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## **The Business Cycle Implications of Reciprocity in Labor Relations**

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**Abstract:**

We develop a reciprocity-based model of wage determination and incorporate it into a modern dynamic general equilibrium framework. We estimate the model and find that, among potential determinants of wage policy, rent-sharing (between workers and firms) and a measure of wage entitlement are critical to fit the dynamic responses of hours, wages and inflation to various exogenous shocks. Aggregate employment conditions (measuring workers' outside option), on the other hand, are found to play only a negligible role in wage setting. These results are broadly consistent with micro-studies on reciprocity in labor relations but contrast with traditional efficiency wage models which emphasize aggregate labor market variables as the main determinant of wage setting. Overall, the empirical fit of the estimated model is at least as good as the fit of models postulating nominal wage contracts. In particular, the reciprocity model is more successful in generating the sharp and significant fall of inflation and nominal wage growth in response to a neutral technology shock.

**Keywords:** Efficiency wages, Reciprocity, Estimated DSGE models

**JEL Classification:** E24, E31, E32, E52, J50

# 1 Introduction

Dynamic stochastic general equilibrium (DSGE) models postulating nominal price and wage rigidities replicate surprisingly well key business cycle properties. They are, for that reason, increasingly used for monetary policy analysis. Recent studies documenting the performance of these models include Christiano, Eichenbaum and Evans (2005), Altig, Christiano, Eichenbaum and Lindé (2004, ACEL henceforth) and Smets and Wouters (2003, 2007). These studies uniformly conclude that assuming rigid nominal wages is critical for the models' performance.

As Barro (1977) and Hall (1980) observed some time ago, however, the allocative role of wage contracts typically implies large inefficiencies in such models as workers are repeatedly pushed off their labor supply schedule. Given the continuing nature of interactions between workers and firms, these inefficiencies are hard to rationalize. Unsurprisingly, all the above studies thus conclude that a deeper understanding of the mechanics behind the observed sluggishness of wages needs to be developed.

In the present paper, we propose a structural model of wage determination based on reciprocity in labor relations. Wages are allocative but since both workers' and the firms' postulated optimality conditions hold in equilibrium, the model is not subject to the Barro-Hall critique. We incorporate the model into a modern DSGE framework and estimate the structural parameters. The obtained estimates are in line with survey evidence on reciprocity in labor relations. In addition the model matches the empirical response of macro aggregates to various exogenous shocks at least as well as an equivalent model postulating nominal wage contracts.

Section 3 describes the model. In line with efficiency wage theory, effort per hour worked is unobservable and thus cannot be contracted upon. The central hypothesis is that workers may derive a psychological benefit from reciprocating a generous wage offer by the firm with harder work, even though providing effort per se is costly and there are no explicit incentives for doing so. If this reciprocity motive is present, firms set wages so as to elicit a profit maximizing level of effort. In the absence of a reciprocity motive, the model collapses to the standard indivisible labor model of Hansen (1985) and Rogerson (1988).

Inspired by Rabin's (1993) introduction of fairness into game theory and building on our previous adaptation of this concept for macroeconomics (Danthine and Kurmann, 2007), we explicitly

model the psychological benefit derived from reciprocity as the product of the worker’s gift to the firm in terms of effort and the firm’s gift to the worker in terms of remuneration. The latter is measured as the difference between the utility resulting from the actual wage offer and the utility obtained under a reference compensation level. Building on the results of micro studies reviewed in Section 2, we let this reference compensation level depend on three potential factors: the worker’s outside option described by external labor market conditions; a measure of firm-internal labor productivity representative of *rent-sharing* considerations; and past wages capturing the notion of *wage entitlement* on the part of workers.

Section 4 analyzes the theoretical implications of the model. We find that balanced growth imposes important restrictions. In particular, the worker’s reciprocity motive must always be positive for equilibrium employment to be positive; moreover the weights on external wage conditions, rent-sharing and wage entitlement in the worker’s reference wage must sum up to one for the labor share to remain bounded. These restrictions imply that our reciprocity-based construct has only two free parameters, a fact that imposes considerable discipline on the estimation.

Section 5 estimates the structural parameters of the model in a modern DSGE framework featuring sticky prices, external habit persistence in consumption, variable capital utilization and investment adjustment cost. We do not impose any prior on the relative importance of the three factors in the reference compensation level. Our strategy consists instead of estimating their empirical relevance as part of the DSGE model subject to the balanced growth restrictions. Aside from the reciprocity-based wage setting block, the DSGE framework closely resembles the one proposed by ACEL (2004). Since we use the same estimation strategy as these authors as well as their data, we can directly compare the empirical performance of their model with ours. The estimation strategy consists of minimizing the distance between the model-based impulse response of macro aggregates to three identified shocks with their empirical counterparts computed from a vector autoregression (VAR). The three identified shocks are a neutral technology shock, an investment specific technology shock and a monetary policy shock. The VAR is composed of 10 post-war quarterly U.S. time series of prominent macroeconomic aggregates.

For our model to replicate the conditional VAR dynamics, the estimation attributes substantial importance to wage entitlement while also giving significant weight to rent-sharing. By contrast, external labor market conditions are estimated to matter only marginally in the construction of the

reference wage. This is largely consistent with survey evidence on reciprocity in labor relations, which find that rent-sharing and wage entitlement are important factors in the workers' fairness evaluation whereas external employment conditions matter much less because workers often know too little about them.

Section 6, finally, contrasts the reciprocity model to a DSGE model with sticky prices and nominal wage contracts (both introduced via a Calvo (1983) mechanism) that has, in many ways, become the standard for monetary policy analysis. Overall, the empirical fit of the reciprocity model is comparable to the performance of the nominal wage contracts model. The reciprocity model is more successful, however, in generating the sharp drop on impact in inflation and nominal wage growth following a neutral technology shock, a reaction that emerges as a robust stylized fact from several VAR studies. By contrast, real wages in the data adjust sluggishly irrespective of the shock. The available evidence thus tends to favor real wage rigidity (as generated by our reciprocity model) over unconditional nominal wage rigidity (as implied by nominal wage contracts models).

## 2 Related Literature

The reciprocity hypothesis receives strong support from a large number of survey studies bearing on labor relations (e.g., Kahneman, Knetsch and Thaler, 1986; or Bewley, 1999) as well as from laboratory experiments in behavioral economics (e.g., Fehr and Falk, 1999). Both strands of literature also document that firms often refrain from offering explicit rewards for effort because enforcing such mechanisms is costly and may negatively affect work morale.<sup>1</sup>

Reciprocity in labor relations was introduced into macroeconomics by Akerlof (1982) under the name of 'partial gift exchange' and 'fair wage hypothesis'. As in more conventional efficiency wage formulations such as Salop's (1979) labor turnover theory or Shapiro and Stiglitz' (1984) shirking model, both rent-sharing and wage entitlement are absent from Akerlof's model. Instead, the reference compensation level depends entirely on the worker's expected earnings outside of the firm.

This focus on firm-external wage references contrasts strongly with the available micro evidence. In many situations, workers appear to have only little reliable information about their own pro-

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<sup>1</sup>See Fehr and Gaechter (1999) and Bewley (2002) for an extensive discussion of the empirical evidence. The appendix of Danthine and Kurmann (2007) also provides a detailed summary.

ductivity or their available outside options. Bewley (2002), for example, concludes his summary of the empirical evidence on reciprocity in labor relations by stating that "*...employees usually have little notion of a fair or market value for their services and quickly come to believe that they are entitled to their existing wage, no matter how high it may be...*" (page 7). More generally, workers seem to care about firm-internal reference points; a concept that Kahneman, Knetsch and Thaler (1986) associate with the notion of dual entitlement: firms are entitled to a reference profit while workers are entitled to a reference salary.<sup>2</sup> This notion of dual entitlement receives strong support from numerous survey and experimental studies. Fehr, Gächter and Kirchsteiger (1990) report, for example, that the firm's ability to pay (i.e. rent-sharing) plays an important role for wage setting. Levine (1993), Campbell and Kamlani (1997) or Bewley (1999), on the other hand, stress the role of the worker's past wages (i.e. wage entitlement) in the determination of the worker's reference salary.

