Performance Pay and Shifts in Macroeconomic Correlations*

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Abstract

We explain the changes in the pattern of correlations between macroeconomic variables detected by Galí and Gambetti (2009) through shifts in the design of labor compensation around the mid-1980s: a greater incidence of performance pay coupled with a higher responsiveness of wages to cyclical conditions. Using a DSGE model we show that this structural change generates the disappearance of the procyclical response of productivity to non-technology shocks and a reduction of the contractionary effects of technology shocks on hours. Moreover, it accounts for the observed drop in output volatility, the increase in wage volatility and the changes in unconditional correlations.

JEL codes: E24, E32, J3 and J22.

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Introduction

Substantial changes in the correlation structure of U.S. macroeconomic series have accompanied the downward shift in the volatility of output in the mid-1980s, which has been described as "the Great Moderation".[1] Galí and Gambetti (GG hereafter) (2009) provide evidence of a significant shift in the patterns of unconditional and conditional co-movements between output, hours, and labor productivity as well as in the impulse responses to identified shocks. Moreover, Galí and van Rens (2010) and Champagne and Kurmann (2011) detect a notable rise in the volatility of the real wage over the post-1984 period, which contrasts with the parallel decline in output volatility.

Whether these volatility breaks and large changes in the pattern of correlations have a common underlying explanation is an open question. In this paper, we claim that these observed developments are related to structural shifts in the design of labor compensation that have been documented for the U.S. economy. In particular, two major modifications in the U.S. wage setting have occurred at around mid-80s. The first one is an overall reduction in the degree of real wage rigidities. For instance, Blanchard and Galí (2009) and Blanchard and Riggi (2009) emphasize the role of increased wage flexibility in accounting for the decrease in the macroeconomic effects of oil shocks. The second striking fact is the substantial increase of firms' reliance on pay-for-performance mechanisms after the early 1980s. Lemieux et al. (2009a), for example, document that the incidence of performance-pay jobs has risen considerably over the past decades and this has been associated with an increased responsiveness of pay to performance (see Cuñat and Guadalupe, 2005).

We argue that the increased flexibility of real wages associated with a higher incidence of performance-related pay may account to a significant extent for the empirical results uncovered by GG (2009), Galí and van Rens (2010) and Champagne and Kurmann (2011). To appraise the validity of our claim we build a Dynamic New Keynesian (DNK) model which includes work effort as an additional dimension of firms' and households'choice. The level of effort exerted is our measure of worker's performance. Labor compensation has two distinct components: one rewarding hours worked and the

[1] The Great Moderation was first documented by Kim and Nelson (1999) and McConnell and Perez-Quiros (2000), who estimate a break year of 1984 for the volatility of US GDP. An overview of the evidence and its explanations is provided by Blanchard and Simon (2001) and Stock of Watson (2002).

other rewarding performance. We use this setup to analyse the macroeconomic implications of the changes occurred in the structure of labor compensation. In particular, we allow for a rise in the responsiveness of labor pay to the business cycle and characterize this higher flexibility by assuming that the relevance of performance pay in the cyclical fluctuations of wages has increased. In other words, we look at what happens to macroeconomic correlations when the larger cyclical movements of labor pay are combined with a higher share of performance pay in workers average earnings.

We calibrate the model to U.S. data and using stochastic simulations we find that, on its own, the shift in the structure of labor pay yields the following implications:

- A vanishing procyclical response of labor productivity to non-technology shocks.
- A shrinking contractionary effects on hours worked of positive technology shocks.
- A dramatic decline in the procyclicality of labor productivity, measured by a notable drop in the unconditional correlation between labor productivity and output as well as by a sign switch in the unconditional correlation with hours, from positive to large negative values.
- A sizeable drop in the volatility of output, i.e. a great part of the "Great Moderation".
- An increase in the relative and absolute volatility of real wages.

These predictions closely correspond to the empirical findings by GG (2009), Galí and van Rens (2010) and Champagne and Kurmann (2011) on the shift in conditional and unconditional second moments of U.S. macroeconomic series between the pre- and the post-1984 period. The link between changes in labor market dynamics and the shift towards performance-pay contracts has also been investigated by Champagne and Kurmann (2011), who develop a model predicting that a large fraction of the increase in relative wage volatility is explained by greater wage flexibility due to deunionization and a higher incidence of performance-pay mechanisms. While their focus is primarily on wage volatility, our analysis spans the whole structure of conditional and unconditional co-movements between output, hours, and labor productivity.

We also show that if the higher real wage sensitivity to the business cycle had been associated with a *lower* share of performance pay in workers average earnings, then the changes in the patterns of conditional and unconditional correlations would have been exactly the opposite to those reported by GG (2009) in their empirical analysis.

Moreover, we investigate whether a structural change in the labor market through a generalized fall in the adjustment costs of labor, rather than through a change in the design of compensation, is conducive in our model to shifts in the pattern of co-movements that resemble the empirical ones.[2] We find that while this explanation does explain, on its own, the vanishing procyclicality of labor productivity, it yields counterfactual predictions on the hours response to technology shocks. Of course, we do not rule out the potential relevance of this and other alternative explanations of the Great Moderation. However, our paper emphasizes that the developments occurred in the design of labor compensation, leading to a higher relevance of performance-related pay in the cyclical fluctuations of wages, have played a significant role in explaining the enhanced macroeconomic stability and the parallel shift in the structure of correlations.

The paper is organized as follows. Section 1 provides evidence on the large changes in the pattern of correlations associated with the Great Moderation. Section 2 presents the theoretical model. Section 3 sheds light on the implications of the structural change in labor compensation for the impulse responses to identified shocks, for the co-movements between output, hours and productivity and for output and wage volatility. Section 4 analyzes the effects of a drop in labor adjustment costs and Section 5 concludes.

1 The Anatomy of the Great Moderation

Changes in conditional correlations The evidence by GG (2009) on the changes in the pattern of conditional correlations is obtained by estimating a time-varying, structural vector autoregression (SVAR) applied to the first-difference of (log) labor productivity and the (log) level of hours. The correlation of labor productivity with both output and hours *conditional* on technology and non-technology shocks shows large shifts since the mid-1980s

[2] Galí and van Rens (2010) build a theoretical model with frictions in adjusting employment and endogenous wage rigidity and derive predictions supporting this interpretation (see also Barnichon, 2010).

which are reflected in the impulse responses to identified shocks and can be summarized in two empirical results.

First, while in the pre-Great Moderation period labor productivity responds positively and significantly to non-technological innovations, displaying a procyclical profile, in the more recent sub-period the response of labor productivity is negative and the latter becomes countercyclical conditional on non-technology shocks. Second, in the pre-Great Moderation period the effect of a technology shock on hours is negative and significant, while in the post-1984 period the effect, albeit still negative, is smaller (in absolute value) and almost reaching zero.[3] Figures 1a and 1b summarize the bulk of this evidence.

Changes in unconditional correlations As for the changes in unconditional correlations, GG (2009) report a dramatic fall in the cyclical behavior of labor productivity. The unconditional correlation between labor productivity and output becomes close to zero in the post-84 sample period while it was 0.61 in the pre-84 period. By using hours worked as the cyclical indicator, labor productivity becomes a countercyclical variable as the unconditional correlation between labor productivity and hours changes from 0.18 to -0.46. Similar results are obtained by Galí and van Rens (2010) and, consistently with them, Barnichon (2010) finds that the sign of the corre-

[3] The effect on impact of technology shocks on labor input is a rather controversial issue in the literature. Galí (1999) and Basu et al. (2006), among many others, document a negative correlation between labor productivity and hours conditional on technology shocks. They use different identification methods: long run restrictions in the former case (exactly as in GG, 2009), a direct measure of technology change derived through a growth accounting approach in the latter case. The finding of a contractionary effect of technology improvements has been questioned along several dimensions. Christiano et al. (2003) argue that it originates from a specification error due to over-differencing of hours worked: if hours (per capita) are assumed to be a stationary variable and their level is used in the VAR analysis, then hours worked would rise, rather than fall, in the aftermath of a technology improvement. Chari et. al (2008) take the stand that Galí's (1999) result is potentially flawed by small-sample bias. In response to these criticisms, Fernald (2007) shows that once one allows for (statistically and economically plausible) trend breaks in productivity, the treatment of hours is relatively unimportant and hours fall sharply on impact following a technology improvement. Francis and Ramey (2005) provide arguments supporting the unit root hypothesis for per capita hours. Indeed, the impulse response functions from the model with stationary hours indicate that non-technology shocks have long-lived significant effects on labor productivity contrary to the fundamental identifying assumption.

lation between cyclical unemployment and the cyclical component of labor productivity switches in the mid-80s: from negative it becomes positive. Stiroh (2009) confirms that the increased output stability in the U.S. reflects a significant decline in the correlation between labor productivity growth and hours growth.

