Shifting Correlation Patterns and Changes in the Structure of Labor Compensation *

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Abstract

A shift in the correlation structure of U.S. macroeconomic series has been documented by Galí and Gambetti (2009) with corresponding changes in the dynamic responses to shocks. We provide an explanation of these findings based on the observed change in the structure of labor compensation and, in particular, on the higher incidence since 1980s of performance-related pay schemes, which has increased the performance sensitivity of compensation. We capture this feature in a DSGE model of the New Keynesian type and show that this interpretation alone can account for the observed changes in the pattern of responses to shocks. In particular, with a higher sensitivity of compensation to workers performance, the response of labor productivity to a non-technology shock switches sign from positive to negative values and the contractionary effect on hours of a technology shock becomes of a smaller size in absolute terms. Alternative explanations of the Great Moderation based on structural changes fall short of accounting for both these documented changes in the dynamic responses to shocks. (JEL E32; J33)

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1 Introduction

Substantial changes in the correlation structure of U.S. macroeconomic series have accompanied the downward shift in the volatility of output and inflation occurred in mid-1980s and recognized as the “Great Moderation” (Kim and Nelson 1999, McConnell and Perez-Quiros 2000, Blanchard and Simon, 2001). By estimating a structural vector autoregression (SVAR) with time-varying coefficients, Galí and Gambetti (2009; GG hereafter) provide evidence about a significant shift in the pattern of both unconditional and conditional comovements among output, hours and labor productivity.

Two empirical results summarize the bulk of their evidence. First, while in the pre-Great Moderation period labor productivity responds positively and significantly to a non-technology innovation, thus displaying a pro-cyclical profile, in the more recent sub-period the response of labor productivity exhibits even a sign reversal becoming negative. The vanishing procyclical response of labor productivity to non-technology shocks is the root of the sharp fall in the contribution of non-technology innovations to the variance of output, which has been the major source of the Great Moderation, and of the dramatic decline in the unconditional correlation between cyclical employment and cyclical components of labor productivity (Barnichon, 2007 and Stiroh 2009).

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 becomes of a smaller size (in absolute value) and almost reaches zero. The smaller negative response of hours to technology innovations implies larger effect on output and thus a rise in the contribution of technology shocks to output volatility.

These findings call into question the explanations of the Great Moderation that rely exclusively on a reduction of the variance of shocks and point to a relevant role of structural changes in accounting for these developments. The structural shifts emphasized in the literature include improved monetary policy (Clarida, Galí and Gertler, 2000), better inventory management (McConnell and Perez-Quiros, 2000) and financial innovation reducing the importance of financial frictions (see e.g. Jermann and Quadrini, 2008).

Our contribution is to provide a novel explanation that accounts for the observed changes in macroeconomic dynamics documented by GG. We shed light on the business cycle implications of a relevant change in the structure of labor compensation experienced in the US economy since the early 1980s.
The literature has already emphasized an overall reduction in the degree of real wage rigidities at around mid-eighties (see e.g. Blanchard and Gali, 2008 and Blanchard and Riggi 2009). We argue that a substantial structural change over the same period must have involved the performance compensation margin. There is an extensive evidence that the firms’ reliance on pay-for-performance mechanisms has increased considerably since the beginning of the 1980s (Lemieux, MacLeod and Parent, 2009) and that this has been associated with an increase in the estimated performance-pay sensitivity (see e.g. Cuñat and Guadalupe, 2005; 2008 and Mitchell, Lewin, and Lawler III, 1990). We show that this shift in the design of labor compensation represents a relevant phenomenon that, once taken into account in a macroeconomic model, can account for the shifts in the conditional correlations among macro variables.

To this aim, we develop a DSGE theoretical framework of the New Keynesian type where work effort is included in the analysis as an additional dimension of firms’ and households’ choice and where the degree of responsiveness of effort compensation to worker performance is explicitly considered. In particular, along the lines of Blanchard and Gali (2007 and 2008), we assume that effort compensation falls short of moving one-to-one with the associated marginal rate of substitution. On the contrary, it moves by less and the extent to which this happens characterizes the (un)responsiveness of real pay to workers performance.

By using stochastic simulations, we analyze the implications of an increase in the responsiveness of effort compensation to worker performance for hours and labor productivity responses to identified sources of shocks. We show that this shift in the structure of labor compensation implies a model-based dynamic response of labor productivity to demand shocks that switches sign from positive to negative values and a (negative) hours response to technology shocks that shrinks considerably in absolute terms. These are precisely the empirical findings uncovered by GG in their contribution.

We argue that a more flexible hourly wage is not able to account for the observed changes in the dynamic responses to shocks. Indeed, we show that a structural decline in the rigidities of hours compensation would have implications for the pattern of impulse responses that go in the opposite direction to those found in data.

We also investigate the ability of some alternative sources of structural change to match the observed changes in the comovements among macro variables. In particular, we analyze the interpretation based on a lower extent
of labor hoarding as a result of a generalized fall in the adjustment costs of labor\textsuperscript{1}. We show that this explanation, whilst able to explain the lower procyclicality of labor productivity, is unsatisfactory in light of the observed changes in the hours response to technology shocks. We also show that this holds true for the interpretation based on better monetary policy, as it falls short of accounting for the disappearance of the procyclical productivity puzzle.

Our explanation for the changed patterns of comovements based on modifications in pay setting strikes us as particularly appealing. On the one hand, it is consistent with the increase in the volatility of wages at the macro level, a fact recently uncovered for the US economy by Galí and van Rens (2008). On the other hand, it provides a potential explanation of an empirical puzzle recently highlighted by Davis and Kahn (2008), namely the notable increase in individual income volatility and earnings uncertainty which has been coincident with the decline in macro volatility. These opposite trends in micro and macro volatility are hard to reconcile with the proposed interpretations of the Great Moderation (see also Comin and Mulani, 2006). A higher incidence of performance-related pay schemes that set pay to reward individual worker characteristics and idiosyncratic effort is consistent with a rise in income volatility and earnings uncertainty at the micro level\textsuperscript{2}.

The paper is organized as follows. Section 2 provides evidence on the large changes in the structure of correlations among output, hours and productivity associated with the Great Moderation, which corroborates the GG’s findings. Section 3 proposes the novel interpretation based on the increase in the sensitivity of labor compensation to workers’ performance. Section 4 presents the theoretical model and sheds light on the implications of a higher responsiveness of the compensation scheme to workers’ performance for the comovements among output, hours and labor productivity conditional to identified sources of shocks. Section 5 analyzes the macroeconomic consequences of other plausible structural changes. In section 6 we use artificial data generated from our model in order to investigate the implications of the different structural changes analyzed in the previous sections for the

\textsuperscript{1}See Barnichon (2007), Galí and van Rens (2008) and the GG’s contribution itself.

\textsuperscript{2}Davis and Kahn (2008) conjecture that, in explaining the Great Moderation, greater pay flexibility has played an important role as it is consistent with increased individual income uncertainty and wage inequality. Lemieux et al. (2007) document that the growing reliance on performance-pay accounts for a large fraction of the growth in wage dispersion between the late 1970s and the early 1990s.
unconditional correlations among macro-variables. Section 7 concludes.

2 Changes in macro dynamics

GG (2008) analyze the correlation structure of U.S. output, labor productivity and hours over the Post-WWII and document a dramatic shift in the pattern of conditional and unconditional second moments of these macroeconomic series at the outset of the Great Moderation. Most of their empirical findings are obtained by estimating a SVAR with time-varying coefficients and stochastic volatility. The model is bivariate and include (log) labor productivity and (log) hours per capita. Technology shocks are identified using long-run restrictions as in Galí (1999): the unit root in labor productivity originates uniquely in technology innovations so that the latter only have permanent effect on productivity.