Danthine and Donaldson (1990) are the first to incorporate reciprocity in labor relations in a modern DSGE context. They find that when the worker's reference compensation level only depends on firm-external labor market conditions as in Akerlof (1982), the model fails to improve the ability of DSGE models to replicate business cycle facts. Collard and De la Croix (2000), Danthine and Kurmann (2004) and De la Croix, De Walque and Wouters (2006) subsequently show that including the workers' past wage in their wage reference generates substantial real rigidity and improves the empirical performance of DSGE models.<sup>3</sup>

In contrast with these studies, our investigation explicitly focuses on the ability of our model to fit the distinct dynamics of labor market and inflation variables in response to various exogenous shocks. In addition, we set our model in a stochastic growth context, which turns out to imply important parameter restrictions; and we formalize the reciprocity motive at the level of individuals' preferences rather than as a reduced-form equation. To our knowledge, Rotemberg (2007) is the

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<sup>2</sup>The notion of dual entitlement is itself closely related to Adam's (1963) theory of equity and Blau-Homan's (1955, 1961) theory of social exchange. Both theories hypothesize that the rewards from an exchange (here between firms and workers) should be proportional to the perceived value of the different parties' inputs. Numerous studies in psychology and sociology have attempted to test these theories. Overall they report strongly supportive results. See Akerlof and Yellen (1990) for a review of this evidence.

<sup>3</sup>De la Croix, De Walque and Wouters (2006) combine reciprocity in labor relations with nominal wage contracts. This combination, however, implies non-trivial heterogeneity across firms that their model fails to take into account.

only other study that explicitly introduces non-pecuniary considerations in labor relations into a dynamic general equilibrium context. His model and empirical strategy are quite different, however, providing an interesting alternative perspective to the present attempt.

Our paper also relates to recent studies by Hall (2005), Shimer (2005) and Krause and Lubik (2007) who assess the empirical performance of DSGE models with job search in the labor market. They conclude that the standard search model where wages are determined by Nash bargaining fails to generate quantitatively important responses to plausible exogenous technology shocks. By contrast, the labor search model becomes more successful if wages are constrained to be a function of past wages. The wage entitlement dimension of our reciprocity-based model offers an explicit rationale for this dependence on past wages.

### 3 The Model

Our model is based on the now standard New Keynesian business cycle framework with nominal price rigidities as described in Goodfriend and King (1998) or Rotemberg and Woodford (1997) and has many elements in common with ACEL (2004). The economy is populated by individuals, intermediate goods firms, final goods firms and a monetary authority. Individuals have preferences over consumption, leisure and effort. Final goods firms transform differentiated inputs from intermediate goods firms into a homogenous product sold competitively to individuals. Intermediate goods firms are monopolistic competitors and set prices according to a variant of the partial adjustment mechanism proposed by Calvo (1983).

In line with efficiency wage theory, we assume that effort per unit of labor is an input to production in the intermediate goods sector but it cannot be directly observed. In contrast to labor hours, effort is therefore not directly contractible. Firms understand, however, that while workers dislike effort *per se*, they may derive utility from reciprocating a generous wage offer with a commensurate effort level even in the absence of monitoring.

#### 3.1 Individuals and households

There is a  $[0, 1]$  continuum of identical individuals spread across a  $[0, 1]$  continuum of identical households. In each household, some of the individuals are working while others are unemployed.

An individual's momentary utility is given by

$$\log(C_t - b\bar{C}_{t-1}) + \log(1 - L_t) - L_t \left[ \frac{1}{2}(E_t - E^n)^2 - \lambda s(E_t, \cdot) \right],$$

where  $C_t$  stands for current consumption,  $\bar{C}_{t-1}$  is the previous period (average) per capita consumption,  $b \geq 0$  is an external habit parameter, 1 is the total number of hours available per individual,  $L_t$  is the fraction of hours worked, and  $E_t - E^n$  is the deviation of effort per hour worked from some norm level  $E^n$  assumed to be constant over time. The term  $\lambda s(E_t, \cdot)$  admits that workers may derive utility from reciprocal behavior towards their employer, with the parameter  $\lambda$  determining the relative importance of such considerations.<sup>4</sup> Anticipating our discussion on optimal behavior in the next section, we note that there is no reciprocity motive when  $\lambda = 0$ , in which case workers supply  $E_t = E^n$  units of effort per hour. When  $\lambda > 0$ , by contrast, workers may be willing – under circumstances described below – to reward (punish) a wage offer perceived as generous (unfair) with effort in excess of (below)  $E^n$  even though no direct material gain derives from such action. The optimality condition that guides this decision is

$$E_t = E^n + \lambda s_E(E_t, \cdot). \tag{1}$$

We call this equation the *Effort Condition* (EC).

Following Rogerson (1988) and Hansen (1985), labor is assumed to be indivisible in the sense that individuals would ideally like to supply  $L_t^*$  but that they have to choose between working a fixed shift  $H > L_t^*$  or not working at all. In such a situation, the household can make its members better off by providing a lottery whereby a fraction  $N_t$  of individuals work a fraction  $H$  hours with consumption  $C_t(1)$  while the remaining  $1 - N_t$  individuals remain unemployed with consumption  $C_t(2)$ . In order to avoid heterogeneity, we assume that households hold all assets, make all investment decisions and redistribute income net of investment to their members. In each period, they collect their workers' labor income, rental payments on capital owned by the family, and dividends from a perfectly diversified portfolio of claims to firms. They then decide on investment in new physical capital,  $I_t$ , and redistribute the rest to their members for consumption. For the type of separable preferences assumed here, efficient risk sharing implies an identical level

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<sup>4</sup>The function  $s(E_t, \cdot)$  potentially depends on many more variables than effort, among them the firm's wage. The atomistic representative worker is assumed to take these additional variables as exogenous.



of consumption for employed and unemployed individuals alike; i.e.  $C_t(1) = C_t(2) = C_t$ .<sup>5</sup> Omitting household indices to simplify notation, we can therefore formulate the household's intertemporal optimization problem as

$$\max_{\{C_t, I_t, K_{t+1}, N_t, E_t\}} \mathbf{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log(C_t - b\bar{C}_{t-1}) + N_t \left[ \log(1 - H) + \frac{1}{2}(E_t - E_n)^2 - \lambda_s(E_t, \cdot) \right] \right\} \quad (2)$$

subject to

$$\begin{aligned} C_t + I_t &\leq W_t N_t + R_t^K K_t + D_t \\ K_{t+1} &= [1 - \delta(U_t)]K_t + V_t F(I_t, I_{t-1}), \end{aligned}$$

where  $\mathbf{E}_0$  is the expectations operator given information at time 0,  $K_t$  stands for the physical capital stock available at the beginning of period  $t$ ;  $\delta(U_t)$  is the rate of capital depreciation, which depends on the level of utilization  $U_t$ , with  $\delta' > 0$ ,  $\delta'' > 0$ ;  $W_t$  denotes the real wage;  $R_t^K$  is the rental rate of capital; and  $D_t$  are dividends paid out on a diversified portfolio of firm shares. Following King and Rebelo (2000), we place the capital utilization decision directly with the firms, which face a trade-off between higher effective capital use and higher depreciation. This trade-off is reflected in higher rental costs associated with more intensive capital use; i.e.,  $R_t^K = [r_t - 1 + \delta(U_t)]/V_t$  where  $r_t$  is the real gross return on a risk-free one-period bond. Following Fisher (2006), new investment  $I_t$  translates into installed capital through  $V_t F(I_t, I_{t-1})$ , where  $V_t$  is an exogenous investment-specific technology shock whose growth rate  $\mu_{V,t} \equiv V_t/V_{t-1}$  evolves according to

$$\mu_{V,t} = \mu_V + \rho_{\mu_V} \mu_{V,t-1} + \varepsilon_{\mu_V,t}, \text{ with } \varepsilon_{\mu_V,t} \text{ iid } (0, \sigma_{\varepsilon_{\mu_V}}^2). \quad (3)$$

As in Christiano, Eichenbaum and Evans (2005) and ACEL (2004), we specify

$$F(I_t, I_{t-1}) = (1 - S(I_t/I_{t-1}))I_t,$$

where  $S$  is an arbitrary function satisfying  $S(\Delta I^{SS}) = S'(\Delta I^{SS}) = 0$  and  $S'' = \chi > 0$ .

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<sup>5</sup>See King and Rebelo (2000) for a discussion. The presence of external habit in consumption does not affect that reasoning, although an internal habit component would. Similarly, separability implies that the extra utility derived from reciprocity by working individuals does not invalidate this statement.