Changes in volatility As for the changes in unconditional volatilities, GG document that the standard deviation of output drops from 2.59 in the pre-84 period to 1.23 in the post-84 period and that the decline in the standard deviation of hours and labor productivity is not as large as that experienced by output. On the other hand, Galí and van Rens (2010) and Champagne and Kurmann (2011) find that the standard deviation of real wages has increased in the post-84 sample compared to the previous sub-period, both relatively to the standard deviation of output and in absolute terms. The size of this increase varies depending on the wage measure. For example, Champagne and Kurmann (2011) document that when data on hourly wages in the non-farm business sector are used (drawn from the BLS labor productivity and cost program, LPC), the standard deviation of real wages increases by 52 per cent.

The complex picture that emerges from these findings challenges the "good luck" view of the Great Moderation and suggests that the U.S. economy has witnessed more than a mere scaling down of the size of shocks. In what follows, we argue that the increased output stability and the shifts in the pattern of macroeconomic correlations have a common source which is related to the important changes occurred in the structure of labor pay.

2 Theoretical Framework

In this section, we develop a dynamic New Keynesian (DNK) model to assess whether the observed changes summarized above can be explained by the increased flexibility in wage setting associated with a shift towards performance pay schemes in the U.S. labor market.

The increased incidence of pay-for-performance mechanisms after the early 1980s is largely documented. Lemieux et al. (2009a), for example, using data from the Panel Study of Income Dynamics (PSID) report that the proportion of performance-pay jobs among salaried workers has risen from about 30 percent in the late 1970s to nearly 50 percent in the late 1990s. Moreover, on the basis of an annual survey of Fortune 1000 corporations, they calculate that the fraction of workers with some forms of performance-pay increased from 20.7 percent in 1987 to 44.5 percent in 2002. Mitchell et al. (1990) point to a significant shift towards adoption of incentive pay plans in the 1980s, after a period following the end of World War II to 1979 which was characterized by a decline in their use.[4] Importantly, the growing reliance on these compensation schemes has affected workers in general (Prendergast, 1999) and the increased share of performance-related pay in workers average earnings is associated with an increase in the estimated performance-pay sensitivity.[5]

The model features can be summarized as follows:

- Effective labor input used by firms is a function of hours worked and effort exerted. The latter is our measure of worker's performance.
- Following Galí (1999), we split labor compensation in two components: the one rewarding hours and the one rewarding performance. Moreover, along the line of Blanchard and Galí (2007 and 2010), we introduce *ad hoc* rigidities in labor compensation.
- We introduce hours' adjustment costs, which, while not needed for the intuition behind our argument, allow us to shed light on how far we can go by assuming a more flexible labor market, which implies a decrease in "labor hoarding", without any changes in the structure of labor compensation.[6]

[4] Similarly, Hall and Liebman (1998) show that the responsiveness of pay to performance for chief executive officers increased after the early 1980s. Jensen and Murphy (1990) estimate low pay-performance sensitivity for top executives in the 1970s to the mid 1980s.

[5] Cuñat and Guadalupe (2005 and 2009) show that the increased responsiveness of pay to performance originates from the trend towards increased product market competition, that induced firms to re-shape the structure of the incentives to reward workers, making performance-related pay schemes more pervasive. Another explanation for the higher incidence of these pay systems is based on the extensive development of performance appraisal systems, due to progress in information and monitoring technologies which provided improved worker performance measures. Lemieux et al. (2009a) discuss these advances and point to the extraordinary expansion over the last 30 years of consulting companies specializing in compensation.

[6] The presence of labor hoarding is a common explanation for the procyclicality of labor productivity and the ensuing short-run increasing returns to labor (SRIRL) puzzle.

- Given our objectives, we assume that there are two sources of fluctuations in the economy: a technology and a non-technology shock. We characterize the nature of the shocks in accordance with the empirical analysis by GG (2009), whose findings we seek to explain. In particular, we assume that the exogenous productivity factor has a unit root and is thus non-stationary in levels, so that a technology shock affects productivity in the long-run. On the contrary, we assume a stationary process for what we call the non-technology shock and characterize it as a preference shock, as in Galí and Van Rens (2010).

2.1 Households

We consider a continuum of households uniformly distributed on the unit interval. Household j maximizes

$$\underset{0}{E} \sum_{t=0}^{\infty} \beta^t \xi_t \left\{ U[C_t(j), C_{t-1}] - g[H_t(j), E_t(j)] \right\}, \tag{1}$$

where $C_t(j)$ is household j's consumption in period t of the usual Dixit-Stiglitz aggregate of goods with elasticity of substitution ϵ, C_{t-1} is the aggregate consumption level in period $t-1$, the function $g(.)$ measures the disutility from work, which depends on hours H_t and effort exerted E_t, and β is the discount factor; ξ_t is a preference disturbance term with mean unity which follows the stationary first order autoregressive process

$$\log \xi_t = \rho_\xi \log \xi_{t-1} + \varepsilon_t^\xi, \tag{2}$$

where ε_t^ξ are zero-mean, i.i.d. innovations. We assume a specification of the period utility consistent with the balanced growth path:

$$U[C_t(j), C_{t-1}] \equiv \log[C_t(j) - hC_{t-1}], \tag{3}$$

where $h \in [0, 1)$ denotes the degree of external habit formation. Following Bils and Cho (1994) and Barnichon (2010), we assume that the period disutility of labor takes the form:

$$g(H_t(j), E_t(j)) = \frac{\lambda_h}{1+\sigma_h} H_t^{1+\sigma_h}(j) + H_t(j) \frac{\lambda_e}{1+\sigma_e} E_t^{1+\sigma_e}(j), \tag{4}$$

where λ_h, λ_e, σ_h, and σ_e are positive constants.

The period budget constraint, conditional on the optimal allocation of expenditures among different goods, is given by:

$$P_t C_t + Q_t B_t = W_t H_t + V_t E_t + B_{t-1} + \Pi_t, \tag{5}$$

where P_t is the price level, Q_t is the price of a one-period nominally riskless bond, paying one unit of money and B_t is the amount of that bond purchased in period t. As in Galí (1999), W_t and V_t represent the nominal prices of one hour's work (nominal hourly wage hereafter) and of a unit of effort, respectively, where the latter represents our measure of performance pay. Π_t denotes the households' profits from ownership of firms.

The optimal consumption/savings and labor supply decisions are described by

$$Q_t = \beta E_t \frac{\xi_{t+1}}{\xi_t} \left(\frac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \right) \frac{P_t}{P_{t+1}} \tag{6}$$

$$W_t^r \equiv \frac{W_t}{P_t} = (C_t - hC_{t-1}) \left(\lambda_h H_t^{\sigma_h} + \frac{\lambda_e}{1+\sigma_e} E_t^{1+\sigma_e} \right) \tag{7}$$

$$V_t^r \equiv \frac{V_t}{P_t} = (C_t - hC_{t-1}) \, \lambda_e H_t E_t^{\sigma_e}. \tag{8}$$

Equations (7) and (8) are the perfectly competitive hour and effort supply schedules, respectively. We relax the assumption of perfect competition in the labor market along the lines suggested by Blanchard and Galí (2007, 2009 and 2010), by introducing *ad hoc* rigidities into the compensation structure, which prevent the cyclical components of both W_t^r and V_t^r from fully adjusting to their competitive counterparts. In particular, let us detrend W_t^r and V_t^r with the non-stationary level of technology, A_t, so that $\widetilde{W}_t^r \equiv \frac{W_t^r}{A_t}$ and $\widetilde{V}_t^r \equiv \frac{V_t^r}{A_t}$ denote the cyclical components of the hourly real wage and the real price of effort, respectively. We then replace equations (7) and (8) with the following hourly wage and performance pay curves, which, together, characterize the structure of labor compensation:

$$\widetilde{W}_t^r = \left[\frac{(C_t - hC_{t-1}) \left(\lambda_h H_t^{\sigma_h} + \frac{\lambda_e}{1+\sigma_e} E_t^{1+\sigma_e} \right)}{A_t} \right]^{1-\gamma_h}, \tag{9}$$

$$\widetilde{V}_t^r = \left[\frac{(C_t - hC_{t-1}) \, \lambda_e H_t E_t^{\sigma_e}}{A_t} \right]^{1-\gamma_e}, \tag{10}$$

The parameters γ_e and γ_h measure the sensitivity of worker's pay to the business cycle. The lower are γ_e and γ_h the higher is the responsiveness of labor compensation to economic conditions.