Whilst the standard deviations of output, labor productivity and hours have declined sharply in absolute terms since the mid-1980s, the volatility of labor productivity and hours has, however, increased relative to output volatility. The observed pattern of comovements among these variables exhibits sizeable changes: the unconditional correlation of labor productivity with hours significantly drops, shifting from values close to zero in the early postwar period to large negative values in more recent decades (see also Barnichon 2007 and Stiroh 2009) and the unconditional correlation of labor productivity with output approaches zero from positive values. GG (2008) appraise the role played by shocks of different type in accounting for these developments and, very importantly, they provide evidence that the pattern of conditional correlations has changed at the time of the volatility break associated with the Great Moderation. Figures 1a and 1b summarize the bulk of their evidence.

The first panel deals with the response of labor productivity to a non-technology shock over the pre-1984 and post-1984 period. Whilst in the pre-Great Moderation period, labor productivity increases in the aftermath of a non-technology innovation, thus exhibiting a pro-cyclical pattern, in the second sub-period, on the contrary, there is a reversal in the sign from positive to negative and labor productivity becomes countercyclical. The vanishing procyclicality of labor productivity conditional on non-technology innovations has implied a sharp fall in the contribution of non-technology shocks to the variance of output, which is the root of the Great Moderation.
Figure 1b documents the responses of hours to a technology shock in the two sub-periods. In the pre-1984 period, the contractionary effect on hours of a technological improvement is sizeable and significant but, in the post-1984 period, such effect, albeit still negative, is of a smaller size (in absolute value). Consistently with this, the contribution of technology shocks to output volatility appears to have increased somewhat over time.

We corroborate the GG’s findings reported in Figure 1 by estimating a bivariate SVAR without time-variation in the coefficients. We estimate it separately on two different sub-period: the first one is 1948:I - 1983:IV and the second is 1984:I - 2008:III. As in GG, the model is applied to \( \Delta(y_t - n_t) \) and \( n_t \), where \( y_t \) and \( n_t \) denote, respectively, the logarithm of output and hours, both in per-capita terms\(^3\). The shock identification procedure is also identical. The impulse response analysis provides a picture that is consistent to that of GG. As Figure 2 shows, whilst labor productivity responds positively and significantly to a non-technology shock in the pre-Great Moderation sample, such effect switches sign and becomes negative in the subsequent period. Moreover, whilst the short-run hours response to a technological improvement is negative and statistically significant in the pre-1984 period, the dynamic effect becomes positive, although not statistically different from zero, in the post 1984.\(^4\)

As highlighted by GG, the above findings call into question the "good luck" explanation\(^5\) of the Great Moderation and point to an important role for structural changes behind the scene of the downward shift in the macroeconomic volatility experienced in the mid 1980s. In the following section we discuss a significant change in the US structure of labor compensation occurred over the last thirty years, that may represent a novel interpretation of the evidence presented in this section.

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\(^3\)We use U.S. quarterly data on real output of the nonfarm business sector and hours of all persons in nonfarm business. Both variables are normalized using the series on civilian noninstitutional population of 16 years and over.

\(^4\)The confidence bands are obtained using a bootstrap Monte Carlo procedure with 1000 replications.

\(^5\)The existing explanations of the Great Moderation fall under two broad categories: the good luck hypothesis, suggesting that an exogenous reduction in the variance of shocks is the driving factor (Stock and Watson 2002; Sims and Zha 2006; Justiniano and Primiceri 2008) and the structural change hypothesis, arguing that improved monetary policy (Clarida, Gali and Gertler 2000; Boivin and Giannoni, 2006 and Benati and Surico 2008) or structural changes (McConnell and Perez-Quiros 2000 and Jermann and Quadrini, 2008) lie behind the observed developments.
3 Changes in the Structure of Labor Compensation

An extensive body of theoretical and empirical literature in the area of personnel economics has addressed the issue of how firms provide incentives to workers through different compensation schemes and how the latter impinge on effort and performance (see Prendergast, 1999 and the references therein and Lazear, 2000). Indeed, in order to motivate workers to exert effort, firms can choose among a variety of payment schemes, such as piece rates, bonuses, options and profit sharing. Labor contracts can be explicitly designed to reward the performance and the compensation can be either based on an observed measure of individual performance, as in sales jobs where commission contracts are common, or on measures of firm’s performance, as in the case of gain and profit sharing. A more recurrent arrangement is the one in which the provision of incentives to workers depends on a discretionary performance assessment by supervisors, based on subjective criteria.

Very importantly, there is a widespread evidence that the firms’ reliance on pay-for-performance mechanisms has increased considerably since the beginning of the 1980s. Lemieux, MacLeod and Parent (2009), for example, using data from the Panel Study of Income Dynamics (PSID) document that the incidence of performance-related pay has grown substantially in the U.S. economy since then. Hall and Liebman (1998) show that the responsiveness of pay to performance for chief executive officers (CEOs) has increased since the early 1980s. In a detailed account of the use of different compensation schemes, Mitchell, Lewin, and Lawler III (1990) point out that a significant shift towards adopting incentive pay plans is documented in the 1980s, after a period, from the end of World War II to 1979, that was characterized by the decline in the use of them.\footnote{Similarly, Jensen and Murphy (1990) estimate a low pay-performance sensitivity for top executives in the 1970s up to mid eighties.}

A number of convincing explanations exist for the finding that in the US and the UK the structure of wages and compensation has changed dramatically over the 1980s and 1990s in light of the higher incidence of performance-related pay systems. One of them deals with the extensive development of performance appraisal systems, due to progress in the technologies of information and monitoring, that allow to enhance the quality of worker performance measures. Lemieux et al. (2009) emphasize these advances and point
to the extraordinary expansion over the last thirty years of consulting companies specializing in compensation. Another driving force behind the higher reliance of performance-related pay is the trend towards increasing product market competition, as a result of globalization and changes in entry barriers. As shown by Cuñat and Guadalupe (2005; 2008), increasing competitive pressure faced by firms have induced them to re-shape the structure of incentives provided to their employees, making performance-related pay schemes more pervasive.

Summing up, the available evidence points to a higher firms’ reliance on performance related compensation schemes as well as to a higher performance-pay sensitivity. Indeed, the responsiveness of pay to effort exerted and to other worker characteristics is found to be larger in performance-pay jobs, with the latter accounting for an increasing proportion of total jobs. Moreover, the performance pay sensitivity has increased over time even within performance-pay jobs, given the improvements in the technology of compensation that include better performance appraisal methods and compensation schemes (see e.g. Lemieux et al., 2009 and Cuñat and Guadalupe, 2005). Besides, whilst the use of performance-related payment schemes has become predominant for individuals in managerial and executive jobs, from lower-level managers to CEOs, the shift towards performance-related pay has characterized, however, all workers in general.

We argue that this shift in the design of wages and compensation that has taken place around the mid-eighties represents an important structural change whose implications at the macroeconomic level might be relevant and should therefore be investigated. Assessing some macro implications of this structural shift in the labor market is the issue that we seek to analyze in this paper. To do so we develop a DSGE theoretical model of the New Keynesian type and embed in it the degree of performance-pay sensitivity. As we will see, the latter is captured by a parameter in the equilibrium condition for effort compensation and what we analyze is whether a modification of this parameter towards a higher responsiveness of compensation to workers effort is able to account for the changing structure of correlations among macro

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As argued convincingly by Prendergast (1999), the large emphasis in the empirical literature on pay-for-performance incentives for top managers hinges on a substantial availability of observable measures of their performance (see Murphy, 1999 for a survey on the evidence). By contrast, most workers are paid based on their performance but the latter is appraised by firms through subjective criteria and this makes empirical investigation less straightforward.
4 Theoretical Framework

In this section we lay out a standard New Keynesian model with variable labor effort. The baseline framework is standard, with two exceptions. First, we allow for “labor hoarding” by introducing convex costs of adjusting hours. Second, we introduce rigidities in the compensation structure. In particular, we assume that, not only the hours compensation, but also effort compensation falls short of moving one-to-one with the associated marginal rate of substitution. The extent to which this happens characterizes the (un)responsiveness of real pay to workers performance.

