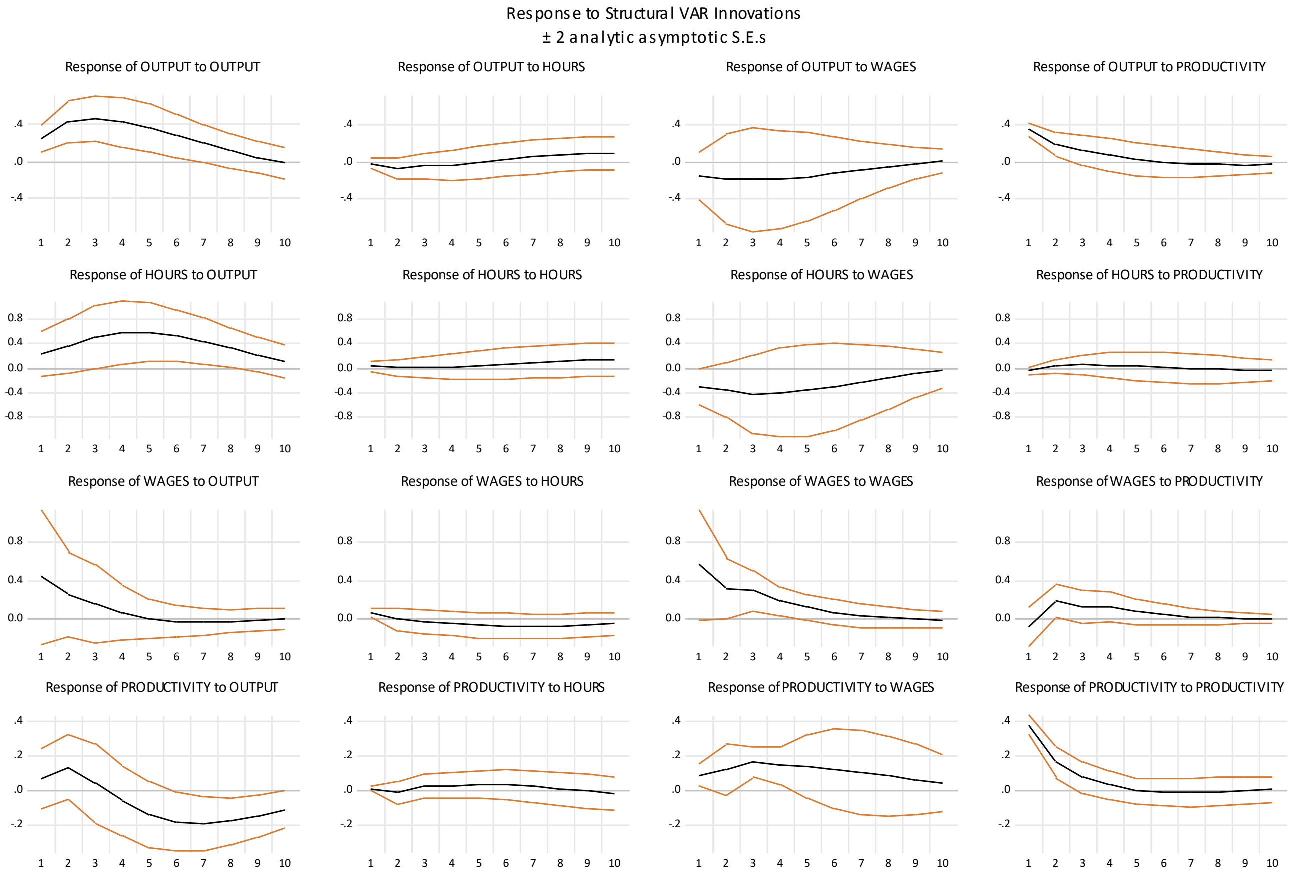


b) Post-1984

Fig. D5. *Impulse response functions, robustness check model 4 (hours worked, nonfarm business)*