Changing γ_h and γ_e, however, affects both the degree of cyclicality of labor compensation as well as the stationarized steady state values of its two components: $\overline{\widetilde{W^r}}$ and $\overline{\widetilde{V^r}}$. In general, an increase in the flexibility of labor compensation may leave unchanged the shares of performance pay and hourly pay in workers average earnings or, conversely, it may be associated with a change in the relative importance of the two compensation margins in workers average earnings. Indeed, for a given value of γ_h, a decrease in γ_e captures a higher flexibility of labor compensation associated with a higher share of effort-related pay in worker's average earnings, $\left(\frac{\overline{\widetilde{V^r}}}{\overline{\widetilde{W^r}}+\overline{\widetilde{V^r}}}\right)$. Conversely, for a given value of γ_e, a decrease in γ_h reflects a higher flexibility of labor compensation associated with a higher share of hourly pay in worker's average earnings, $\left(\frac{\overline{\widetilde{W^r}}}{\overline{\widetilde{W^r}}+\overline{\widetilde{V^r}}}\right)$.

Hence, for a given value of γ_h, a decrease in γ_e depicts the increased cyclical responsiveness of labor compensation as being associated with an increased relevance of performance related pay. By contrast, for a given value of γ_e, a decrease in γ_h represents an increase in the responsiveness of labor compensation associated with a decrease in the relative importance of the performance remuneration margin.

2.2 Firms

We distinguish between two sectors: retail and wholesale firms. Households are employed by wholesale firms which face convex costs of varying their hours input and operate in a competitive market in relation to the goods they produce. Wholesale firms sell their output to retailers, which are monopolistically competitive and set prices in a staggered fashion, as in Calvo (1983).[7]

2.2.1 Wholesale firms

Production by wholesale firm j is

[7] Distinguishing between the two sectors allows us to provide a convenient separation in the model of the sticky-price friction and the labor adjustment cost friction.

$$Y_{jt}^{w}=A_{t}L_{jt}^{\alpha}, \tag{11}$$

where $\alpha\in(0,1]$ and L_{jt} denotes the effective labor input defined as a function of hours and effort:[8]

$$L_{jt}=H_{jt}E_{jt}, \tag{12}$$

and A_t was defined earlier as the productivity factor common across firms. We assume a trending nonstationary process for the technology level, A_t, to be consistent with the identification approach in GG (2009) which assumes that only technology shocks have a permanent effect on the level of productivity. Following Altig et al. (2005) and Gertler et al. (2008), we assume that $Z_t\equiv\frac{A_t}{A_{t-1}}$ obeys the following exogenous stochastic process:

$$\log Z_t=(1-\rho_a)\log\gamma_a+\rho_a\log Z_{t-1}+\varepsilon_t^a, \tag{13}$$

where γ_a defines the constant growth rate and ε_t^a is the i.i.d. technology shock.

Each firm j varies its hours input by facing convex costs, which are increasing with the speed of the desired adjustment and are measured in terms of the final good, according to the following adjustment cost function:

$$G_{jt}=\frac{\phi_h}{2}\left(\frac{H_{jt}}{H_{jt-1}}-1\right)^2Y_t, \tag{14}$$

where $\phi_h\geq 0$ is the hours' adjustment cost parameter. Equation (14) implies that firms have an incentive to make gradual changes to hours which result in an intertemporal smoothing of their demand for hours.

Let Π_{jt} denote firm j' s period t profit. The wholesale firm maximizes

$$E_t\sum_{k=0}^{\infty}\beta^k\frac{\xi_{t+k}}{\xi_t}\left(\frac{C_t-hC_{t-1}}{C_{t+k}-hC_{t+k-1}}\right)\Pi_{jt+k} \tag{15}$$

subject to (11), where $\Pi_{jt}=\frac{1}{\mu_t}Y_{jt}^w-\frac{W_t}{P_t}H_{jt}-\frac{V_t}{P_t}E_{jt}-\frac{\phi_h}{2}(\frac{H_{jt}}{Hjt-1}-1)^2Y_t$ and $\mu_t=\frac{P_t}{P_t^w}$ is the markup of retail over wholesale prices. The first order conditions for this problem imply

[8] See Galí (1999); as in the standard literature, we assume that effort is perfectly observable.

$$V_t^r \equiv \frac{V_t}{P_t} = \frac{MPE_{jt}}{\mu_t} \tag{16}$$

and

$$\begin{aligned} W_t^r \equiv \tfrac{W_t}{P_t} = \tfrac{MPH_{jt}}{\mu_t} - \phi_h \left(\tfrac{H_{jt}}{H_{it-1}} - 1 \right) \tfrac{Y_t}{H_{jt-1}} + \\ + \beta E_t \tfrac{\xi_{t+1}}{\xi_t} \tfrac{C_t - hC_{t-1}}{C_{t+1} - hC_t} \phi_h \left(\tfrac{H_{jt+1}}{H_{jt}} - 1 \right) \tfrac{H_{jt+1}}{H_{jt}^2} Y_{t+1} \end{aligned} \tag{17}$$

where $MPH_{j,t}$ is the marginal product of hours ($MPH_{j,t} \equiv \alpha A_t H_{jt}^{\alpha-1} E_{jt}^{\alpha}$) and $MPE_{j,t}$ is the marginal product of effort ($MPE_{j,t} \equiv \alpha A_t H_{jt}^{\alpha} E_{jt}^{\alpha-1}$). In symmetric equilibrium $H_{j,t} = H_t$ and $E_{j,t} = E_t$ for all j, since all wholesale firms are identical and make the same decisions.

2.2.2 Retailers

We assume a continuum of monopolistically competitive retailers, indexed by i on the unit interval. The retail firm purchases the wholesale output and converts it into a differentiated final good, according to the following technology:

$$Y_t(i) = Y_t^w(i), \tag{18}$$

where $Y_t^w(i)$ is the quantity of the (single) wholesale good.

Following Calvo (1983), retailers can reset their price at random dates: in each period only a randomly chosen fraction $(1-\theta)$ of retailers adjusts their prices. The remaining retailers keep their prices unchanged. The pricing decision of a retail firm obeys the following equilibrium condition:

$$\underset{t}{E} \sum_{k=0}^{\infty} \theta^k Q_{t,t+k} Y_{t+k/t} \left(\frac{P_t^*}{P_{t-1}} - \frac{\epsilon}{\epsilon - 1} MC_{t+k/t} \frac{P_{t+k}}{P_{t-1}} \right) = 0 \tag{19}$$

where $MC_{t+k/t}$ denotes the real marginal cost in $t+k$ for a firm that last reset its prices in t and $Q_{t,t+k}$ is the stochastic discount factor for nominal payoffs, $Q_{t,t+k} \equiv \beta^k \frac{\xi_{t+k}}{\xi_t} \left(\frac{C_t - hC_{t-1}}{C_{t+k} - hC_{t+k-1}} \right) \frac{P_t}{P_{t+k}}$. Assuming that hours' adjustment costs are distributed to the aggregate households, market clearing requires[9]

[9] Market clearing for good i requires $A_t L_{i,t}^{\alpha} = C_t(i)$. Integrating over i yields $A_t L_t^{\alpha} = \int_0^1 C_t(i) di = C_t \int_0^1 \frac{C_t(i)}{C_t} di = C_t \int_0^1 \left[\frac{P_t(i)}{P_t} \right]^{-\epsilon} di.$

$$A_t L_t^{\alpha} = C_t \int_0^1 \left[\frac{P_t(i)}{P_t} \right]^{-\epsilon} di. \tag{20}$$

2.3 Monetary Policy

The model is closed by a monetary policy rule. We assume that monetary policy obeys a simple Taylor rule, in which the nominal interest rate reacts to the current level of inflation and to the cyclical behavior of output:

$$\frac{1+i_t}{\overline{R}} = \pi_t^{\phi_\pi} \left(\frac{Y_t}{A_t} \right)^{\phi_y}$$

where $\overline{R}$ is the steady state nominal gross rate and ϕ_π and ϕ_y are parameters.