4.1 Households

The representative infinitely-lived household seeks to maximize

\[
E \sum_{t=0}^{\infty} \beta^t \left[ \frac{C_t^{1-\sigma_c}}{1-\sigma_c} - g(H_t, E_t) \right]
\]

where \( C_t \equiv \left( \int_{0}^{1} C_t(i) \frac{1}{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} \) is a CES index of differentiated goods \( i \) with elasticity of substitution \( \epsilon \), \( \beta \) is the discount factor and \( \sigma_c \) is the inverse of the intertemporal elasticity of substitution. Optimal allocation of consumption expenditures among different goods, obtained by maximizing the consumption index \( C_t \) for any given level of expenditures \( \int_{0}^{1} P_t(i)C_t(i)di \), yields the following demand function for each good:

\[
C_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\epsilon} C_t
\]

where \( P_t \equiv \left[ \int_{0}^{1} P_t(i)^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}} \) is the price index.

Following Bils and Cho (1994), we assume that the disutility from work depends on hours (\( H \)) and effort (\( E \)) accordingly to the following functional form, which implies that the marginal disutility of effort per hour is increasing with the number of hours:

\[
g(H_t, E_t) = \frac{\lambda_h}{1+\sigma_h} H_t^{1+\sigma_h} + H_t \frac{\lambda_e}{1+\sigma_e} E_t^{1+\sigma_e}
\]
where \( \lambda_h, \lambda_e, \sigma_h, \) and \( \sigma_e \) are positive constants and \( \sigma_e \) is the effort elasticity of the marginal disutility of effort.

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

\[
P_tC_t + Q^B_t B_t = W_t H_t + V_t E_t + B_{t-1} + \Pi_t
\]

(4)

where \( Q^B_t \) is the price of a one-period nominally riskless bond, paying one unit of money and \( B_t \) is the quantity of that bond purchased in period \( t \). As in Galí (1999), \( W_t \) and \( V_t \) represent the nominal prices of an hour of work (nominal hourly wage hereafter) and of a unit of effort, respectively.

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

\[
Q^B_t = \beta E_t \left\{ \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \right\}
\]

(5)

\[
\frac{W_t}{P_t} = C_t^{\sigma_e} \left[ \lambda_h H_t^{\sigma_h} + \frac{\lambda_e}{1 + \sigma_e} E_t^{1+\sigma_e} \right]
\]

(6)

\[
\frac{V_t}{P_t} = C_t^{\sigma_e} \lambda_e H_t E_t^{\sigma_e}
\]

(7)

Equations (6) and (7) represent the competitive labor and effort supply, respectively. We relax, however, the assumption of perfectly competitive labor market by introducing, along the lines suggested by Blanchard and Galí (2007 and 2008), a certain degree of rigidities in the compensation structure, which prevents \( \frac{W_t}{P_t} \) and \( \frac{V_t}{P_t} \) to fully adjust to their competitive counterparts. Letting \( \gamma_h \in [0, 1] \) and \( \gamma_e \in [0, 1] \) denote the degree of rigidities in the hourly real wage and in the real price of effort, respectively, we replace equations (6) and (7) with the following wage and performance compensation curves:

\[
\frac{W_t}{P_t} = \left\{ C_t^{\sigma_e} \left[ \lambda_h H_t^{\sigma_h} + \frac{\lambda_e}{1 + \sigma_e} E_t^{1+\sigma_e} \right] \right\}^{1-\gamma_h}
\]

(8)

\[
\frac{V_t}{P_t} = \{ C_t^{\sigma_e} \lambda_e H_t E_t^{\sigma_e} \}^{1-\gamma_e}
\]

(9)

where the coefficient \( 1 - \gamma_e \) can be interpreted as a measure of the sensitivity of pay to workers performance. The lower is \( \gamma_e \) the higher is the
responsiveness of the compensation to the marginal rate of substitution between consumption and effort. In the limiting case of $\gamma_e = 1$, an improvement in the performance, which is captured here by an increase in individual effort exerted, does not lead to any change in the compensation of performance $\frac{V_t}{P_t}$. Thus, a low value of $\gamma_e$ can be thought of as being associated with an extensive firm’s reliance on performance-related pay schemes.

4.2 Firms

We distinguish between two types of firms: retailers and wholesale firms. Households are employed by wholesale firms which face a convex cost of varying their hours input and operate in a competitive market for 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).

4.2.1 Wholesale firms

Production by wholesale firm $j$ is

$$Y_{jt}^w = Z_t L_{jt}^\alpha$$  \hspace{1cm} (10)

where $Z_t$ is an aggregate technology index, which varies exogenously over time. $L_{jt}$ denotes the effective labor input and $\alpha \in (0,1]$ is the elasticity of output with respect to effective labor input. We define effective labor input as a function of hours and hourly effort\(^8\):

$$L_{jt} = H_{jt}^{\varphi} E_{jt}^{1-\varphi}$$  \hspace{1cm} (11)

where $\varphi \in (0,1)$. Each intermediate input producing firm varies its hours input by facing convex costs, which are increasing with the speed of the desired adjustment and are measured in term of the final good:

$$G_{jt} = \frac{\phi_h}{2} \left[ \frac{H_{jt}}{H_{jt-1}} - 1 \right]^2 Y_t$$  \hspace{1cm} (12)

where $\phi_h \geq 0$ is the hour-adjustment cost parameter. The adjustment cost function implies that firms have an incentive to perform hours changes gradually and they therefore intertemporally smooth their labor demand.

\(^8\)As it is standard in the literature, we assume that effort is perfectly observable.
Let $\Pi_{jt}$ denote firm $j$’s period $t$ profit. The problem of the intermediate input producing firm is to maximize

$$E_t \sum_{k=0}^{\infty} Q_{t+k} \Pi_{jt+k}$$

subject to (10), where $Q_{t+k} \equiv \beta^k \left( C_{jt+k}^{\infty} \frac{p_t}{C_{jt+k}^{\infty} F_{jt+k}} \right)$ is the stochastic discount factor for nominal payoff, $\Pi_{jt} = \mu_t Y_{wjt} - W_t P_t H_{jt} - V_t P_t E_{jt} - \phi_h \left[ \frac{H_{jt}}{H_{jt-1}} - 1 \right]^2 Y_t$ and $\mu_t = \frac{p_t}{F_t}$ is the markup of retail over intermediate input prices. The first order conditions for the firm’s problem are:

$$\mu_t^{-1} - \psi_{jt} = 0$$

$$-\frac{V_t}{P_t} + \psi_{jt} \alpha (1 - \varphi) Z_t H_{jt}^{\alpha \varphi} E_{jt}^{\alpha (1 - \varphi) - 1} = 0$$

$$-\frac{W_t}{P_t} - \phi_h \left[ \frac{H_{jt}}{H_{jt-1}} - 1 \right] Y_t + \psi_{jt} \alpha \varphi Z_t H_{jt}^{\alpha \varphi - 1} E_{jt}^{\alpha (1 - \varphi)} +$$

$$+ E Q_{t+1} \phi_h \left[ \frac{H_{jt}}{H_{jt-1}} - 1 \right] Y_{t+1} H_{jt+1}^{\alpha \varphi - 1} E_{jt+1} = 0$$

where $\psi_{jt}$ define the Lagrangian multiplier on (10).