### 3.2 Reciprocity

To formalize reciprocity, we follow the approach of Rabin (1993) as adapted to a modern macroeconomic setting by Danthine and Kurmann (2007). We define  $s(E_t(i), \cdot)$  as the product of the respective “gifts” of a representative worker and his firm  $i$

$$s(E_t(i), \cdot) = d(E_t(i), \cdot)g(W_t(i), \cdot).$$

The term  $d(E_t(i), \cdot)$  represents the gift of the worker towards firm  $i$ , with  $d_E(E_t(i), \cdot) > 0$  and  $d_{EE}(E_t(i), \cdot) < 0$ . Similarly, the term  $g(W_t(i), \cdot)$  represents the gift of firm  $i$  towards the worker, with  $g_W(W_t(i), \cdot) > 0$  and  $g_{WW}(W_t(i), \cdot) < 0$ , where  $W_t(i)$  is the real wage paid by firm  $i$ . Hence, when workers perceive a wage offer as generous (i.e.,  $g(W_t(i), \cdot) > 0$ ), their utility may increase if they reciprocate with a gift of higher effort (i.e.,  $d(E_t(i), \cdot) > 0$ ). The representative agent assumption of the indivisible labor framework implies that for this calculation, workers do not take into account the impact of their own effort on firm  $i$ 's output and thus on the gift of the firm. In other words,  $g_E(W_t(i), \cdot) = 0$  in the eyes of the representative worker and thus, the optimal effort decision depends only on the marginal gift of the worker towards the firm,  $d_E(E_t(i), \cdot)$ , and the level of the firm's gift  $g(W_t(i), \cdot)$ .

In defining  $d(E_t(i), \cdot)$  and  $g(W_t(i), \cdot)$ , we follow Rabin one more step and measure the gifts as the deviation of effort and wages, respectively, from some reference level. For  $d(E_t(i), \cdot)$ , the effort reference is, quite naturally, the norm effort level  $E^n$ . We thus specify

$$d(E_t(i), \cdot) = f(E_t(i)) - f(E^n), \tag{4}$$

with  $f' > 0$  and  $f'' \leq 0$ . The only important restriction in this specification is that  $E_t(i)$  enters additively with respect to any other (omitted) determinant. This assumption is not as innocuous as it may seem. Rabin assumes, for example, that the worker's gift is measured in terms of its impact on the firm; i.e., output per worker  $Y(E_t(i), \cdot)/N_t(i)$ , an assumption that violates the above restriction. In the empirical part of the paper, we consider Rabin's specification as an alternative but note already that since output per worker is growing over time while effort is bounded above and below, we need to normalize this measure by some trend productivity level. Hence, Rabin's alternative specification of the worker's gift in our context takes the form

$$d(E_t(i), \cdot) = \frac{\frac{Y(E_t(i), \cdot)}{N_t(i)} - \frac{Y(E^n, \cdot)}{N_t(i)}}{X_t}. \tag{5}$$

where  $Y(E_t(i), \cdot)/N_t(i)$  is firm  $i$ 's labor productivity and  $X_t$  the relevant trend productivity level (to be defined later).

The definition of the wage reference is more critical in the specification of firm  $i$ 's gift to its workers because the level  $g(W_t(i), \cdot)$  matters for the optimal effort decision. As reported in Section 2, various hypotheses have been entertained on this point. Our strategy is to adopt an encompassing and flexible specification with the goal of letting the data speak. We thus define

$$g(W_t(i), \cdot) = \log[(1 - \tau_t(i))W_t(i)] - \varphi_1 \log[(1 - \tau_t(i))Y_t(i)/N_t(i)] - \varphi_2 \log[(1 - \tau_t(i))\bar{W}_t\bar{N}_t] - \varphi_3 \log[(1 - \tau_t(i))W_{t-1}]. \quad (6)$$

The first term,  $\log[(1 - \tau_t(i))W_t(i)]$ , is the utility from consumption that a worker at firm  $i$  obtains under the actual wage offer. The variable  $\tau_t(i)$  in this expression denotes the state-contingent tax rate that the household applies to the revenue of workers at firm  $i$  so as to implement optimal risk sharing across household members. The remaining terms in  $g(W_t(i), \cdot)$  define a weighted sum of utility levels that would obtain for different reference compensation points. In particular, the term  $\log[(1 - \tau_t(i))Y_t(i)/N_t(i)]$  describes the utility obtained if the firm distributed its entire revenue to its workers and thus proxies for the firm's ability to pay. The term  $\log[(1 - \tau_t(i))\bar{W}_t\bar{N}_t]$  measures the worker's outside option; i.e., the utility from the remuneration the worker expects to obtain if she were to refuse the actual wage offer and leave the firm. Finally, the term  $\log[(1 - \tau_t(i))W_{t-1}]$  captures the utility level obtained if the salary were to stay at last period's level.<sup>6</sup>

### 3.3 Firms

Final goods firms produce a composite good  $Y_t$  by combining a continuum of intermediate goods  $Y_t(i)$ ,  $i \in [0, 1]$  with technology

$$Y_t = \left[ \int_0^1 Y_t(i)^{(\theta_p - 1)/\theta_p} dz \right]^{\theta_p/(\theta_p - 1)}, \quad (7)$$

where  $\theta_p > 1$  denotes the elasticity of substitution across intermediate goods. Let  $P_t(i)$  be the price of intermediate good  $i$  and  $P_t$  the price of the final good sold to consumers in a perfectly

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<sup>6</sup>By formulating this last part in terms of  $W_{t-1}$  rather than  $W_{t-1}(i)$ , we implicitly assume that firms do not internalize the effect of workers' past wages into their wage decision. This assumption corresponds to a high-mobility economy where workers change firms frequently.

competitive market. The objective of the final goods firm is to choose  $Y_t(i)$  in order to minimize  $P_t Y_t = \int_0^1 P_t(i) Y_t(i) di$  subject to (7).

Given the differentiated nature of goods  $Y_t(i)$ , intermediate goods firms are monopolistic competitors. As in ACEL (2004), we suppose that intermediate goods firms set prices according to a variant of the partial adjustment process proposed by Calvo (1983). In every period, a fraction  $\kappa_p$  of intermediate goods firms are deprived of the opportunity to reoptimize their price  $P_t(i)$ . They instead update their price according to

$$P_t(i) = \pi_{t-1}^\omega \bar{\pi}^{1-\omega} P_{t-1}(i), \quad (8)$$

where  $\pi_{t-1} \equiv P_{t-1}/P_{t-2}$  denotes last period's aggregate inflation, and  $\bar{\pi}$  denotes average inflation. The probability  $\kappa_p$  is constant through time and independent of firms' individual pricing history. The case  $\omega = 1$  corresponds to ACEL's specification for which there is full indexation of prices to past inflation. For  $\omega = 0$ , non-optimizing firms simply adjust their price according to the average inflation rate.

Given the price  $P_t(i)$ , firm  $i$  is assumed to satisfy the quantity demanded, which it produces with technology

$$Y_t(i) = (A_t E_t(i) N_t(i))^\alpha (U_t(i) K_t(i))^{1-\alpha}, \quad (9)$$

with  $0 < \alpha < 1$ , and where  $A_t$  denotes an exogenous neutral technology shock common to all firms. The growth rate  $\mu_{A,t} \equiv A_t/A_{t-1}$  evolves according to

$$\mu_{A,t} = \mu_A + \rho_{\mu_A} \mu_{A,t-1} + \varepsilon_{\mu_A,t} \quad \text{with } \varepsilon_{\mu_A,t}, \text{ iid } (0, \sigma_{\varepsilon_{\mu_A}}^2). \quad (10)$$

Effort  $E_t(i)$  cannot be observed directly by the firm. However, firms understand that workers provide effort according to the effort condition laid out in (1). Furthermore, the firm knows that households let their members participate in the labor market only if the wage exceeds the total marginal disutility from working. The intermediate goods firm's problem therefore consists of setting prices  $P_t(i)$  and real wages  $W_t(i)$ , hiring labor  $N_t(i)$ , renting capital  $K_t(i)$  and deciding on capital utilization  $u_t(i)$  in order to maximize the present value of current and expected future real profits

$$\mathbf{E}_t \sum_{j=0}^{\infty} \beta^j \Lambda_{t+j} \left[ \frac{P_{t+j}(i)}{P_{t+j}} Y_{t+j}(i) - W_{t+j}(i) N_{t+j}(i) - R_{t+j}^K K_{t+j}(i) \right] \quad (11)$$

subject to the final goods firm's demand, the firm's price adjustment restrictions, the worker's effort condition and the household's participation constraint. Since firms are assumed to pay out their net proceeds in the form of dividends to households at the end of each period, future profits are discounted at  $\beta^j \Lambda_{t+j}$ , with  $\Lambda_{t+j}$  denoting the marginal utility of the household's average consumption level.