2.4 The stationary representation of the model

The non-stationary technology process induces a stochastic trend in C_t, Y_t, W_t^r and V_t^r. To obtain the stationary representation of the model, the nonstationary variables are rescaled by the level of technology: $\widetilde{X}_t = \frac{X_t}{A_t}$, where X_t is a generic variable and $\widetilde{X}_t$ its corresponding stationary ratio (see Gertler *et al.*, 2008, Juillard *et al.,* 2008 and Smets and Wouters, 2007). The detrended model is then log-linearized around the balanced growth steady state. The complete system of log-linear equations in stationary form is the following:

1. Technology

$\widetilde{y}_t = \alpha \left(h_t + e_t \right)$

2. Euler Equation

$$\widetilde{c}_t = \frac{\frac{h}{\gamma_a}}{1+\frac{h}{\gamma_a}} \left(\widetilde{c}_{t-1} - z_t \right) + \frac{1}{1+\frac{h}{\gamma_a}} E_t \left(\widetilde{c}_{t+1} + z_{t+1} \right) + \\ - \frac{1-\frac{h}{\gamma_a}}{1+\frac{h}{\gamma_a}} \left(i_t - E_t \pi_{t+1} + E_t \Delta \log \xi_{t+1} \right)$$

3. Performance Compensation

$$\widetilde{v}_t^r = \left(1 - \gamma_e \right) \left[\frac{1}{1-\frac{h}{\gamma_a}} \left(\widetilde{c}_t - \frac{h}{\gamma_a} \widetilde{c}_{t-1} + \frac{h}{\gamma_a} z_t \right) + h_t + \sigma_e e_t \right]$$

4. Hour Compensation

$$\widetilde{w}_t^r = (1-\gamma_h)\left[\frac{1}{1-\frac{h}{\gamma_a}}\left(\widetilde{c}_t - \frac{h}{\gamma_a}\widetilde{c}_{t-1} + \frac{h}{\gamma_a}z_t\right) + \frac{\lambda_h\sigma_h}{\lambda_h + \frac{\lambda_e}{1+\sigma_e}\overline{E}^{1+\sigma_e}}h_t + \frac{\lambda_e\overline{E}^{1+\sigma_e}}{\lambda_h + \frac{\lambda_e}{1+\sigma_e}\overline{E}^{1+\sigma_e}}e_t\right]$$

5. Phillips Curve

$$\pi_t = \beta E_t\pi_{t+1} +$$
$$+\frac{(1-\beta\theta)(1-\theta)}{\theta}\frac{\alpha}{\alpha+\epsilon(1-\alpha)}\left[\widetilde{w}_t^r - \widetilde{y}_t + h_t + \frac{\epsilon}{\epsilon-1}\frac{\phi_h}{\alpha}\left(h_t - h_{t-1}\right) - \beta\frac{\epsilon}{\epsilon-1}\frac{\phi_h}{\alpha}\left(E_t h_{t+1} - h_t\right)\right]$$

6. Aggregate Resource Constraint

$\widetilde{y}_t = \widetilde{c}_t$

7. Efficient Price Frontier

$\widetilde{v}_t^r = \widetilde{w}_t^r - e_t + h_t + \frac{\epsilon}{\epsilon-1}\frac{\phi_h}{\alpha}\left(h_t - h_{t-1}\right) - \beta\frac{\epsilon}{\epsilon-1}\frac{\phi_h}{\alpha}\left(E_t h_{t+1} - h_t\right)$

8. Monetary policy rule

$i_t = \phi_\pi\pi_t + \phi_y\widetilde{y}_t$

3 The role of Performance-related Pay

This section establishes that the higher flexibility of labor compensation, coupled with a higher share of performance-related pay in workers average earnings, does explain most of the empirical evidence summarized in section 2. In order to pin down the role of changes in the U.S. design of labor compensation, we fix all the model's parameters except γ_e and investigate if an increasing relevance of performance-related pay in the cyclical fluctuations of labor compensation (a drop in γ_e) can account for the observed shifts associated with the Great Moderation. It is important to emphasize that, in doing so, we do not maintain that the U.S. economy has not undergone relevant structural changes other than those occurred in the structure of labor pay. By keeping all the parameters but γ_e fixed across periods, we try to ascertain the specific ability of changes in labor pay in accounting for the shifting patterns of macroeconomic correlations and volatilities.

In line with what is widely accepted in the literature, we calibrate the discount factor β to a value of 0.99 and the elasticity of substitution among differentiated goods ϵ to a value of 6, which is consistent with a gross steady state markup of 20 percent. The sticky price parameter θ is calibrated equal to 0.6, which implies an average price duration of three quarters, a value consistent with the empirical evidence (see Sbordone, 2006). The degree of external habit formation h is set equal to 0.6. As for the monetary policy rule, we set $\phi_\pi = 1.2$, in the range of values $(1, 5]$ that cover the empirically plausible set conditional on having a unique equilibrium, and $\phi_y = 0.1$. We calibrate the elasticity of output with respect to effective labor input, α, to a value of $2/3$, and the labor adjustment cost parameter, ϕ_h, is set equal to 1. We assume that the elasticity of the marginal disutility of effort with respect to effort is equal to 1 ($\sigma_e = 1$) and we calibrate σ_h to 1, in accordance with Schor's (1987) estimate of 0.5 for the elasticity of effort with respect to hours, $\frac{\sigma_h}{1+\sigma_e}$. The steady state balanced growth term γ_a is calibrated equal to 1.004, consistent with the average quarterly output growth of 0.4 per cent recorded in the U.S. data. Following Altig et al. (2005), Gertler et al. (2008) and Juillard et al. (2008) we assume a trending nonstationary $AR(2)$ process for the level of technology, A_t, by setting $\rho_a = 0.5$. The non-technology disturbance term is assumed to follow a stationary $AR(1)$ process characterized by a first order autocorrelation parameter, ρ_ξ, equal to 0.9.

3.1 Performance related pay and Changes in the Structure of Conditional Correlations

The response of labor productivity to non-technology shocks

Figure 2a highlights that the response at impact of labor productivity to a non-technology shock is monotonically strictly increasing in γ_e and this holds true for any given value of γ_h. Hence, an increase in the responsiveness of the real wage to economic conditions associated with a higher relevance of the performance-related component in the cyclical fluctuations of labor compensation lowers the procyclicality of labor productivity conditional on non-technology shocks. When the share of performance-related pay is sufficiently large, labor productivity becomes countercyclical.

Conversely, figure 2b shows that high values of γ_h are associated with countercyclical responses of labor productivity conditional on non-technology shocks. Labor productivity becomes procyclical as γ_h approaches zero. The response at impact of labor productivity to non-technology shocks is therefore monotonically strictly decreasing with γ_h, regardless of the values assigned to γ_e. In other words, an increase in the flexibility of labor compensation associated with a lower relative share of performance pay would imply an increase in the degree of procyclicality of labor productivity conditional on non-technology shocks.