The first of these conditions implies $\psi_{jt} = \mu_t^{-1}$ for all $j$. Using this result in the last first order condition and defining the marginal productivity of hours, $MPH_{jt} \equiv \alpha \varphi Z_t H_{jt}^{\alpha \varphi - 1} E_{jt}^{\alpha (1 - \varphi)}$, we obtain the relative price of intermediate goods, which coincides with the real marginal cost faced by retailers

$$\frac{1}{\mu_t} = \frac{W_t}{P_t MPH_{jt}} + \phi_h \left[ \frac{H_{jt}}{H_{jt-1}} - 1 \right] \frac{Y_t}{MPH_{jt}} +$$

$$- E Q_{t+1} \phi_h \left[ \frac{H_{jt+1}}{H_{jt}} - 1 \right] \frac{Y_{t+1} H_{jt+1}}{MPH_{jt}^2}$$

In symmetric equilibrium $H_{jt} = H_t$ and $E_{jt} = E_t$ for all $j$, since all wholesale firms are identical and adopt the same decisions.

### 4.2.2 Retailers

We assume a continuum of monopolistically competitive retailers, indexed by $i$ on the unit interval. Retailers purchase the intermediate output and convert it into a differentiated final good, according to the following technology:
\[ Y_t(i) = Y_t^w(i) \]  

Following Calvo (1983), retailers can reset their price at random dates: each period only a randomly chosen fraction \((1 - \theta)\) of retailers reset their prices. The remaining retailers, with measure \(\theta\), keep their prices unchanged. Let \(P_t^*\) denote the price newly set by a retailer at time \(t\); the aggregate price index satisfies

\[ P_t = \left[ \theta (P_{t-1})^{1-\epsilon} + (1 - \theta) (P_t^*)^{1-\epsilon} \right]^{\frac{1}{\epsilon}} \]  

(16)

When a retailer has the chance of changing its price, it maximizes:

\[
\max_{P_{t,t}^*} E_t \sum_{k=0}^{\infty} \theta^k Q_{t,t+k} \left( \frac{P_{t,t}^*}{P_{t+k}} - \mu_{t+k} \right) Y_{t+t+k/t} 
\]  

(17)

where \(Y_{i,t+k/t}\) denotes output in period \(t+k\) for a firm resetting its price in period \(t\), subject to the sequence of demand constraint \(Y_{i,t+k/t} = \left( \frac{P_{t+k}}{P_{t+k}} \right)^{-\epsilon} C_{t+k}\). The optimal pricing decision is thus given by:

\[
E_t \sum_{k=0}^{\infty} \theta^k Q_{t,t+k} Y_{t+k/t} \left( \frac{P_{t+k}}{P_{t-1}} - \left( \frac{\epsilon}{\epsilon - 1} m_{t+k/t} \frac{P_{t+k}}{P_{t-1}} \right) \right) = 0 
\]  

(18)

where \(m_{t+k/t}\) denotes the real marginal cost in \(t+k\) for a firm that last reset its price in \(t\).

Combining the optimal pricing decision with the aggregate price dynamics yields the standard New Keynesian Phillips curve:

\[
\pi_t = \beta E_t \pi_{t+1} + \frac{(1 - \theta) (1 - \beta \theta)}{\theta} \frac{\alpha}{\alpha + (1 - \alpha) \epsilon} m_{t} \]  

(19)

where \(\pi_t\) is the inflation rate. Assuming that hours adjustment costs are distributed to the aggregate households, market clearing requires

\[
Z_t C_t^\alpha = C_t \int_0^1 \left[ \frac{P_t(i)}{P_t} \right]^{-\epsilon} di 
\]  

(20)

We assume an interest rate rule of the form

\^9\text{Market clearing for good } i \text{ requires } Z_t L_t^\alpha = C_t(i). \text{ Integrating over } i \text{ yields } Z_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
\[ i_t = -\log \beta + \phi_{dp} \pi_t \]

(21)

where \( \phi_{dp} > 1 \).

The economy is hit by both technology and demand innovations. In particular, the total factor productivity and the demand shocks are assumed to follow independent first-order autoregressive processes, with autoregressive coefficients \( \rho_z \) and \( \rho_g \) respectively. The exogenous demand shock is introduced as an additive term in the log-linearized Euler equation and is assumed not to affect the natural level of output, as in the case of a shock to the discount rate.

4.3 Performance-related Pay and the Flexibility of Labor Compensation

4.3.1 The Procyclicality of Productivity and the Performance Sensitivity of Effort Compensation

In this section we investigate whether an increase in the degree of performance sensitivity of labor compensation may account for the reversal in the sign of the correlation of labor productivity with labor input conditional on non-technology shocks.

Preliminary to this, we first discuss the baseline calibration of all parameters of the model. As widely accepted by the literature on the subject matter, we calibrate the discount factor \( \beta = 0.99 \), the sticky price parameter \( \theta = 0.8 \) and the elasticity of substitution among differentiated goods \( \epsilon = 6 \), which is consistent with a gross steady state markup of 20 per cent. The Taylor coefficient \( \phi_{dp} \) is set equal to 1.5, in the range \((1, 5)\) of values that cover the empirically plausible set, conditional on having an unique equilibrium. We calibrate the elasticity of output with respect to effective labor input, \( \alpha = 1 \), and we ensure that hours are more productive than effort by setting \( \phi = 0.8 \).

The risk aversion coefficient \( \sigma_c \) is calibrated equal to 2, which implies a plausible degree of the intertemporal elasticity of substitution (0.5). We assume hours elasticity equal to 1 (\( \sigma_h = 1 \)) and we calibrate \( \sigma_c = 1 \), following Schor’s (1987) estimate for the elasticity of effort with respect to hours \( \frac{\sigma_c}{1+\sigma_e} = 0.5 \).

The adjustment cost parameter \( \phi_h \) is set equal to 0.2 and the degree of real wage rigidities \( \gamma_h = 0.8 \). According to the empirical evidence, we assume that the technology shock is characterized by an higher degree of persistence \( (\rho_a = 0.9) \) than the demand shock \( (\rho_g = 0.5) \).
Concerning the parameter $\gamma_e$, the literature does not provide much support in setting a value for it. Our chief focus, however, is on its variations and on the associated changes in the pattern of comovements among macro variables. Figure 3 displays the IRF of labor productivity to a demand shock under two different values in the calibration of $\gamma_e$: 0.9 and 0.5. The Figure shows that the more sensitive is effort compensation to productive performance, the lower is the degree of procyclicality of labor productivity. Moreover, consistently with the empirical findings documented in section 2, our model predicts a switch in the sign of the response, with labor productivity turning countercyclical.

In order to investigate the economic intuition behind this result we look at the equilibrium relationship between productivity and hours. To keep algebra simple, in what follows we abstract, without loss of generality, from labor adjustment costs by setting $\phi_h = 0$.