### 3.4 Monetary policy

We close the model with the assumption that monetary policy follows an exogenous money growth rule of the form

$$\Delta \log M_t = \mu_{M,t} + \phi_A \mu_{A,t} + \phi_V \frac{1-\alpha}{\alpha} \varepsilon_{Vt}, \quad (12)$$

with

$$\mu_{M,t} = \mu_M + \rho_{\mu_M} \mu_{M,t-1} + \varepsilon_{\mu_M,t} \quad \text{and} \quad \varepsilon_{\mu_M,t} \text{ iid } (0, \sigma_{\varepsilon_{\mu_M}}^2).$$

Here,  $M_t$  denote nominal balances;  $\varepsilon_{\mu_M,t}$  represents the shock to monetary policy; and  $\phi_A, \phi_V$  allow for accommodation of the two real shocks. While the two technology shocks occur at the beginning of the period prior to the private agents' optimal decisions, the monetary shock is assumed to occur at the end of the period after decisions have been taken. This timing assumption ensures that the model is consistent with the identifying restrictions of the empirical monetary shock described in the empirical part of the paper.

Money demand, in turn, is summarized by a reduced-form process, as in King and Watson (1996) or Dotsey and King (2002):

$$\log M_t + \varsigma \log R_t = \log Y_t + \log P_t, \quad (13)$$

where  $R_t$  is the average quarterly gross nominal interest rate on a riskless bond, and  $-\varsigma$  is the interest semi-elasticity of money demand.<sup>7</sup>

Our characterization of monetary policy and money demand is similar to the specification in ACEL (2004), except that their monetary shock process allows for more degrees of freedom and

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<sup>7</sup>The interest semi-elasticity of money demand is defined as  $\partial \log M_t / \partial r_t$  where  $r_t$  is the net nominal interest rate. Since  $\log R_t = \log(1 + r_t) \approx r_t$ ,  $\varsigma = \partial \log M_t / \partial r_t$ .

that they adopt an explicit transaction cost framework where firms need to borrow their wage bill in advance.

### 3.5 Aggregation and general equilibrium

The Calvo price setting mechanism adopted here implies that the distribution of intermediate goods prices and output levels is infinite at each point in time. As Yun (1996) shows, however, assuming a constant-returns-to-scale technology and economy-wide homogenous factor markets implies that all firms face the same real marginal cost independently of their output level. Consequently, the price distribution is fully summarized by the price level uniformly selected by all reoptimizing firms and the average price charged by non-optimizing firms, which is simply last period's aggregate price times the adjustment factor  $\pi_{t-1}^\omega \bar{\pi}^{1-\omega}$  (see equation (8)).

At first sight, our model suffers from further heterogeneity problems because an intermediate firm's wage  $W_t(i)$ , and thus the effort of its employees  $E_t(i)$ , not only depend on aggregate variables but also on the firm-specific labor productivity  $Y_t(i)/N_t(i)$ , which in turn depends on the demand for the firm's product and thus on its price  $P_t(i)$ . The following proposition, however, establishes that a variant of Yun's (1996) aggregation results applies:

**Proposition 1.** *Under the assumptions of constant-returns-to-scale technology and frictionless physical capital markets, intermediate goods firms find it optimal to produce at the same effective capital labor ratio. Hence, they set identical wages and, when allowed to optimize, select identical prices independently of their pricing history.*

*Proof.* See the appendix.<sup>8</sup>

□

Proposition 1 informs us that for all practical purposes our firms are homogenous. Effort, wages and labor productivity are identical across firms; i.e.,  $W_t(i) = \bar{W}_t = W_t$  and  $Y_t(i)/N_t(i) =$

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<sup>8</sup>A recent literature analyzes how the assumption of firm-specific capital affects the price aggregation across firms (see references in ACEL, 2004). The main result coming out of this investigation is that in a log-linear context, as we adopt here, firm-specific capital only changes the definition of the slope parameter of the inflation equation. This result should carry through to our model. Given that our focus is on the implications of alternative wage setting mechanisms, we do not extend our model in this direction.

$Y_t/N_t$ . Furthermore, we have  $\int_0^1 u_t(i)di = u_t$ ,  $\int_0^1 N_t(i)di = \bar{N}_t = N_t$ ,  $\int_0^1 K_t(i)di = K_t$ ,  $Y_t = \left(\frac{\bar{P}_t}{P_t}\right)^{\theta_p} \int_0^1 Y_t(i)di$ , where  $\bar{P}_t = \left[\int_0^1 P_t(i)^{-\theta_p} di\right]^{-1/\theta_p}$  is an auxiliary aggregate price index, and  $D_t \equiv \int_0^1 D_t(i)di = Y_t - W_t N_t - r_t^K K_t$ . Combining this last equation with the representative household's budget constraint, we obtain the familiar national income account equation

$$Y_t = C_t + I_t. \quad (14)$$

The general equilibrium dynamics of our model is thus described by the system of equations made up of the effort condition (1), the optimality conditions for the household's problem (2) with respect to  $C_t$ ,  $I_t$ ,  $K_{t+1}$  and  $N_t$ , the aggregate version of the production function (9), the optimality conditions for the intermediate goods firms' problem (11) with respect to  $P_t^*$  (the homogenous optimal price in case of adjustment),  $N_t$ ,  $W_t$ ,  $K_t$ ,  $U_t$ , the definition of the aggregate price index  $P_t = \left[\int_0^1 P_t(i)^{1-\theta_p} di\right]^{1/(1-\theta_p)}$ , the money growth rule (12), money demand (13) and the national income account equation (14).

The quantitative results discussed in Section 5 come from log-linearizing the system of equations just described around the non-stochastic steady states of the different variables after normalizing and solving for the rational expectations equilibrium with the numerical algorithm developed by King and Watson (1998).<sup>9</sup>

## 4 Model implications: a stylized case

Before moving to the quantitative evaluation of the model, we analyze a stylized version that abstracts from physical capital. We first study the labor market properties of our economy. We then detail the business cycle implications of rent-sharing and wage entitlement.

### 4.1 Labor market properties

Without physical capital, the intermediate firm's production reduces to  $Y_t = A_t(E_t N_t)^\alpha$ , (we omit firm indices  $i$  to economize on notation). The worker's gift to the firm is

$$d(E_t, \cdot) = \left(\frac{A_t^\alpha N_t^{\alpha-1}}{X_t}\right)^v (E_t^\alpha - (E^n)^\alpha).$$

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<sup>9</sup>See the appendix for details. We thank Bob King for providing us with the solution code.

For  $v = 0$ , this expression corresponds to definition (4); for  $v = 1$ , to (5).<sup>10</sup> With this definition and the (unchanged) definition of the firm's gift (6), the effort condition (1) becomes

$$(E_t^{2-\alpha} - E^n E_t^{1-\alpha}) = \alpha\lambda \left( \frac{A_t^\alpha N_t^{\alpha-1}}{X_t} \right)^v \quad (15)$$

$$* \left[ \begin{array}{l} \log W_t - \varphi_1 \log \left( \frac{Y_t}{N_t} \right) - \varphi_2 \log (\bar{W}_t \bar{N}_t) - \varphi_3 \log W_{t-1} \\ + (1 - \varphi_1 - \varphi_2 - \varphi_3) \log(1 - \tau_t) \end{array} \right],$$

where we isolated the state-contingent tax part for convenience.