The economic intuition behind this result is as follows. The apparent feature of short run increasing returns to labor (SRIRL) derives from the fact that firms vary the intensity of labor utilization over the cycle. The extent to which this happens depends on the short run profitability of substituting increases in effort for increases in hours of work. Profitability depends on the structure of labor compensation and in particular on the shares of the two compensation margins: following an increase in demand, the smaller the increase in the compensation of performance, the more profitable it will be to react to current and expected changes in the economy by varying labor effort and the higher will be the degree of procyclicality of labor productivity.

To see this, consider the efficient price frontier:

$$\widetilde{v}_t^r - \widetilde{w}_t^r = h_t - e_t + \frac{\epsilon}{\epsilon - 1}\frac{\phi_h}{\alpha}\left(h_t - h_{t-1}\right) - \beta\frac{\epsilon}{\epsilon - 1}\frac{\phi_h}{\alpha}\left(E_t h_{t+1} - h_t\right) \tag{21}$$

Combining the efficient price frontier with the aggregate production function yields the following expression for the cyclical component of labor productivity:

$$\widetilde{mph}_t = \alpha\left(\widetilde{w}_t^r - \widetilde{v}_t^r\right) + (2\alpha - 1)h_t + \frac{\epsilon}{\epsilon - 1}\phi_h\left(h_t - h_{t-1}\right) - \beta\frac{\epsilon}{\epsilon - 1}\phi_h\left(E_t h_{t+1} - h_t\right) \tag{22}$$

In the aftermath of a positive non-technology shock, both effort and hours compensation tend to increase and so do hours. The previous equation therefore highlights that the sign of the response of labor productivity, $\widetilde{mph}_t$, to a non-technology shock depends crucially on the relative movements of the two compensation margins, $\widetilde{w}_t^r$ and $\widetilde{v}_t^r$. Labor productivity can more likely show a positive response to an expansionary non-technology shock if hours wages rise by more than performance compensation. Thus, the fact that the larger cyclical movements of labor compensation have been associated with an increased incidence of performance-related pay may account for the vanishing positive correlation between labor productivity and hours, conditional on non-technology shocks.

The response of hours to technology shocks

Figure 3a shows that (the absolute value of) the response at impact of hours worked to technology improvements is monotonically strictly increasing in γ_e, irrespective of the value assigned to the parameter γ_h. Conversely, Figure

3b highlights that (the absolute value of) the response at impact of hours worked to technology improvements is monotonically strictly decreasing in γ_h, regardless of the value taken by the parameter γ_e.

The economic intuition is the following. The model predicts a negative response of firms' use of labor input. Indeed, the negative response of labor input to a technology expansion is theoretically consistent with a sticky price economy in which monetary policy is not fully accommodative (Galí, 1999, Basu et al. 2006, Dotsey, 2002 and Galí and Rabanal, 2004).[10] Following a technology shock, both the performance and hours compensation tend to rise. The efficient price frontier (21) implies that hours contraction will be larger the higher is the increase in hourly wages (i.e. the lower is γ_h; see Riggi, 2010 and Riggi and Tancioni, 2010) and the smaller is the increase in performance compensation (i.e. the higher is γ_e). Thus, for a given value of γ_h, an increase in the flexibility of labor compensation associated with an increase in the relevance of performance pay (i.e. a lower γ_e) drives down the (absolute value of the) negative correlation between hours and productivity conditional to a technology shock, because it induces firms to reduce labor input by adjusting on the performance side more than on the hours side.

Calibrating the parameters related to wage setting

A natural question emerges about the ability of the structural change on which are focusing in accounting, on its own, for the observed shifts in conditional correlations. To provide an answer we fix all the model's parameters and, separately for the pre- and post-1984 periods, we find the values of γ_e that minimize the distance between the theoretical, model-based impulse response functions (IRFs) and the empirical, SVAR-based average IRFs of labor productivity and hours to non-technology and technology shocks, respectively. We set $\gamma_h = 0.7$ in order to capture the high degree of rigidities in labor compensation documented for the pre-1984 period (see Blanchard and Riggi, 2009) and we maintain the other parameters fixed at the calibration discussed above. The values of γ_e that provide the best approximation of the empirical SVAR-based IRFs are $\gamma_e = 0.719$ in the pre-1984 sample and

[10] Following a technology improvement aggregate demand does not grow as much as it would under price flexibility and therefore the more productive firms are able to satisfy demand with fewer hours worked by employees.

$\gamma_e = 0.274$ in the post-1984 sample.[11] These values imply an increase of more than 16 percent in the share of performance pay in workers average earnings.[12]

Figures 4a and 4b report the theoretical IRFs under the calibrated values together with the empirical IRFs. It turns out that if the increased flexibility of compensation combined with a higher relevance of performance pay in the cyclical movements of wages had been the sole structural shift in the economy, then it would have gone a long way in accounting for the observed changes in the conditional co-movements between output, hours, and productivity. Indeed, the variation in γ_e allows to replicate pretty well the change from positive to negative in the sign of the response of labor productivity to non-technology shocks and the drop (in absolute value) of the negative response of hours to technology improvements.

We now seek to gauge whether the two values found with impulse response matching are reasonable for the U.S. economy. While the literature does not provide direct guidance about setting a value for γ_e and even less so for calibrating a value to the pre-1984 period and another one to the post-1984 period, we first rely on a recent paper by Lemieux et al. (2009b), based on PSID microeconomic data. Using the county unemployment rate as a proxy for local labor market shocks, they find that the cyclical sensitivity of labor compensation is much higher for workers under performance-pay contracts. In particular, they estimate that while a one percentage point increase in the county unemployment rate is generally conducive to a one per cent reduction of wages in performance-pay jobs, the effect on wages is not statistically different from zero in non-performance pay jobs. Assuming that this implies a value of γ_e equal to zero in performance-pay jobs and equal to one in non-performance pay jobs, we supplement this information with that on the incidence of performance-pay jobs in the pre- and post-1984 period. Following Champagne and Kurmann (2011), who convincingly elaborate on the evidence reported by Lemieux et al. (2009a), we set the share of performance-pay jobs to 0.3 in the pre-1984 period and to 0.6 in the post-1984 period. Combining all this empirical evidence, the resulting value

[11] The standard deviation of the estimated value of γ_e in the pre-1984 is 0.0212. The standard deviation of the estimated value of γ_e in the post-1984 is 0.0196.

[12] Indeed, given the calibration of the other parameters, the two values of γ_e imply an increase in $\frac{\widetilde{\overline{V^r}}}{\widetilde{\overline{W^r}}+\widetilde{\overline{V^r}}}$ from to 0.432 to 0.503. For details on this, see the Appendix on steady state calculations.

of γ_e for all jobs in the pre-1984 period would be 0.7; by contrast, in the post-1984 period it would be 0.4.

Interestingly, the value of γ_e for the pre-1984 period is very close to the one derived above based on impulse response matching (0.719). As for the post-1984 sample, the value of γ_e is somewhat higher than 0.274. However, this is consistent with the fact that the impulse response matching exercise has been performed assuming that the variation of γ_e had been the sole structural change in the economy.

3.2 Performance pay and Changes in the Structure of Unconditional Second Moments

Stiroh (2009) and GG (2009) argue that a substantial fraction of the decline in output volatility characterizing the Great Moderation period can be explained by the relevant decline in the correlation between labor productivity and hours. In order to analyze the implications of the changes in the structure of labor compensation for macroeconomic unconditional correlations and volatilities, we use artificial data generated from our model economy in which both technology and non-technology shocks are present. In particular, we consider the two values of γ_e obtained in the previous calibration exercise: 0.719 and 0.274. For each parameterization, we extract randomly 1,000 samples of 100 observations each from the artificial dataset, compute second moments and average them across the 1,000 samples.[13] To appraise the ability of the increased performance pay sensitivity to account on its own for the observed changes in correlations and volatilities, we keep the remaining parameters fixed at the calibrated values previously described in this section.