Cost minimization implies the following optimal condition:

$$\frac{W_t}{V_t} = \varphi \frac{E_t}{1 - \varphi H_t}$$

Combining (22) with (8) to (11) after log-linearizing these equations around a zero-inflation steady state (see Appendix A) yields:

$$\hat{e}_t = \frac{\sigma_c(\gamma_e - \gamma_h)\alpha(1-\varphi)(1-\gamma_h)\Gamma_\lambda^E \sigma_e + (1-\gamma_e)\sigma_e}{1-\sigma_c(\gamma_e - \gamma_h)\alpha(1-\varphi)(1-\gamma_h)\Gamma_\lambda^E \sigma_e + (1-\gamma_e)\sigma_e} \hat{z}_t$$

where $\Gamma = \frac{1}{\lambda_h \lambda_h + \frac{1}{\lambda_h \lambda_h} \sigma_e}$ and lower-case variables with the “$\hat{}$” symbol denote their log deviation from the steady-state value. By plugging equation (23) in the production function, we get the reduced form equilibrium relationship between labor productivity and hours:

$$\hat{y}_t - \hat{h}_t = (r_h - 1)\hat{h}_t + r_z \hat{z}_t$$

where $r_h \equiv \frac{(1-\varphi)\alpha(\sigma_c(\gamma_e - \gamma_h)\alpha(1-\varphi)(1-\gamma_h)\Gamma_\lambda^E \sigma_e + (1-\gamma_e)\sigma_e)}{1-\sigma_c(\gamma_e - \gamma_h)\alpha(1-\varphi)(1-\gamma_h)\Gamma_\lambda^E \sigma_e + (1-\gamma_e)\sigma_e} + \alpha \varphi$. 

15
If \( r_h \) is greater than one, then we have the so called short run increasing returns to labor (SRIRL hereafter) outcome and labor productivity is procyclical. In order to analyze how the degree of rigidity in effort compensation affects the procyclicality of labor productivity, we study the sign of \( \frac{\partial r_h}{\partial \gamma_e} \).

It can be shown (see appendix B) that \( \frac{\partial r_h}{\partial \gamma_e} \) is non negative under the sufficient condition that \( 1 + \sigma_e \geq \frac{1 - \phi}{\phi} \), which is actually met for any economic reasonable parameterization of the above entities. Therefore, the higher is the performance sensitivity of effort compensation (i.e., a lower \( \gamma_e \)), the less likely is the SRIRL result.

The economic intuition is the following. The apparent feature of SRIRL comes 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. Such profitability increases with the rigidity of effort compensation: following an increase in demand, the smaller is the increase in effort compensation, the more profitable would be to react to current and expected changes in economy conditions by varying labor effort. So, an increase in the responsiveness of effort compensation to performance (a drop in \( \gamma_e \)) reduces the procyclicality of labor productivity.

Thus, the slump in the correlation of labor productivity with hours conditional on non-technology shocks, starting in the early 1980s, could be explained in terms of an increase in the sensitivity of pay to workers performance.

4.3.2 The Hours Response to Technology Shocks and the Performance Sensitivity of Effort Compensation

We now turn to investigate if the increasing sensitivity of effort compensation to workers performance can account for the observed differences in the dynamic response of hours to technology shocks between the pre- and post 1984 sample. Indeed, as figure 3 shows, the hours response does depend on the performance sensitivity of effort compensation in a way which is consistent with the empirical findings. In particular, for a higher responsiveness of effort compensation to workers performance the hours response, whilst still negative, is of a lower size in absolute terms.

The intuition of this finding is straightforward. Galí (1999) and Basu, Fernald and Kimball (2007) point out that the negative response of hours
worked to a technology shock is theoretically consistent with a sticky price economy in which monetary policy is not fully accommodative (Dotsey 2002 and Galí and Rabanal 2004). 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 their demand with fewer hours worked by employees.

In the aftermath of the technology shock, both effort and hour compensation tend to increase. Cost minimization implies that hours contraction would be larger the higher is the increase in the hourly wage (i.e., the lower is $\gamma_h$) and the smaller is the increase in effort compensation (i.e., the higher is $\gamma_e$). As a matter of fact, for a given degree of hourly wage rigidity, a higher responsiveness of effort compensation would imply a higher increase of $V_t / P_t$ after the technology shock and this would induce firms to adjust labor input by reducing it more on the effort side than on the hours side. As a consequence, a more responsive effort compensation is associated with less severe contractionary implications on hours of technology shocks.

We have therefore shown that a structural change taking the form of a higher sensitivity of effort compensation to workers performance can account for both changes in the dynamic responses to shocks uncovered by GG. Of course this does not rule out the potential relevance of other explanations for the changing structure of conditional comovements among variables. However, as we show in the next section, each of the alternative interpretations, taken alone, seems to fall short of accounting for both changes in the dynamic responses to shocks.

5 Alternative Sources of Structural Change

5.1 A Decrease in Hourly Wage Rigidity

Blanchard and Galí (2008) argue that the post-1984 period has been characterized by a decrease in the degree of real wage rigidities relative to the earlier period. The weakening of unions and the disappearance of wage indexation have led to a greater responsiveness of compensation to labor market conditions.

As shown in the previous section, we find that the greater flexibility of labor compensation is, in fact, consistent with both the disappearance of the SRIRL, conditional on a non technology shock, and with the reduction (in
absolute value) of the negative correlation between hours and productivity, conditional on technology shock, when it originates from a greater performance sensitivity of effort compensation $\frac{V_t}{P_t}$, i.e., from a decline in $\gamma_e$.

Conversely, if the greater flexibility of labor compensation arises as a result of a greater responsiveness of the real price of a hour $\frac{W_t}{P_t}$, i.e. from a decline in $\gamma_h$, then this would even amplify the procyclicality of labor productivity conditional on demand shocks and the contraction of hours after a technology shock, thus implying counterfactual changes in the patterns of comovements among macro variables.

Figure 4 shows that, if the value of $\gamma_h$ is high ($\gamma_h = 0.9$), labor productivity is strongly countercyclical conditional on a non technology shock and hours respond positively to a technology innovation (Riggi 2009 and Riggi and Tancioni 2009). Conversely, if the value of $\gamma_h$ reflects a lower rigidity of the hourly wage ($\gamma_h = 0.5$), then labor productivity becomes procyclical conditional on a non technology shock and the contractionary effects on hours following a technology innovation become more severe. Thus an increase in the hourly wage flexibility implies changes in the correlations pattern which are at odds with the evidence found on the empirical ground.

In terms of intuition, with hourly wage rigidity the increase of hourly wage spurred by higher demand is lower than in the case of flexibility. Consequently, when the economy is hit by a non-technology shock, the higher is the degree of hourly wage rigidity, the less profitable would be to substitute increases in the rate of labor effort for increases in measured employment or hours, and so the less procyclical would be labor productivity. On the other hand, when the economy is hit by a technology shock, the lower increase in hourly real wage implied by a higher value of $\gamma_h$ induces, ceteris paribus, a less pronounced hours contraction.

We study how the term $(\gamma_h - 1)$, representing the equilibrium relationship between labor productivity and hours in equation (24), moves with changes in the parameter $\gamma_h$. Indeed, as it is shown in the Appendix, the derivative term $\frac{\partial r_h}{\partial \gamma_h}$ turns out to be non positive under the sufficient condition that $1 + \sigma_e \geq \frac{1 - \sigma}{\varphi}$, which is identical to the one presented before to characterize the non negative sign of the derivative term $\frac{\partial r_h}{\partial \gamma_e}$. We conclude that a higher hourly real wage flexibility, i.e. a decline of $\gamma_h$, amplifies the procyclical response of labor productivity.
5.2 A Decrease in Hours Adjustment Costs

The Keynesian explanation for the procyclical behavior of labor productivity is labor hoarding, which originates from the existence of a variety of costs 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, labor force is smoothed over the cycle and the cyclical variations in labor effort, which increases in booms and decreases in recessions, generate the perception of SRIRL.

It follows that a straightforward interpretation for the decline in the correlation between labor productivity and hours, conditional on non-technology shocks, could rely upon the drop in the costs associated with the adjustment of labor force and the consequent decrease in excess labor, which has been due, in the last decades, to higher competition, more flexible labor market and tougher corporate governance.