The intermediate goods firms' problem in this stylized environment reduces to selecting their price when possible, and deciding on employment and wages so as to minimize labor costs  $W_t N_t$  while satisfying the demand for their product  $Y_t \leq (A_t E_t N_t)^\alpha$  given the workers' effort condition (15).<sup>11</sup> The necessary first-order conditions are

$$W_t = \alpha \Psi_t \frac{Y_t}{N_t} \left[ 1 + \frac{\partial E_t}{\partial N_t} \frac{N_t}{E_t} \right] \quad (16)$$

$$N_t = \alpha \Psi_t \frac{Y_t}{E_t} \frac{\partial E_t}{\partial W_t}, \quad (17)$$

where  $\Psi_t$  denotes real marginal cost, or the inverse of the markup charged by the monopolistic firm. Equation (16) describes labor demand. The term  $\partial E_t / \partial N_t * N_t / E_t > 0$  takes into account the fact that higher employment decreases labor productivity, thereby increasing the firm's gift and thus effort (*ceteris paribus*). At a given wage, this leads firms to overhire in comparison to their optimal hiring level in a standard case where this effect is absent. Equation (17) can be combined with (16) to yield

$$1 = \frac{\partial E_t}{\partial W_t} \frac{W_t}{E_t} - \frac{\partial E_t}{\partial N_t} \frac{N_t}{E_t} \quad (18)$$

Danthine and Kurmann (2007) refer to this equation as the *Modified Solow Condition* (MSC). For  $\partial E_t / \partial N_t * N_t / E_t = 0$ , the MSC would reduce to Solow's (1979) original condition, which says that at the optimal wage rate, the marginal cost of an effective unit of work equals its average cost. But for  $\partial E_t / \partial N_t * N_t / E_t > 0$ , Solow's condition no longer applies because a marginal wage increase has an additional positive effect on labor productivity, which in turn decreases the firm's gift and thus effort.

<sup>10</sup>We thus posit that  $f(E_t) = E_t^\alpha$  in (4). All the results below carry over for more general formulations of  $f(E_t)$ .

<sup>11</sup>In principle firms also need to satisfy the household's participation constraint. As the appendix details, however, this constraint is always satisfied in our model.



Using the implicit function theorem, the MSC can be made explicit as (see appendix for the derivation)

$$E_t^{\alpha v} [(2 - \alpha)E_t^{2-\alpha} - (1 - \alpha)E^n E_t^{1-\alpha}] = \alpha\lambda \left(\frac{Y_t/N_t}{X_t}\right)^v [1 + (1 - \alpha)vg(W_t, \cdot) - \varphi_1]. \quad (19)$$

This expression describes the effort level optimally induced by the firm through its wage policy. It leads to the following proposition:

**Proposition 2.** (i) For  $v = 0$ , the firm's optimal wage policy is such that effort is constant; (ii) for  $v > 0$ , the firm's optimal wage policy is such that effort is variable.

*Proof.* For  $v = 0$ , (19) collapses to  $[(2 - \alpha)E_t^{2-\alpha} - (1 - \alpha)E^n E_t^{1-\alpha}] = \alpha\lambda [1 - \varphi_1]$ . The only potentially time-varying element in that expression is  $E_t$ , which means that  $E_t = E$  at all times.  $\square$

Applying the implicit function theorem to (16) and combining the resulting equation with the above MSC, we obtain an explicit expression for labor demand

$$W_t = \alpha\Psi_t \frac{Y_t}{N_t} \left[ \frac{1}{1 + (1 - \alpha)vg(W_t, \cdot) - (1 - \alpha)\varphi_1} \right]. \quad (20)$$

Note that for the constant effort case ( $v = 0$ ), this equation is equivalent to a standard labor demand up to a constant  $1/(1 - (1 - \alpha)\varphi_1) > 1$ . The constant subsumes the overhiring tendency discussed above.

We can furthermore combine the MSC (19) with the effort condition (15) to obtain an explicit expression for the firm's optimal wage

$$\begin{aligned} \log W_t &= \frac{E_t^{1-\alpha(1-v)}(E_t - E^n)}{\alpha\lambda \left(\frac{Y_t/N_t}{X_t}\right)^v} + \varphi_1 \log \left(\frac{Y_t}{N_t}\right) + \varphi_2 \log(\bar{W}_t \bar{N}_t) + \varphi_3 \log W_{t-1} \\ &\quad - (1 - \varphi_1 - \varphi_2 - \varphi_3) \log(1 - \tau_t). \end{aligned} \quad (21)$$

This equation replaces the labor supply schedule of standard competitive models of the labor market. For  $\varphi_1 > 0$ , the optimal wage increases with the firm's revenue per worker, a notion that we associate with *rent-sharing*. For  $\varphi_2 > 0$ , the optimal wage increases with the aggregate wage and employment level, two measures that capture *external labor market conditions*. For  $\varphi_3 > 0$ , the optimal wage depends positively on the individual's past real wage, a dependence that can be linked to the notion of *wage entitlement*.

The wage setting equation (21) implies important parameter restrictions for an environment with stochastic growth such as ours. In particular, real wages and labor productivity both increase over time whereas effort and the labor share  $W_t N_t / Y_t$  are stationary by definition. The following proposition ensures that these conditions are met:

**Proposition 3.** *Stationarity of effort and the labor share  $W_t N_t / Y_t$  along the balanced growth path requires  $\varphi_1 + \varphi_2 + \varphi_3 = 1$ .*

*Proof.* See the appendix.<sup>12</sup> □

A final property of the model obtains when we normalize the various labor market variables with their respective growth rates and combine the steady state version of the labor demand and wage setting equations. The following proposition obtains:

**Proposition 4.** *The reciprocity parameter  $\lambda$  is strictly positive for all admissible values of the other parameters.*

*Proof.* See the appendix. □

This result is interesting because it says that independently of the parametrization of the gifts of the worker and the firm, the equilibrium of our model is always consistent with positive reciprocity,  $\lambda > 0$ .<sup>13</sup> Note that all the stated propositions remain valid for the full model of the previous section, that is, in the presence of physical capital, variable utilization and investment adjustment cost.

## 4.2 Business cycle implications of rent-sharing and wage entitlement

In order to get a sense of the role of rent-sharing and wage entitlement considerations over the business cycle, we express the various equations of our stylized model in loglinear terms and focus on the constant effort case ( $v = 0$ ). Ignoring constants, aggregate production, labor demand and

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<sup>12</sup>The proposition also implies that state-dependent household taxes drop out of all the equations presented above.

<sup>13</sup>Since  $\lambda$  does not appear in any of the loglinearized equations used in the estimation of the model, the proposition also implies that we cannot test whether  $\lambda$  is significantly different from zero.

optimal wage setting become, respectively,

$$\begin{aligned} y_t &= a_t + \alpha n_t \\ w_t &= \psi_t + y_t - n \\ (1 - \varphi_2)w_t &= \varphi_1(y_t - n_t) + \varphi_2 n_t + \varphi_3 w_{t-1}. \end{aligned}$$

Lower-case variables denote logarithms from now on. Imposing the balanced growth restriction from Proposition 3, we obtain, after some rearrangement, the following equations for real wages and the real marginal cost

$$w_t = \frac{\varphi_1}{\varphi_1 + \varphi_3} a_t + \frac{\varphi_2 - (1 - \alpha)\varphi_1}{\varphi_1 + \varphi_3} n_t + \frac{\varphi_3}{\varphi_1 + \varphi_3} w_{t-1} \quad (22)$$

$$\psi_t = -\frac{\varphi_3}{\varphi_1 + \varphi_3} a_t + \frac{\varphi_2 + (1 - \alpha)\varphi_3}{\varphi_1 + \varphi_3} n_t + \frac{\varphi_3}{\varphi_1 + \varphi_3} [a_{t-1} + \psi_{t-1} - (1 - \alpha)n_{t-1}]. \quad (23)$$

Despite their partial equilibrium character ( $w_t$  and  $\psi_t$  both depend on  $n_t$  and past endogenous variables), these two equations reveal interesting properties of our model. In particular, all right-hand-side terms in the two equations are divided by  $\varphi_1 + \varphi_3$ . Hence,  $\varphi_1$ ,  $\varphi_2$  and  $\varphi_3$  do not matter individually, but only in relative terms, for the model dynamics.<sup>14</sup> This implies that the reciprocity block of our model adds only two free parameters.

Let us analyze the import of rent-sharing considerations. Equation (22) tells us that the more workers' effort depends on the firm's ability to pay ( $\varphi_1 > 0$ ), the stronger is the direct impact of technology shocks  $a_t$  on the optimal wage, and the smaller is the wage response to fluctuations in hours worked  $n_t$ . Rent-sharing thus has an ambiguous general equilibrium effect on the response of wages to technology shocks. If, *ceteris paribus*, the equilibrium response of hours worked to technology shocks is large, rent-sharing reduces the wage response. If, instead, hours worked react little or even inversely to technology shocks, rent-sharing increases the wage response to these shocks. Figure 1a illustrates these effects by contrasting a labor market with rent sharing (solid wage setting curve) with a labor market without rent sharing (dotted wage setting curve). Suppose that before the technology shock, both economies are in the same equilibrium (point E). If, as depicted, the labor demand curve shifts out relatively little in response to a technology change  $\Delta a_t > 0$ , then the real wage adjusts more in the rent-sharing economy (point E' vs. point E'').