The first panel of table 1 shows the evidence by GG (2009) on the observed shift in correlations between output, productivity and hours. The second panel of table 1 reports the variations in the cyclical co-movements between output and hours, hours and productivity, and output and productivity computed on the artificial data generated within our model by assuming that the change in γ_e had been the sole structural change occurred in the economy. The comparison between the model-based changes in cross correlations and the corresponding observed changes reported in the first panel

[13] The sample length of 100 quarters is empirically reasonable since it broadly resembles the period associated with the Great Moderation (from 1984:1 onwards) and the pre-Great Moderation period (from 1948:1 to 1983:4).

reveals that the structural shift on which we are focusing can account for the modification in the pattern of co-movements between macroeconomic variables. The correlation between output and hours is stable across the two subsamples, as documented by GG. Conversely, the procyclical behaviour of labor productivity seems to vanish when we turn to the post-1984 sample. Indeed, when we take output as a cyclical indicator, in the second sub-sample labor productivity becomes an essentially acyclical variable. In particular, GG document that the unconditional correlation between labor productivity and business output drops to 0.03 from a value of 0.61. In our analysis we document that, when γ_e takes a lower value, such correlation drops to 0.03 (from a value of 0.95). By taking hours worked as a cyclical indicator labor productivity becomes a countercyclical variable. Indeed, GG report that the actual correlation shifts from 0.18 to -0.46 and our model predicts a shift from 0.90 to -0.38.

In table 2 we compare the evidence provided by GG and Galí and van Rens (2010) on the changes in the volatility of output and other variables with our results from artificial data when we vary the parameter γ_e. By itself, the increased performance sensitivity of pay accounts for a sizeable part of the drop in output volatility documented in the literature on the Great Moderation. GG report that the standard deviation of B-P filtered output declines by about 53 per cent in the post-1984 period and our model predicts a reduction of 22 percent when γ_e is set at the lower value.[14] GG also report a decline in the volatility of labor productivity and hours but they emphasize that it is less pronounced than that of output. Our model-based data, on the contrary, indicate that the standard deviation of labor productivity and hours has increased, rather than decreased (although to a small extent in the case of hours).[15]

[14] In our model economy, we calibrate the standard deviation of the two shocks (and keep them unchanged in all simulation exercises) so as to obtain - in the high γ_e case - a standard deviation of output that is exactly equal to the actual standard deviation of output in the pre-1984 sample.

[15] The increase in the unconditional volatility of hours is explained by the contribution of non-technology shocks. If the compensation of performance becomes less rigid (i.e. γ_e shrinks), while the compensation for hours is as rigid as before (i.e. γ_h stays unchanged), then following a demand shock it is profitable for firms to react by adjusting on the hours margin to a larger extent than before. This implies that the volatility of hours is expected to rise. By contrast, the increase in the unconditional volatility of labor productivity is mainly driven by the contribution of technology shocks. If the compensation for effort becomes less rigid, then in the aftermath of a technology shock the variation (in absolute

The increase in the volatility of labor compensation in real terms, driven by the higher performance sensitivity of pay and measured by a shift in the standard deviation from 1.82 to 2.63, is consistent with the empirical evidence for the U.S. economy reported by Galí and Van Rens (2010) and Champagne and Kurmann (2011). For example, when real compensation per hour is considered, using the compensation deflator from the BLS (Labor productivity and cost program, LPC), Galí and Van Rens (2010) report that the standard deviation shifts from 0.71 to 0.99 for the pre- and post-1984 periods. We believe that this finding ought to be emphasized as it stands in contrast with the overall, parallel decline of macroeconomic volatility.[16]

4 The role of hours adjustment costs

A common explanation for the procyclical behavior of labor productivity is labor hoarding, which is caused by a variety of costs involved in adjusting the labor force. Since the latter cannot be costlessly adjusted in the short run, firms react to changes in demand by varying the intensity of labor utilization. Thus, the labor force is smoothed over the cycle, and the cyclical variations in labor effort, which increases in booms and decreases in recessions, generate a perception of SRIRL (Sbordone, 1996). It follows that a straightforward interpretation of the decline in the correlation between labor productivity and hours, conditional on non-technology shocks, would be based on the decrease of labor adjustment costs over the recent decades, due to higher competition, a more flexible labor market and tougher corporate governance. By developing a theoretical model, Galí and van Rens (2010) point to the decline in labor market frictions as the major source of the vanishing procyclicality of labor productivity. Moreover, the reduction in adjustment costs in their model endogenously makes wages more responsive to shocks and this increases wage volatility.

value) of the performance pay relative to the variation of the hourly wage tends to be higher than before and this induces a smaller adjustment of hours worked and a larger variation of worker's performance. This implies an increase in the volatility of labor productivity.

[16] As a robustness inspection of the results documented in Tables 1 and 2, we have verified whether the values of the unconditional moments computed on the artificial data may depend on initial conditions. To tackle this issue we have eliminated the first 100 observations from the overall sample of 10000 observations and extracted randomly, as before, 1,000 samples of 100 observations each from this revised artificial dataset. The results remain virtually unchanged.

In our model economy, the reduction in labor market frictions that make employment adjustment costly is captured by a decrease in the value of the parameter ϕ_h. The role of ϕ_h in shaping the procyclicality of labor productivity is highlighted by equation (22) which establishes that higher labor adjustment costs renders the SRIRL outcome more likely. Accordingly, Figure 5a shows that a downward shift of ϕ_h, taking up different values ranging from two to zero, does yield a gradual disappearance of the procyclical response of labor productivity to non-technology shocks. Indeed, the response at impact of labor productivity to a non-technology shock is monotonically strictly increasing in ϕ_h, regardless of the parameterization used for γ_e.

However, the drop in labor hoarding driven by lower adjustment costs would lead to an even larger initial drop in hours following a technology innovation, in contrast with the evidence in GG (2009). Figure 5b shows that the response at impact of hours worked to technology improvements is, in general, monotonically strictly declining (in absolute value) in the adjustment cost parameter, ϕ_h. Intuitively, hours response to a technology shock would be lower the higher are the hours' adjustment costs.

Of course, the inability of the decrease in labor adjustment costs to account on its own for both changes in the dynamic responses to shocks does not rule out the potential relevance that decreasing labor market frictions may have had for the Great Moderation and for the vanishing procyclicality of labor productivity. For example, the drop in labor adjustment costs combined with a stronger anti-inflationary stance of the monetary policy could make a good job in explaning the Great Moderation and the parallel shifts in macroeconomic correlations.

5 Conclusions

Galí and Gambetti (2009) show that large changes in the patterns of conditional and unconditional correlations among output, hours and labor productivity have accompanied the substantial decline in macroeconomic volatility experienced by the U.S. economy since the mid-1980s.

In this paper we have proposed a novel explanation for these observed patterns based on the extensive evidence that the U.S. design of labor compensation has changed around the mid-1980s, towards an increased flexibility of workers' pay combined with a greater relevance of performance pay in the cyclical fluctuations of wages.

Using stochastic simulations, we have shown that this structural change, by itself, can account for the following empirical patterns: a) the disappearance of the procyclical response of labor productivity to non-technology shocks; b) the smaller contractionary effects on hours of a technology improvement; c) the decline in the unconditional correlation between labor productivity and both output and hours; d) the decline in output volatility and e) the parallel increase in the volatility of real wage.

We have also showed that if the higher wage flexibility had been accompanied by a lower share of the performance-related component in workers compensation, the implications for the patterns of co-movements would have gone in the opposite direction to those that emerge from empirical analysis.

The evidence by GG and Galí and van Rens (2010) is useful to shed light on the merits of different explanations for the Great Moderation. We do not claim that the shift in the design of labor compensation is the sole structural change behind the complex picture associated with the Great Moderation. However, our goal is to emphasize that the developments occurred in the design of labor compensation, leading to a higher relevance of performance-related pay in the cyclical fluctuations of wages, have played an important role in explaining the enhanced macroeconomic stability and the parallel shift in the structure of correlations.

On the other hand, the explanation of the shifts in macroeconomic comovements based on modifications to pay settings is particularly appealing as it can be reconciled with an empirical puzzle highlighted by Davis and Kahn (2008), namely that the substantial slump in the volatility of aggregate real activity has been coincident with an increase in *individual* income volatility and earnings uncertainty (see also Comin and Mulani, 2006). Arguably, these opposite trends in micro and macro volatility are potentially consistent with a higher incidence of the performance-related component of labor compensation, that rewards idiosyncratic effort and individual worker characteristics.