However, while this channel could explain the sign switch in the response of labor productivity to non-technology shocks, the drop in hours adjustment costs would lead to an even larger initial drop in hours following a technology innovation. This is in contrast with the evidence provided by GG and confirmed by our SVAR-based IRFs. The economic intuition is straightforward. Given the sluggish response of aggregate demand to a technology innovation, firms will reduce their input demand along both margins. Higher costs of adjusting hours increase firms’ incentive to react to a technology shock by varying the intensity of effort while smoothing hours response. Conversely, lower adjustment cost will lead, ceteris paribus, to a larger contraction in hours.

In the model, the decline in labor adjustment costs is captured by a decrease in the parameter $\phi_h$. Figure 5 shows the IRF of the marginal productivity of hours to a demand shock and the IRF of hours to a technology shock under two different calibrated values of $\phi_h$. By reducing $\phi_h$ we obtain a vanishing procyclical response of labor productivity to a demand shock but, at the same time, a larger short run contraction in hours following a technology expansion.

5.3 Improvements in the Conduct of Monetary Policy

The role of monetary policy in shaping the Great Moderation has been investigated by a number of recent contributions, as an explanation alternative to
the "good luck" view. Indeed, a plausible interpretation for the substantial decline in the macroeconomic volatility is that a greater responsiveness of the interest rate to fluctuations in economic conditions, coupled with an improvement in monetary policy credibility (Blanchard and Gali 2008 and Blanchard and Riggi 2009), has made central bank more effective in the achievement of its stabilization goal. Along this line, the recent contributions of Clarida, Galí and Gertler (2000), Lubik and Schorfheide (2004) Boivin and Giannoni (2006) and Castelnuovo and Surico (2006) have described the Great Moderation as an indeterminacy-determinacy story, according to which the pre-Great Moderation period was characterized by sunspot fluctuations and indeterminate equilibriums, while in the post Great Moderation period Central Bank has strengthened the reaction of nominal rate to inflation and becomes more successful at ruling out undesired non fundamental fluctuations.

In our model the more aggressive inflation policy is captured by an increase in the Taylor coefficient $\phi_{dp}$. As shown by Galí and Rabanal (2004), the change in the interest rate coefficient affects the equilibrium response of labor input to a technology shock. For a given set of the other parameters, a higher degree of the inflation coefficient in the Taylor rule $\phi_{dp}$ means a higher degree of policy accommodation and thus a less negative response of labor input to a technology improvement.

Figure 6 displays hours response to a technology shock under two different values in the calibration of the parameter $\phi_{dp}$ (from 1.5 to 5.0). Given the other parameters, the increase in the Taylor coefficient is able to explain the change in the pattern of the response of hours to a technology shock found in data. Thus, the large and significant contractionary effects of technology shock on labor input in the pre-Volcker period and the small and largely insignificant short term effects over the Volcker-Greenspan period can be reasonably explained by a strengthening of monetary policy.

However, though being highly supported by the empirical evidence, the change in the conduct of monetary policy is not able alone to explain the more complex picture of changes in the conditional correlations. As a matter of fact, variations in the Taylor coefficient do not affect $(r_h - 1)$, i.e. the degree of SRIRL found in the economy, and thus are not able to explain the sharp decline in the procyclicality of labor productivity conditional on non technology shocks. This is why we argue that more was at work.
6 A Further Investigation Using Artificial Data

We now turn to analyze the implications of the different structural changes for the volatility and the unconditional correlations among macro variables. To do so, we use artificial data generated from the model presented in previous sections. In particular, we first consider the structural change associated with an increase in the sensitivity of effort compensation to workers performance by using two different calibrations for $\gamma_e$. For each parameterization, we extract randomly 1,000 samples of 100 observations each from the artificial data set, compute second moments on the first-differenced data taken in natural logarithms and then average them across the 1,000 samples.\footnote{The sample length of 100 quarters is empirically reasonable as it broadly resembles the one associated with the Great Moderation (from 1984:1 onwards) as well as the one of the pre–Great Moderation period (from 1948:1 to 1983:4).}

In Table 1A we focus on the unconditional correlation between labor productivity and hours and between labor productivity and output. An increase in the performance sensitivity of pay is conducive to a sharp reduction in the unconditional correlation of labor productivity with both hours and output. The correlation with hours shifts sign from a low positive value (0.19) to a negative value (-0.29), while the correlation with output falls from 0.61 to 0.12. These patterns are consistent with the empirical evidence reported by GG on cross-correlations on actual data in the pre- and post-1984 periods. We also use the artificial data to examine the degree to which this structural change explains the observed reduction in the macroeconomic volatility. We find that the increase in the sensitivity of pay to workers performance can account alone only for a 4 percent decline (see Table 1B), which is insignificant compared to that documented on actual data\footnote{GG report a decrease in the standard deviation of the first-difference of business output (after taking natural logarithm) from 1.57 to 0.68. In our investigation on artificial data we calibrate the standard deviation of the two shocks in our economy by requiring the model in the high $\gamma_e$ case to match the actual volatility of output in the pre-1984 sample.}. We also find that a higher performance sensitivity of pay is conducive to a sharp increase in the volatility of labor compensation in real terms. This pattern is consistent with the empirical evidence recently reported by Galí and Van Rens (2009) for the US economy, who uncover a sizeable increase in the volatility of actual (real) wages over the post-1984 period\footnote{When they consider the product wages transformed using the four-quarter difference of the (log of) variable, the standard deviation shifts from 1.24 to 1.6 between the pre-and post-1984 periods.}. This finding ought to be emphasized.
as it stands in contrast with the overall, parallel decline of macroeconomic volatility.

Therefore, the higher sensitivity of pay to workers performance allows to account for the observed differences in conditional and unconditional comovements patterns across pre- and post-1984 subsamples. This structural shift, however, is not sufficient to explain the overall drop of output volatility. On the other hand, neither the other structural shifts are not conducive to a dramatic drop of output volatility and, in general, they also fail to account for the observed changes in the pattern of correlations among macro variables.

In Tables 2, we focus on a higher degree of hourly wage flexibility (i.e., a lower $\gamma_h$). The patterns of unconditional correlations move in opposite direction to that documented at the empirical level: the correlation of labor productivity with both hours and output goes up as the degree of wage flexibility increases. At the same time, the reduction of output volatility uncovered from the artificial data continues to be of a negligible size.

We also focus on the structural shift associated with lower adjustment costs on labor input (i.e., a lower $\phi_h$). As Table 3 shows, the cross-correlations obtained on data generated by the model with a lower $\phi_h$ are indeed of a smaller size than those obtained in the case of a higher $\phi_h$. Whilst this is consistent with the patterns documented on empirical grounds, the artificial data point, however, to an increase in the standard deviation of output and a decrease in the standard deviation of wage, which are at odds with the empirical findings.

Finally, we examine a shift in the conduct of monetary policy towards a more aggressive central bank’s attitude against inflation. Table 4 indicates that whilst such change is conducive to a reduction in the standard deviation of output from 1.58 to 1.22, the other results obtained on the artificial data are difficult to square with the empirical evidence. The wage volatility decreases and the correlation of labor productivity with output and hours moves in opposite direction with respect to that uncovered at the empirical level.

Summing up, the structural shift based on a higher sensitivity of pay to workers performance does a good job in matching the observed differences in the conditional and unconditional correlation structure among macro variables in the pre- and post-1984 samples. On the other hand, however, it cannot fully account for the decline in output volatility. This suggests that whilst, alone, good luck explanations of the Great Moderation fail to account for the changes in cross-correlations, at the same time the interpre-
tation based on a change in the structure of labor compensation should be supplemented by additional assumptions, dealing for example with a parallel reduction in the variance of shocks.