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<sup>14</sup>To see this, divide both numerator and denominator of each right-hand-side term by  $\varphi_3$ . The only terms that remain are the fractions  $\varphi_1/\varphi_3$  and  $\varphi_2/\varphi_3$ .

By contrast, rent-sharing unambiguously dampens the reaction of wages to non-technology shocks because, in this case,  $a_t$  does not change. In fact, if rent-sharing is sufficiently important relative to external labor market considerations (i.e., if  $\varphi_2 - (1 - \alpha)\varphi_1 < 0$ ), then wages and employment move in opposite directions. Figure 1b depicts such a situation for a shock that only shifts out the labor demand.

The impact of rent-sharing considerations on the real marginal cost in response to a neutral technology shock are equally ambiguous. The stronger the rent-sharing forces, the smaller the response of real marginal cost to technology shocks and the changes in hours worked. But because technology  $a_t$  and employment have opposite effects on real marginal cost, the overall response depends on the general equilibrium elasticity of employment to technology shocks. Rent-sharing thus also has an ambiguous effect on inflation dynamics. To understand this, note that our pricing restrictions imply a loglinear equation of the form (again ignoring constants)

$$(1 - \beta\omega)\pi_t = \beta E_t \pi_{t+1} + \omega\pi_{t-1} + \gamma\psi_t,$$

with  $\gamma \equiv (1 - \kappa_p)(1 - \beta\kappa_p)/\kappa_p$ . Following the literature, we refer to this equation as the New Keynesian Phillips curve (NKPC). Let  $\theta_1 \leq 1$  ( $\theta_2 \geq 1$ ) denote the stable (unstable) root of this equation, then the NKPC can be expressed in present-value form as

$$\pi_t = \theta_1 \pi_{t-1} + \left(\frac{\gamma}{\beta\theta_2}\right) \sum_{j=0}^{\infty} \left(\frac{1}{\theta_2}\right)^j E_t \psi_{t+j}.$$

The smaller the response of current and future expected real marginal costs to fluctuations in technology and other variables, the smoother the dynamics of inflation.

Let us now consider the effects of external employment conditions. Equations (22) and (23) tell us that the more workers take into account aggregate employment conditions ( $\varphi_2 > 0$ ), the more sensitive real wages and real marginal cost become to movements in employment. As in a Walrasian labor market with an inelastic labor supply, shocks have smaller quantity and larger price effects, that is, they translate into larger changes in real wages and inflation.

Finally, consider the effects of wage entitlement. Equation (22) indicates that the more past wages influence worker's effort and thus the firm's wage decision ( $\varphi_3 > 0$ ), the smaller are the effects of movements in technology and employment and the larger is the persistence of wage movements. According to equation (23), wage entitlement also unambiguously increases the contemporaneous reaction of real marginal cost to technology and employment fluctuations.

In sum, the stylized case illustrates that rent-sharing and wage entitlement have intricate implications for wages, employment and inflation dynamics. It appears, in particular, that, if these considerations are relevant, real wages and inflation may display very different reactions depending on the nature of the shocks.

## 5 Empirical evaluation

We now move beyond partial equilibrium and proceed with a quantitative evaluation of the full DSGE model described in Section 3. In a first step, we estimate the model using the impulse response estimator applied by Christiano, Eichenbaum and Evans (2005) and more recently ACEL (2004). This estimation allows us to quantify the empirical relevance of the various elements of our model. In a second step, we assess the relative contribution of rent-sharing, wage entitlement and external employment conditions to the empirical performance of the model.

### 5.1 Estimation approach

The estimation strategy of Christiano, Eichenbaum and Evans (2005) and more recently ACEL (2004) consists of minimizing the distance between a set of impulse responses functions (IRFs) implied by the model and their empirical counterparts. We adopt this limited information estimator rather than a full-information likelihood-based estimator for two reasons. First, our focus is on the dynamics of a small set of variables in response to specific shocks. Second, for the sake of comparability, we strive to remain as close as possible to recent studies analyzing the empirical performance of New Keynesian DSGE models with nominal wage rigidities. In particular, we employ exactly the same VAR specification, shock identification and dataset as ACEL (2004).<sup>15</sup>

Since ACEL (2004) provide a detailed description of their estimator and the data, we restrict ourselves to a brief summary. ACEL's VAR is based on a 10-dimensional data vector containing stationary combinations of different macro aggregates.<sup>16</sup> ACEL then identify a monetary policy

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<sup>15</sup>We thank Larry Christiano for generously making the entire ACEL Matlab code, data and appendix available on his website.

<sup>16</sup>The variables used in the VAR are: (1) the change in the relative price of investment; (2) labor productivity growth; (3) GDP deflator inflation; (4) capacity utilization; (5) total hours; (6) labor income share; (7) the

shock, a neutral technology shock and an investment-specific technology shock based on the following restrictions developed in previous work by Shapiro and Watson (1988), Blanchard and Quah (1989), Christiano, Eichenbaum and Evans (1998) and Fisher (2006):

- The monetary policy shock has no contemporaneous effect on any of the macro aggregates but the federal funds rate, money growth and velocity.
- The neutral technology shock and the investment-specific technology shock are the only shocks that may have a permanent effect on labor productivity.
- The investment-specific technology shock is the only disturbance that may have a permanent effect on the relative price of investment.

Since the timing and statistical properties of the shock processes in our model satisfy all these restrictions by construction, we can directly compare the IRFs of our model with the empirical VAR responses.

Denote by  $\hat{\Psi}$  the vector of IRFs over a time period of 20 quarters for each of the three shocks obtained from the identified VAR. Likewise, denote by  $\Psi(\zeta)$  the same vector of IRFs implied by our model, where  $\zeta$  contains all the structural parameters of the model. Then, ACEL's estimator of some parameter subset  $\zeta^* \subseteq \zeta$  is the solution to

$$\hat{\zeta}^* = \arg \min_{\zeta^*} \left[ \hat{\Psi} - \Psi(\zeta) \right]' \Omega^{-1} \left[ \hat{\Psi} - \Psi(\zeta) \right],$$

where  $\Omega$  is a diagonal matrix with the sample variances of  $\hat{\Psi}$  along the diagonal.<sup>17</sup>

## 5.2 Structural VAR evidence

Following ACEL, we estimate the VAR on quarterly data for the period 1959:2–2001:4 with the number of lags set to 4. Figure 2 displays the IRFs of the four key variables, output, average consumption-output ratio; (8) the investment-output ratio; (9) the federal funds rate; (10) the velocity of MZM transaction balances. See ACEL (2004) for a detailed description.

<sup>17</sup>Jorda and Kozicki (2005) extend this estimation method with an efficient weighting matrix that allows for statistical testing. Hall, Inoue, Nason and Rossi (2007) apply a formal information criteria for the selection of the impulse responses to be matched. We refrain from applying these econometric extensions so as to remain comparable to ACEL (2004).

hours, real wages, inflation and nominal wage growth, to a one standard deviation change in each of the three identified shocks. The thin solid lines are the point estimates of the SVAR, with the surrounding grey areas representing the 95% confidence intervals.<sup>18</sup> The circled lines pertain to the IRFs of the estimated model and are discussed afterwards.

As ACEL (2004) document, the three shocks together account for about half of all cyclical fluctuations of output. For the monetary policy shock, we identify the following stylized facts: (i) both output and hours respond with a significant hump that peaks about 4 quarters after the shock; (ii) real wages react slightly inversely, if at all; (iii) inflation and nominal wage growth react insignificantly and with a prolonged hump. These reactions to the monetary policy shock are largely consistent with results reported in other studies. Employing the same identification approach but different VAR specifications and data samples, Christiano, Eichenbaum and Evans (1998, 2003), Edge, Laubach and Williams (2003) and Alves (2004) all report that output, hours and inflation display a hump-shaped response, with inflation displaying substantially more persistence than the real variables.<sup>19</sup> Real wages, by contrast, hardly move. The insignificant procyclical or even countercyclical response of real wages is confirmed by other structural VAR studies on the effects of non-permanent shocks (that do not necessarily need to be monetary shocks).<sup>20</sup>

For the neutral technology shock, the following observation stand out: (i) output jumps on impact and then gradually increases to its new permanent level; (ii) hours react little on impact before displaying a hump-shaped response back to their initial value; (iii) real wages hardly react on impact and converge only very slowly to their new permanent level; (iv) inflation and nominal wage growth both drop sharply on impact before slowly returning towards their initial rate. While the reaction of hours to the technology shock is a topic of much controversy, the sharp drop in inflation

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<sup>18</sup>The confidence intervals were computed by bootstrap simulation. See ACEL (2004) for details. The appendix contains the IRFs for other prominent macro aggregates that can be computed from the VAR.