We therefore see two natural directions for future research. First, an extension of the model by allowing for heterogeneous consumers to investigate the coincidence between changes in the structure of macroeconomic correlations and the increased volatility of earnings at the individual level; and second, a structural estimation of the model.

Appendix

Steady state calculation

As it is standard in the literature, we normalize $\overline{H}$ to be equal to one (see, e.g., Smets and Wouters, 2007). In order to compute the performance pay share on workers labor compensation, we need to recover the steady state value of $\overline{E}$. To this aim, we combine the cost minimization condition with (9) and (10) in the main text:

$$\overline{E} = \frac{\overline{\widetilde{W}^r}}{\overline{\widetilde{V}^r}} = \frac{\left[\left(\overline{\widetilde{C}} - \frac{h}{\gamma_a}\overline{\widetilde{C}}\right)\left(\lambda_h + \frac{\lambda_e}{1+\sigma_e}\overline{E}^{1+\sigma_e}\right)\right]^{1-\gamma_h}}{\left[\left(\overline{\widetilde{C}} - \frac{h}{\gamma_a}\overline{\widetilde{C}}\right)\lambda_e\overline{E}^{\sigma_e}\right]^{1-\gamma_e}} \tag{1A}$$

Using $\overline{\widetilde{C}} = \overline{E}^{\alpha}$, (1A) can be rewritten as follows:

$$\frac{\left[\lambda_h + \frac{\lambda_e}{1+\sigma_e}\overline{E}^{1+\sigma_e}\right]^{1-\gamma_h}\overline{E}^{\alpha(1-\gamma_h)}}{\left(\lambda_e\overline{E}^{\sigma_e}\right)^{1-\gamma_e}\overline{E}^{\alpha(1-\gamma_e)}}\left(1 - \frac{h}{\gamma_a}\right)^{\gamma_e-\gamma_h} = \overline{E} \tag{2A}$$

Rearranging yields:

$$\frac{\left(\lambda_h + \frac{\lambda_e}{1+\sigma_e}\overline{E}^{1+\sigma_e}\right)^{1-\gamma_h}}{\lambda_e^{1-\gamma_e}}\left(1 - \frac{h}{\gamma_a}\right)^{\gamma_e-\gamma_h} = \overline{E}^{1-\alpha(\gamma_e-\gamma_h)+\sigma_e(1-\gamma_e)} \tag{3A}$$

By solving the polinomial equation, we recover the steady state value of $\overline{E}$, which depends on γ_e (among the other parameters) and we are able to study how the performance pay share in workers labor compensation varies with γ_e. Indeed, the relative share of performance pay is equal to

$$\frac{\overline{\widetilde{V}^r}}{\overline{\widetilde{W}^r} + \overline{\widetilde{V}^r}} = \frac{1}{\overline{E}+1} \tag{4A}$$

or, equivalently, looking at the share from the supply side:

$$\begin{aligned}\frac{\overline{\widetilde{V}^r}}{\overline{\widetilde{W}^r}+\overline{\widetilde{V}^r}} &= \frac{\left(\widetilde{C}-\frac{h}{\gamma}\widetilde{C}\right)^{1-\gamma_e}\lambda_e^{1-\gamma_e}E^{\sigma_e(1-\gamma_e)}}{\left(\widetilde{C}-\frac{h}{\gamma}\widetilde{C}\right)^{1-\gamma_e}\lambda_e^{1-\gamma_e}E^{\sigma_e(1-\gamma_e)}+\left(\widetilde{C}-\frac{h}{\gamma}\widetilde{C}\right)^{1-\gamma_h}\left(\lambda_h+\frac{\lambda_e}{1+\sigma_e}E^{1+\sigma_e}\right)^{1-\gamma_h}} = \\ &= \frac{1}{1+\frac{E^{\alpha(\gamma_e-\gamma_h)-\sigma_e(1-\gamma_e)}\left(1-\frac{h}{\gamma}\right)^{\gamma_e-\gamma_h}\left(\lambda_h+\frac{\lambda_e}{1+\sigma_e}E^{1+\sigma_e}\right)^{1-\gamma_h}}{\lambda_e^{1-\gamma_e}}}\end{aligned} \tag{5A}$$

The value of the share obtained by plugging the model-consistent value of $\overline{E}$ into(4A) coincides with the value obtained by plugging $\overline{E}$ into (5A). We are thus able to recover the change in the ratio of performance pay to workers labor compensation which is consistent with the variation in γ_e, suggested by the minimum distance exercise presented in section 3.1.

Figure 1a
The average responses of labor productivity to non-technology shocks

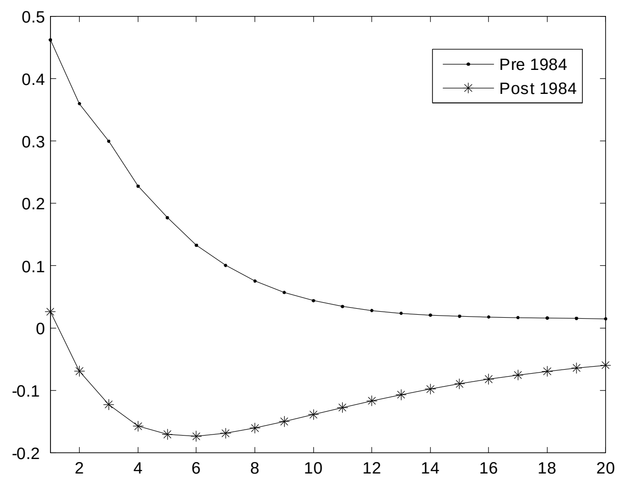
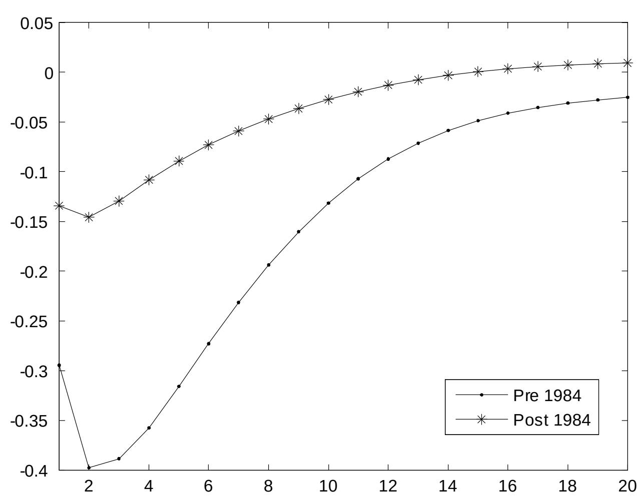


Figure 1b
The average responses of hours to technology shocks



Source: our replication of Galí and Gambetti (2009)'results (see figures 6.B and 7.B on pages 47-48 of their paper).