7 Concluding Remarks

As shown by GG, large changes in the correlations structure among output, hours and labor productivity and in the dynamic responses to shocks have accompanied the substantial decline in the macroeconomic volatility experienced by the US economy since the mid-80s. The recent decades have been characterized, on the one hand, by a sign switch, from positive values to negative values, in the correlation of labor productivity with both hours and output conditional on non-technology shocks and, on the other hand, by a shrinking contractionary effects on hours of technology shocks.

In this paper we have provided a novel explanation for these patterns, which relies upon a relevant structural change occurred in the US economy since the early 1980s: the remarkable increase in the firms’ reliance on pay-for-performance mechanisms. There is an extensive evidence that the structure of compensation has changed dramatically over the 1980s and 1990s in a way that has increased the performance pay sensitivity.

By developing a New Keynesian model with variable effort, where the degree of responsiveness of compensation to effort exerted is explicitly allowed for, we have shown that a structural change towards higher sensitivity of compensation to workers effort can account for both the disappearance of the procyclical productivity puzzle and the smaller size of the contractionary effects on hours of a technology improvement.

We have also stressed that a lower degree of hourly wage rigidity alone would have implications for the patterns of second moments that go in exactly the opposite direction to those uncovered at the empirical level. However, a higher flexibility of hourly wage can be reconciled with the two stylized facts if a major part of rising labor compensation flexibility has involved the performance compensation margin.

Of course, we do not believe that the one proposed in this paper is the sole structural change occurred in the economy lying behind the complex picture of the evolving nature of the U.S. business cycle. For example, an improvement in monetary policy and a reduction in labor market frictions, in the form of a decrease in hours adjustment cost, may have played a role.
However, by using the model developed, we have shown that each of the alternative explanations falls short of accounting for both observed changes in the dynamic responses to shocks.

Furthermore, a structural shift based on the increase in the performance sensitivity of labor compensation seems to be consistent with a puzzling evidence concerning the Great Moderation that was highlighted by Davis and Kahn (2008): the substantial slump in the volatility of aggregate real activity has been coincident with an increase in individual income volatility and earnings uncertainty. Although this pattern is not a prediction of our macroeconomic model, we believe however that a story based on a greater performance-pay sensitivity is also able to explain why the drop in macro volatility did not translate into a reduction in earnings uncertainty.

Therefore, we see two natural directions for future research. On one side, the extension of the model by allowing for heterogeneous consumers to investigate the coincidence between the changes in the macroeconomic correlations structure and rising earnings volatility at the micro level and, on the other, the structural estimation of the model.
Figure 1.A. The average responses of labor productivity to non technology shocks


Figure 1.B. The average responses of hours to technology shocks
Figure 2. IRFs from SVAR estimation

Note: Dashed lines are 90 percent confidence bands. The first subperiod refers to the interval 1948:1-1983:4. The second subperiod refers to 1984:1-2008:3
Figure 3. Dynamic effects of an increase in the sensitivity of effort compensation to worker performance

IRFs are obtained under the following calibration: $\beta=0.99$, $\alpha=1$, $\phi=0.8$, $\sigma_c=2$, $\sigma_e=1$, $\sigma_h=1$, $\epsilon=6$, $\theta=0.8$, $\phi_{dp}=1.5$, $\phi_h=0.2$, $\gamma_h=0.8$, $\rho_g=0.5$, $\rho_z=0.9$ for both samples. We calibrate $\gamma_e=0.9$ for the pre-1984 sample and $\gamma_e=0.5$ for the post-1984 sample.
Figure 4. Dynamic effects of a decrease in hourly wage rigidity

IRFs are obtained under the following calibration: $\beta=0.99$, $\alpha=1$, $\varphi=0.8$, $\sigma_c=2$, $\sigma_e=1$, $\sigma_h=1$, $\epsilon=6$, $\theta=0.8$, $\phi_{d\nu}=1.5$, $\gamma_e=0.8$, $\phi_h=0.2$, $\rho_g=0.5$, $\rho_z=0.9$ for both samples. We calibrate $\gamma_h=0.9$ for the pre-1984 sample and $\gamma_h=0.5$ for the post-1984 sample.
Figure 5. Dynamic effects of a decrease in hours adjustment cost

IRFs are obtained under the following calibration: $\beta=0.99$, $\alpha=1$, $\varphi=0.8$, $\sigma_c=2$, $\sigma_e=1$, $\sigma_h=1$, $\epsilon=6$, $\theta=0.8$, $\phi_{dp}=1.5$, $\gamma_e=\gamma_h=0.5$, $\rho_g=0.5$, $\rho_z=0.9$ for both samples. We calibrate $\phi_h=5$ for the pre-1984 sample and $\phi_h=0$ for the post-1984 sample.
Figure 6. Dynamic effects of an increase in the Taylor coefficient

IRFs are obtained under the following calibration: $\beta=0.99$, $\alpha=1$, $\varphi=0.8$, $\sigma_c=2$, $\sigma_e=1$, $\sigma_h=1$, $\epsilon=6$, $\theta=0.8$, $\phi_{dp}=1.5$, $\gamma_e=\gamma_h=0.5$, $\phi_h=0.2$, $\rho_g=0.5$ for both samples. We calibrate $\phi_{dp}=1.5$ for the pre-1984 sample and $\phi_{dp}=5$ for the post-1984 sample.
Table 1
Second moments of artificial model-based data
The explanation based on the performance sensitivity of effort compensation

A) Cyclical behavior of Labor Productivity

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Hours</th>
<th>Correlation with Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High $\gamma_e$</td>
<td>Low $\gamma_e$</td>
</tr>
<tr>
<td>First-difference</td>
<td>0.19</td>
<td>-0.29</td>
</tr>
</tbody>
</table>

B) Volatility of output and labor compensation

<table>
<thead>
<tr>
<th></th>
<th>Standard deviation</th>
<th>Relative Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High $\gamma_e$</td>
<td>Low $\gamma_e$</td>
</tr>
<tr>
<td>First-difference</td>
<td>Output</td>
<td>Labor Compensation</td>
</tr>
<tr>
<td></td>
<td>1.55</td>
<td>0.79</td>
</tr>
<tr>
<td></td>
<td>1.49</td>
<td>2.10</td>
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<tr>
<td></td>
<td>0.96</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.41</td>
</tr>
</tbody>
</table>

Legend: as in Fig. 3, the higher value of $\gamma_e$ is calibrated at 0.9 and the lower value at 0.5.

Table 2
Second moments of artificial model-based data
The explanation based on hourly wage flexibility

A) Cyclical behavior of Labor Productivity

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Hours</th>
<th>Correlation with Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High $\gamma_h$</td>
<td>Low $\gamma_h$</td>
</tr>
<tr>
<td>First-difference</td>
<td>0.04</td>
<td>0.14</td>
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</table>

B) Volatility of output and labor compensation

<table>
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<tr>
<th></th>
<th>Standard deviation</th>
<th>Relative Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High $\gamma_h$</td>
<td>Low $\gamma_h$</td>
</tr>
<tr>
<td>First-difference</td>
<td>Output</td>
<td>Labor Compensation</td>
</tr>
<tr>
<td></td>
<td>1.58</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>0.87</td>
<td>1.83</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Legend: as in Fig. 4, the higher value of $\gamma_h$ is calibrated at 0.9 and the lower value at 0.5.
### Table 3
Second moments of artificial model-based data
The explanation based on adjustment cost on labor

A) Cyclical behavior of Labor Productivity

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Hours</th>
<th>Correlation with Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High $\phi_h$</td>
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</tr>
<tr>
<td>First-difference</td>
<td>0.44</td>
<td>-0.27</td>
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</table>

B) Volatility of output and labor compensation

<table>
<thead>
<tr>
<th></th>
<th>Standard deviation</th>
<th>Relative Standard deviation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>High $\phi_h$</td>
<td>Low $\phi_h$</td>
</tr>
<tr>
<td>First-difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>1.55</td>
<td>1.69</td>
</tr>
<tr>
<td>Labor Compensation</td>
<td>3.05</td>
<td>2.79</td>
</tr>
</tbody>
</table>

Legend: as in Fig. 5, the higher value of $\phi_h$ is calibrated at 5 and the lower value at 0.