<sup>19</sup>Romer and Romer (2004) employ a different identification scheme based on internal Fed documents. Interestingly, they find that the response of inflation to a monetary shock is even more delayed but that the humpshape is significant.

<sup>20</sup>Studies documenting a small inverse response of real wages to a monetary shock include Gamber and Joutz (1997) and Fleischman (1999). Studies reporting a small positive response are Gamber and Joutz (1993) and Balmaseda et al. (2000). The latter study includes evidence for 16 OECD countries with real wages reacting inversely in all countries under consideration but the U.S.

and the sluggish reaction of real wages are a robust feature of many other VAR studies.<sup>21,22</sup> The marked fall in nominal wage growth, by contrast, is barely discussed in the literature. To some extent, this fall comes mechanically as a result of the sluggish real wage response and the sharp drop of inflation on impact. What is remarkable, however, is that this fall in nominal wage growth is also highly significant.<sup>23</sup>

For the investment-specific technology shock finally, both output and hours increase on impact but the confidence intervals are close to zero. Inflation reacts positively but insignificantly and real wages again move sluggishly to their new permanent level.

In sum, the striking observation from ACEL's VAR is the sluggish response of real wages, irrespective of the type of shock, and the very distinct reaction of inflation and nominal wage growth with respect to monetary vs. neutral technology shocks.

### 5.3 Estimation results

We partition the parameters of our model into three groups. The first group consists of model parameters that we calibrate such as to match salient long-run characteristics of the data. Specifically, we follow ACEL (2004) and set  $\alpha = 0.67$ ,  $\beta = 0.9971$ ,  $\delta = 0.025$ ,  $\theta_p = 10$ ,  $\mu_V = 1.0042$ ,

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<sup>21</sup>Specifically, if hours enter the VAR in levels, then the variable reacts positively but often insignificantly on impact (e.g. Edge, Laubach and Williams, 2003; or Christiano, Eichenbaum and Vigfusson, 2004a, 2004b). If hours enter the VAR in first differences, instead, then the variable usually drops on impact (although in many instances insignificantly) and becomes positive only after several periods. Despite these differences, a robust feature of all these studies is that the response of hours on impact is modest relative to the response of output (e.g. Galí, 1999; Francis and Ramey, 2005; or Alves, 2004). Shapiro and Watson (1988) and Blanchard and Quah (1989) reported similar results 10 years earlier but it apparently went unnoticed.

<sup>22</sup>See for example Gamber and Joutz (1993, 1997) Fleischman (1999), Balmaseda et al. (2000), Edge et al. (2003), Francis and Ramey (2005), Alves (2004), Liu and Phaneuf (2006) or Dupor, Han and Tsai (2007). Interestingly, much of the VAR evidence on the effects of neutral technology shocks is corroborated by Basu, Fernald and Kimball (2004) who use a purified Solow residual based on industry data to identify technology shocks instead of long-run VAR restrictions. They find that a positive technology shock leads to a modest rise of real wages on impact and a gradual adjustment thereafter while prices decline sharply on impact and remain permanently below thereafter. Total hours decline modestly on impact before returning back to their initial level.

<sup>23</sup>The significant drop in nominal wage growth contrasts with Liu and Phaneuf (2006) who only find a relatively modest and insignificant drop in nominal wage growth. However, their results are based on a small 4-variable VAR, which is likely to suffer from omitted variable bias.



$\mu_A = 1.00013$  and  $\mu_M = 1.017$ . These values imply, respectively, a capital share of roughly one third, an average annualized real interest rate of 3 percent, an annual steady state depreciation rate of 10 percent, an average annual decrease in the price of investment relative to the GDP deflator of 1.68 percent, a steady state growth rate of real GDP of  $\mu_A \mu_V^{\frac{1-\alpha}{\alpha}} = 1.045$  and an average growth rate of money of 1.017.

The second group consists of the model parameters  $\varphi_2, \varphi_3, \gamma, \omega, \xi, b, \chi, \varsigma$  that we estimate. As discussed in the previous section, the model dynamics only depend on the ratios  $\varphi_1/\varphi_3$  and  $\varphi_2/\varphi_3$  and balanced growth imposes  $1 = \varphi_1 + \varphi_2 + \varphi_3$ . We thus estimate only  $\varphi_2$  and  $\varphi_3$ . For pricing, there is a direct correspondence between the NKPC slope parameter  $\gamma$  and the probability of price reoptimization  $1 - \kappa_p$ . We thus estimate  $\gamma$  directly. For capital utilization, the only parameter that matter is the steady state elasticity of  $\delta'$  with respect to  $U$ ; i.e.  $\xi = \partial \delta''(U)U/\delta'(U)$  (see the appendix). For  $\xi = 0$ , capital utilization becomes infinitely variable whereas for  $\xi \rightarrow \infty$ , capital utilization is constant. Finally, we refrain from estimating the parameter  $v$  and set it to  $v = 0$ ; this is the case where workers do not take into account the productive situation of the firm when evaluating their gift. As it turns out,  $v = 0$  is a global optimum. For space reasons, we refer the reader to the appendix for the alternative case where  $v = 1$ .

The third group of parameters pertains to the exogenous shock processes. These parameters,  $\rho_{\mu_A}, \sigma_{\mu_A}, \rho_{\mu_V}, \sigma_{\mu_V}, \sigma_{\mu_A}, \phi_{\mu_A}, \phi_{\mu_V}$ , are also estimated.<sup>24</sup>

The first two columns of Table 1 (attached at the end of the paper) display the point estimates and standard errors for the second and third group of parameters. The small, yet significant estimate of  $\varphi_2$  indicates that external employment conditions play only a minor role for wage setting. The coefficient on wage-entitlement, by contrast, is more than eight times larger (i.e.  $\hat{\varphi}_3/\hat{\varphi}_2 = 0.621/0.072 = 8.6$ ) and relatively precisely estimated. Also, wage entitlement is estimated to be about twice as important as rent-sharing, (i.e.  $\hat{\varphi}_3/\hat{\varphi}_1 = \hat{\varphi}_3/(1 - \hat{\varphi}_2 - \hat{\varphi}_3) = 0.621/(1 - 0.072 - 0.621) = 2.03$ ).

The estimated relative weights of wage entitlement and rent sharing in the worker's reference accords with the finding of survey studies on reciprocity. As Bewley (1999) and others report,

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<sup>24</sup>Note that we do not estimate the persistence parameter on money growth,  $\rho_{\mu_M}$ . In all estimations, this parameter was consistently estimated at its lower bound zero. We thus simply set  $\rho_{\mu_M} = 0$  in order to reduce estimation uncertainty.

external labor market conditions are rarely important for workers because they often know too little about them. Past wages, however, are perfectly observed and unsurprisingly they appear to take on the role of a benchmark against which workers compare their current remuneration. Studies by Kahneman, Knetsch and Thaler (1986) or Fehr, Gächter and Kirchsteiger (1997), on the other hand, emphasize that the firm’s ability to pay and the extent to which the rent is being shared are also important dimensions along which workers assess a wage offer.<sup>25</sup> Our estimates for  $\varphi_1/\varphi_3$  and  $\varphi_2/\varphi_3$  can be viewed as the macroeconomic counterpart of the available micro evidence, notably comforting the small purported role of external employment conditions.