Figure 2. Nontechnology Shocks: Response at impact of labor productivity

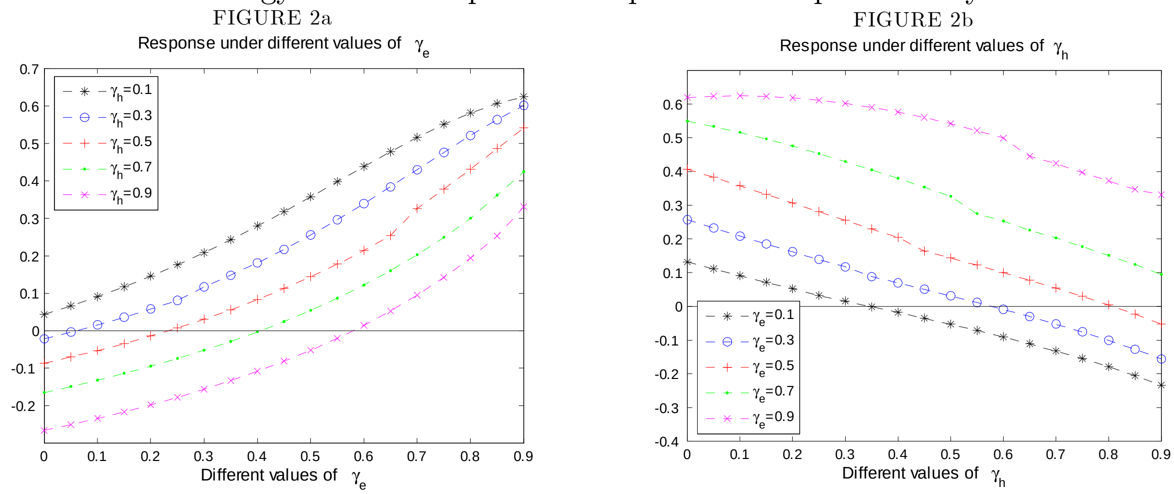


Figure 3. Technology Shocks: Response at impact of hours

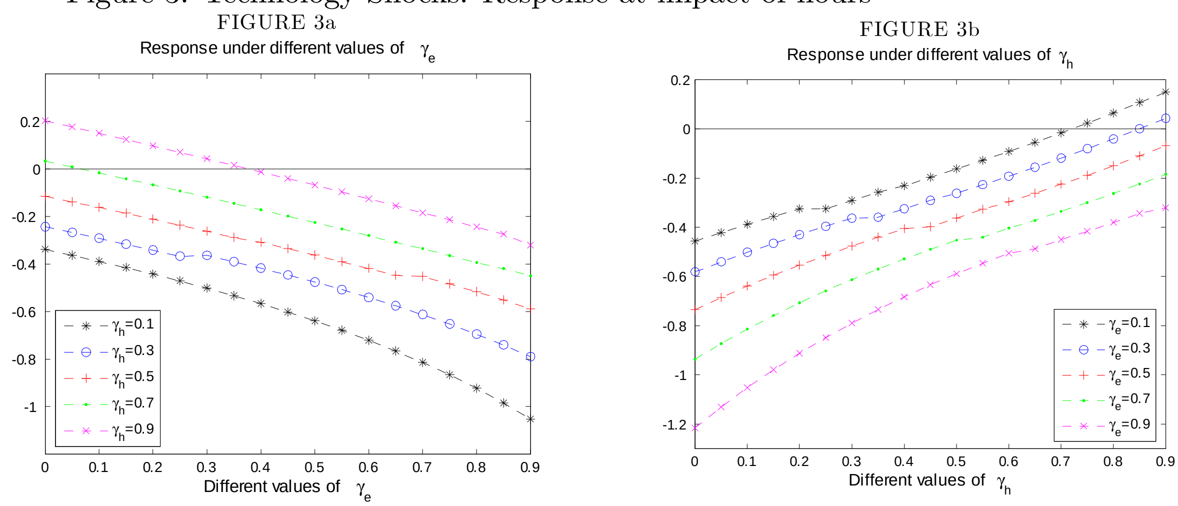


Figure 4a. Nontechnology Shocks: Labor Productivity response

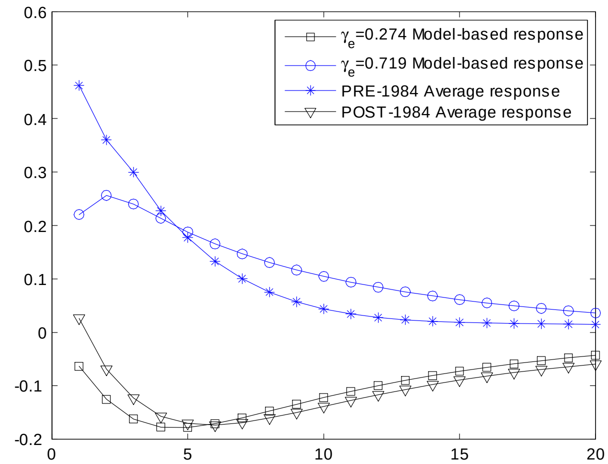


Figure 4b. Technology Shocks: Hours response

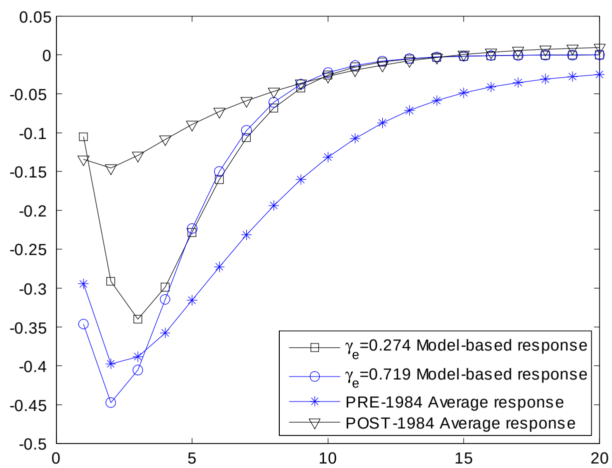


Table 1 Changes in Cross Correlations

	Evidence from GG (*)			Second moments of artificial, model-based data (cyclical components)		
	Pre-1984	Post-1984	Change	γ_e= 0.719	γ_e= 0.274	Change
Output, hours	0.89	0.86	−0.02	0.99	0.91	−0.08
Hours, productivity	0.18	−0.46	−0.65	0.90	−0.38	−1.28
Output, productivity	0.61	0.03	−0.58	0.95	0.03	−0.92

(*) see table 3 on p. 31 of GG (2009). Correlation coefficients are computed on B-P filtered logarithms of the variables.

Table 2 Changes in Volatility

	Evidence from GG (*) and Galí-Van Rens (**)			Second moments of artificial, model-based data (cyclical components)		
	Pre-1984	Post-1984	$\frac{\text{Post-1984}}{\text{Pre-1984}}$	γ_e= 0.719	γ_e= 0.274	$\frac{\text{Post-1984}}{\text{Pre-1984}}$
Output	2.59	1.23	0.47	2.59	2.02	0.78
Hours	2.08	1.39	0.67	1.94	2.19	1.12
Productivity	1.18	0.68	0.57	0.69	0.87	1.26
Real Wage	0.71	0.99	1.38	1.82	2.63	1.44

(*) see table 2 on p. 31 of GG (2009). Standard deviation of output, hours and productivity are computed on B-P filtered logarithms of the variables. (**) See table 3 of Galí-Van Rens (2010). Standard deviation of NIPA real compensation per hour is computed on B-P filtered logarithms of the variable.

Figure 5. The role of hours adjustment costs

FIGURE 5a. Non technology shocks
Response at impact of labor productivity

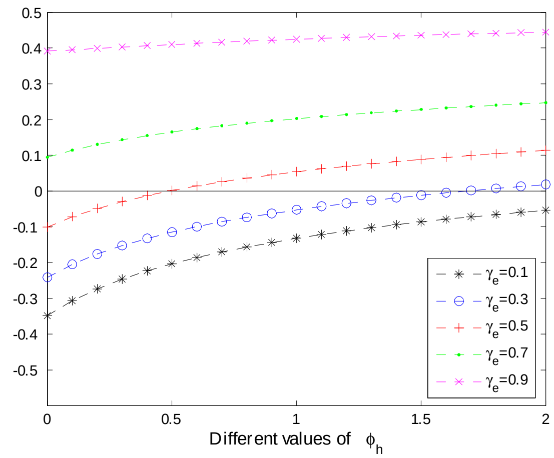
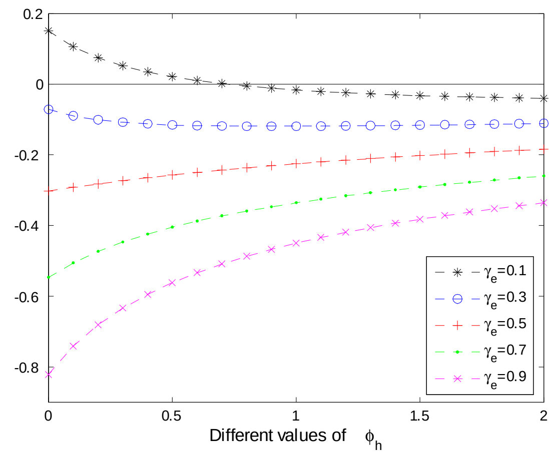


FIGURE 5b. Technology shocks
Response at impact of hours



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