### Table 4
Second moments of artificial model-based data
The explanation based on improvements in monetary policy

A) Cyclical behavior of Labor Productivity

<table>
<thead>
<tr>
<th></th>
<th>Correlation with Hours</th>
<th>Correlation with Output</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low $\phi_{dp}$</td>
<td>High $\phi_{dp}$</td>
</tr>
<tr>
<td>First-difference</td>
<td>-0.15</td>
<td>-0.03</td>
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B) Volatility of output and labor compensation

<table>
<thead>
<tr>
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<th>Relative Standard deviation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Low $\phi_{dp}$</td>
<td>High $\phi_{dp}$</td>
</tr>
<tr>
<td>First-difference</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>1.58</td>
<td>1.22</td>
</tr>
<tr>
<td>Labor Compensation</td>
<td>2.66</td>
<td>1.87</td>
</tr>
</tbody>
</table>

Legend: as in Fig. 6, the lower value of $\phi_{dp}$ is calibrated at 1.5 and the higher value at 5.
Appendix A

Equation (23) along with (24) containing the expression for \( r_h \) reported in the text are explicit reduced-form equilibrium relationships and are obtained as follows. We first log-linearize (8) and (9) around the steady state and then combine the resulting expression with the log-linearized counterpart of (10), (11) and (22).

In order to study the derivative of \( r_h \) with respect to \( \gamma_e \) in equation (24) in the text and thus better characterize the equilibrium behavior of labor productivity, we first ought to determine the steady state values of effort and hours. If we combine (22) with (8) and (9) and assume for simplicity that \( \gamma_e = \gamma_h = 0 \), the steady state expression for \( E_t \) is

\[
E = \left[ \frac{(1 - \varphi)(1 + \sigma_e)\lambda_h}{\varphi(1 + \sigma_e) - (1 - \varphi)\lambda_e} \right]^{1 + \sigma_e}H^{1 + \sigma_e} \tag{25}
\]

where \( E \) and \( H \) denote the steady-state counterpart of \( E_t \) and \( H_t \). If we normalize \( H \) to be equal to one, as, for example, in Smets and Wouters (AER, 2007), then

\[
E = \left[ \frac{(1 - \varphi)(1 + \sigma_e)\lambda_h}{\varphi(1 + \sigma_e) - (1 - \varphi)\lambda_e} \right]^{1 + \sigma_e} \tag{26}
\]

If we use this expression for \( E \), along with \( H = 1 \), equation (23) in the text becomes:

\[
\hat{e}_t = \frac{\sigma_e(\gamma_e - \gamma_h)}{1 + \sigma_e(1 - \varphi)\alpha(\gamma_h - \gamma_e) - \frac{\sigma_e(1 - \varphi)\alpha(\gamma_h - \gamma_e)}{\sigma_e(1 + \sigma_e)(1 - \varphi)}}\hat{z}_t + \frac{\sigma_e(\gamma_e - \gamma_h)}{1 + \sigma_e(1 - \varphi)\alpha(\gamma_h - \gamma_e) - \frac{\sigma_e(1 - \varphi)\alpha(\gamma_h - \gamma_e)}{\sigma_e(1 + \sigma_e)(1 - \varphi)}}\hat{h}_t \tag{27}
\]

By plugging equation (27) in the production function yields

\[\text{It is important to note that the simplifying assumption of setting } \gamma_e = \gamma_h = 0 \text{ in the calculation of the steady-state value of } E_t \text{ was adopted only in the “by hand” calculation of the derivative of labor productivity with respect to hours. In the simulation of the model, the steady-state value used for } E_t \text{ is the one consistent with the calibration assigned to } \gamma_e \text{ and } \gamma_h \text{ and was obtained using numerical approximations. However, we have also verified that this simplifying assumption, whilst allowing us to provide useful information on the behavior of labor productivity, does not alter the variables dynamic in response to shocks in any significant way.}\]
\[
\hat{y}_t - \hat{h}_t = (r_h - 1)\hat{h}_t + r_z \hat{z}_t \tag{28}
\]

where
\[
r_h \equiv \frac{\varphi \alpha [1 - \frac{1}{\varphi}(1 - \gamma_h)] + \varphi \alpha \sigma_c + \alpha (1 - \varphi) - \varphi \sigma_e \gamma_e + (1 - \varphi) \alpha (1 - \gamma_h) \sigma_h \frac{\varphi(1 + \sigma_e) - (1 - \varphi)}{\varphi(1 + \sigma_e)}}{1 + \sigma_c (1 - \varphi) \alpha (\gamma_h - \gamma_e) - \frac{1}{\varphi}(1 - \gamma_h) + (1 - \gamma_e) \sigma_e}
\]

and
\[
r_z \equiv \frac{1 - \frac{1}{\varphi}(1 - \gamma_h) + (1 - \gamma_e) \sigma_e}{1 + \sigma_c (1 - \varphi) \alpha (\gamma_h - \gamma_e) - \frac{1}{\varphi}(1 - \gamma_h) + (1 - \gamma_e) \sigma_e}
\]

After some algebraic calculations, the derivative of \( r_h \) with respect to \( \gamma_e \) can be expressed as follows
\[
\frac{\partial r_h}{\partial \gamma_e} = \frac{1}{1 - \sigma_c (\gamma_e - \gamma_h) \alpha (1 - \varphi) - (1 - \gamma_h) \sigma_e} \left\{ \gamma_h \left[ \alpha \varphi \sigma_e + (1 - \varphi) \left( \alpha \sigma_e + \frac{1}{\varphi} \right) \right] (1 - \varphi) \alpha + 
+ \left[ 1 + \sigma_e - \frac{1}{\varphi} \right] \left[ 1 + \alpha \varphi \sigma_e (1 - \gamma_h) + \sigma_e (1 - \gamma_h) \alpha (1 - \gamma_e) \sigma_h \right] (1 - \varphi) \alpha \right\} \tag{29}
\]

It can be seen from the above expression that, under the sufficient condition that \( 1 + \sigma_e \geq \frac{1 - \varphi}{\varphi} \), the above derivative term is clearly non-negative. This sufficient condition is actually met for any economic reasonable parametrization of the above entities.

Moreover, the derivative of \( r_h \) with respect to \( \gamma_h \) can be written as follows
\[
\frac{\partial r_h}{\partial \gamma_h} = \frac{1}{1 - \sigma_c (\gamma_e - \gamma_h) \alpha (1 - \varphi) - (1 - \gamma_h) \sigma_e} \left\{ -\sigma_h \frac{1 + \sigma_e - (1 - \varphi)}{1 + \sigma_e} \left[ 1 + (1 - \gamma_e) \alpha \sigma_c (1 - \varphi) + \sigma_e \right] + 
- \alpha \sigma_c \left[ \frac{1}{\varphi} \gamma_e + (1 - \gamma_e) \frac{1 + \sigma_e - (1 - \varphi)}{1 + \sigma_e} \right] (1 - \varphi) \alpha \right\} \tag{30}
\]

Under the sufficient condition that \( 1 + \sigma_e \geq \frac{1 - \varphi}{\varphi} \), the above derivative is non-positive. This sufficient condition is exactly the same as that established before to characterize the sign of \( \frac{\partial r_h}{\partial \gamma_e} \).
References