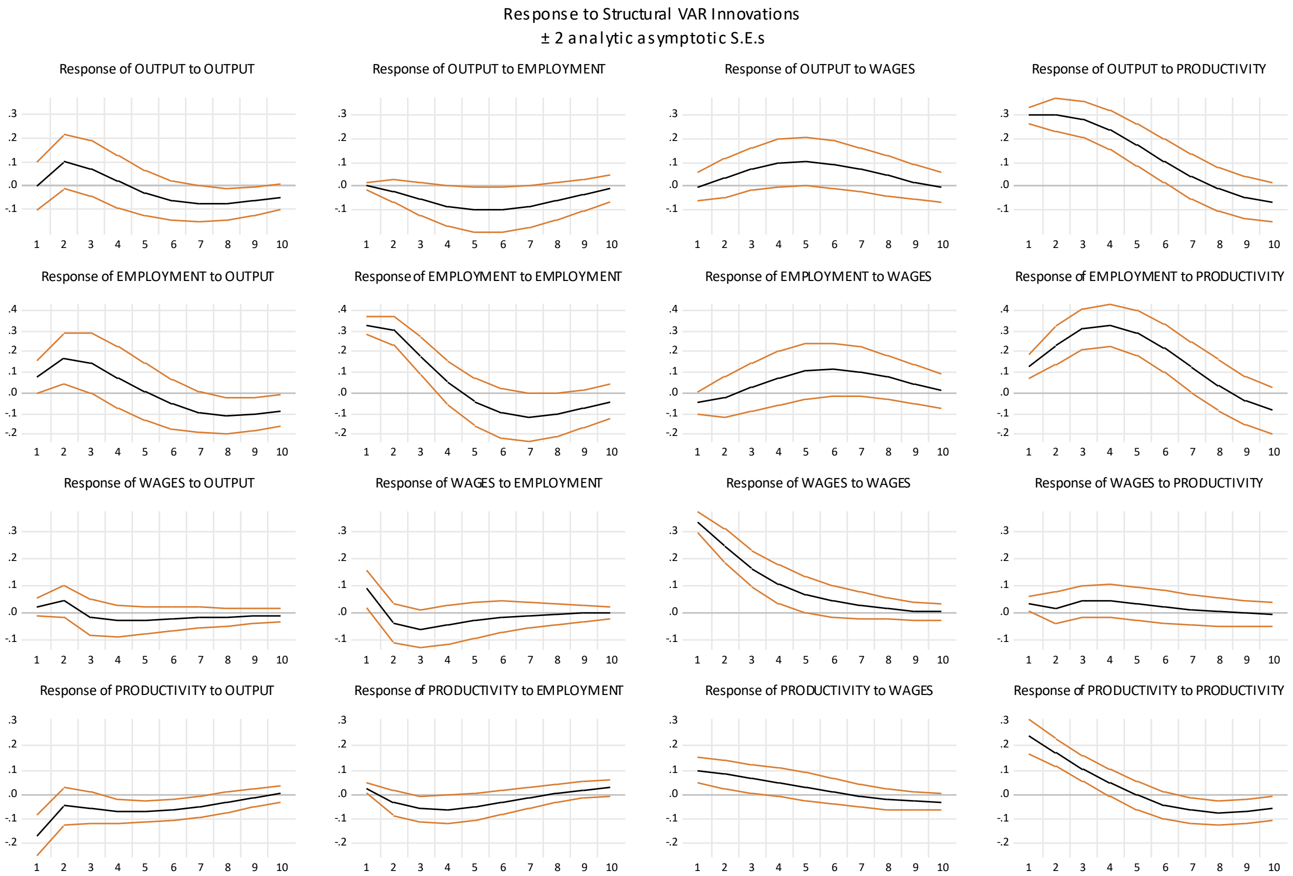


a) Pre-1984

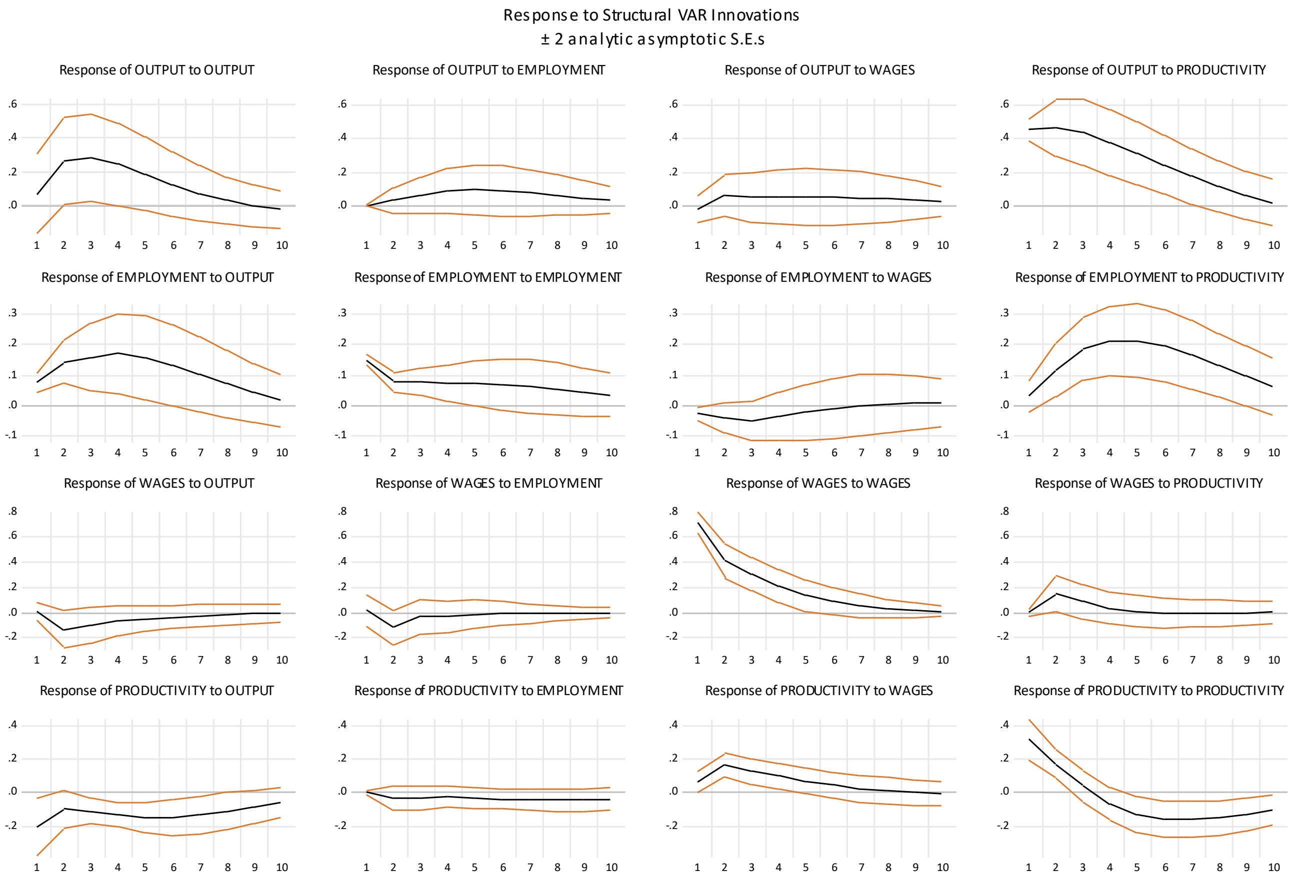


b) Post-1984

Fig. D6. *Impulse response functions, robustness check model 5 (alternative identifying restrictions)*



a) Pre-1984



b) Post-1984

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