The estimates of the other structural parameters of the model are similar to those reported in ACEL (2004). We therefore refer to their paper for a general discussion. Three parameter estimates deserve special attention, however. First, the coefficient on the real marginal cost in the NKPC is estimated at  $\hat{\gamma} = 0.040$ . This implies an average price duration of about 5.5 quarters under the frictionless capital markets assumption entertained here. As ACEL (2004) show, however, the same slope estimate implies a price duration of only 1.5 quarters if capital is assumed to be firm-specific. Second, the price indexation estimate of  $\hat{\omega}_p = 1$  is at its upper bound and implies that non-reoptimizing firms update their prices with lagged inflation. The NKPC therefore implies that inflation depends equally on expected future and lagged inflation.<sup>26</sup> This feature turns out to be important to match the dynamic response of inflation to a monetary shock and we return to the effects of this parameter further below. Third, the interest semi-elasticity of money  $-\hat{\zeta} = 2.603$  is relatively close to the corresponding estimate of  $4 * 0.80 = 3.2$  reported in ACEL notwithstanding the fact that their money demand block is more complex than ours.<sup>27</sup>

Considering finally the third group of parameters, we first remark that the neutral technology growth is estimated to be very persistent but that the innovation standard deviation is less than half that obtained by ACEL (2004). The persistence and volatility of the investment-specific technology shock are very similar to the estimates reported in ACEL. In line with ACEL, we also find that the volatility of monetary innovations is about one-third. Our estimates for the parameters defining the

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<sup>25</sup>See Bewley (2002) or the appendix of Danthine and Kurmann (2007) for a discussion of this evidence.

<sup>26</sup>We do not report standard errors here as they would not be very meaningful since this estimate is at its upper bound.

<sup>27</sup>ACEL (2004) define the interest semi-elasticity as  $\frac{100 * \partial \log M_t}{400 * \partial R_t}$ . Hence, our estimate corresponds to four times their estimate.

degree of monetary accommodation are quite different, however. While ACEL set accommodation of both technology shocks equal to unity, we obtain an estimate of  $\hat{\phi}_{\mu_A} = 0.316$  for the neutral technology shock, which is close to what Liu and Phaneuf (2006) find from a reduced-form estimation.<sup>28</sup> For the investment-specific technology shock, our estimate of  $\hat{\phi}_{\mu_V} = 2.32$  implies a much stronger degree of accommodation. We assess the implications of these differences later on when we compare the empirical performance of our model with that of a nominal wage contract model closely resembling the one specified in ACEL (2004).

## 5.4 Inspecting the model properties

### 5.4.1 Responses to different shocks

We now evaluate the performance of our model by comparing the model-induced and the empirical VAR responses of output, hours, real wages, inflation and nominal wage growth. Reconsider Figure 2, remembering that the solid lines represent the VAR responses with the grey-shaded area defining the 95% confidence intervals, and that the dotted lines trace the IRFs of the estimated model. Overall the fit is surprisingly good. In particular, the model succeeds in generating the smooth real wage responses, the hump-shaped response of output and hours as well as the small and delayed response of inflation and nominal wage growth with respect to the monetary policy and the investment-specific shocks.

The estimated model fares less well with respect to the neutral technology shock. While the model is again successful in generating the sluggish real wage reaction, the responses of both output and hours are too small on impact (although they converge to their empirical long-run levels). This shortcoming is due to a combination of a small (estimated) standard deviation of the neutral technology shock innovation together with a small accommodation coefficient in the money growth rule. Note also that there is considerable uncertainty as to the exact dynamics of output and

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<sup>28</sup>We also examine the robustness of our results to an interest rate rule of the form

$$\log R_t = \log R + \gamma \log R_{t-1} + (1 - \gamma)[\theta_\pi \log \pi_t + \theta_y(\log Y_t - \log \bar{Y}_t)] + \varepsilon_{Rt}$$

where  $\bar{Y}$  is the potential output level that would obtain in a world without nominal frictions. In this case, money demand is irrelevant for the dynamics of the model. Interestingly, our results are robust to this change. See the appendix for details.

hours conditional on a neutral technology shock (see the discussion above). Hence, in a differently specified VAR, our model might be right on target with respect to these two variables.

A more important shortfall of the estimated model is the small response on impact of inflation and nominal wage growth in response to the neutral technology shock. According to the VAR, both these variables experience a large and significant drop over the first few periods after the neutral technology shock. The major reason for this failure is the estimated inflation indexation coefficient ( $\hat{\omega}_p = 1$ ) that makes inflation dynamics depend on past inflation. This estimate helps generate the sluggish, hump-shaped response of inflation to a monetary policy shock but at the same time prevents inflation from falling sharply on impact. Given the sluggish adjustment of real wages, this means in turn that nominal wage growth does not react much. By the same token, if inflation dropped markedly, nominal wage growth would also fall, in line with the evidence. In Section 6, we revisit the dynamics of prices and wages and show that setting  $\omega_p = 0$  resolves much of the problem.

#### **5.4.2 The role of external employment conditions, rent-sharing and wage entitlement**

To illustrate the role of external employment conditions for wage setting, we set  $\varphi_2 = 0.9$  and, consequently,  $\varphi_1 = \varphi_3 = 0.05$  in order to respect the balanced growth restriction of Proposition 3 (with all the other parameters kept unchanged). This corresponds to a situation where the importance of external employment conditions relative to wage entitlement is increased by a factor of about 150. Figure 3 displays the results.

Real wages, inflation and nominal wage growth become considerably more sensitive to monetary policy and investment-specific technology shocks. In fact, the responses of inflation and nominal wage growth remain hump-shaped only because of the other real rigidities and the inflation indexing feature of the model. Furthermore, the model loses a substantial part of its internal amplification.

The sensitivity of real wages and inflation when external labor market conditions play a more prominent role is consistent with the partial equilibrium analysis of the previous section. Faced with a monetary or an investment-specific shock, firms increase labor input. This pushes up the reference compensation level and firms find it optimal to increase wages and consequently prices. As Danthine and Donaldson (1990) and Danthine and Kurmann (2007) point out, it is the strong dependence on outside labor conditions in traditional efficiency wage models such as Salop's (1979) labor turnover

theory, Shapiro and Stiglitz' (1984) shirking model but also Akerlof's (1982) original formulation of the fair wage hypothesis that explains why these models fail to generate sluggish real wage adjustment and internal amplification. Our results confirm this conclusion and suggest, in addition, that models emphasizing firm-internal (or local labor market) conditions rather than aggregate labor conditions have the potential to replicate the dynamics of important macro aggregates.

The second sensitivity check is with respect to the relative importance of rent-sharing and wage entitlement. In particular, we set  $\varphi_1 = 0.01$  and  $\varphi_3 = 1 - 0.01 - \hat{\varphi}_2 = 0.918$ . This corresponds to a situation with wage entitlement only. Then, we set  $\varphi_1 = 0.918$  and  $\varphi_3 = 1 - 0.918 - \hat{\varphi}_2 = 0.01$ , which corresponds to a situation with rent-sharing only. In both cases we keep all other parameters unchanged. Figure 4 displays the results.

In line with the partial equilibrium analysis of Section 4, more weight on rent-sharing dampens, or even changes the direction of the response of real wages to monetary policy and investment-specific shocks. As a result, marginal cost reacts to a lesser extent, which in turn generates a smoother, dampened response of inflation. More weight on wage entitlement has the opposite effect on wages and inflation with respect to monetary and investment-specific technology shocks. With respect to neutral technology shocks, more weight on wage entitlement makes real wages less reactive while generating a larger drop in inflation and thus nominal wage growth (the reaction on impact of the two variables remains small because of inflation indexing). These results explain why the estimation attributes such an important role to wage entitlement but why, at the same time, rent-sharing remains a crucial ingredient for the model to match the dynamics of real wages and inflation.

## 6 Nominal wage rigidity

To put in perspective the performance of our model, we compare it with the nominal wage contracts model proposed by Erceg, Henderson and Levin (2000) and applied more recently by ACEL (2004), Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2004, 2007), among others. First, we briefly describe the nominal wage contracts model and discuss its empirical fit relative to our model. Then we analyze the conditions under which the reciprocity model, on the one hand, the wage contracts model, on the other, are capable of generating the observed dynamics of inflation

and nominal wage growth in response to a neutral technology shock.

## 6.1 Nominal wage contracts

The assumptions underlying the nominal wage contracts model are identical to those in ACEL (2004). We therefore limit the description of the model to a strict minimum and refer the reader to these authors for details. There is a continuum of households  $h \in [0, 1]$  with preferences given by

$$E_t \sum_{j=0}^{\infty} \beta^j \left[ \log(C_{t+j} - b\bar{C}_{t+j-1}) - \phi \frac{N_{h,t+j}^\eta}{\eta} \right], \quad (24)$$

where  $C_{t+j}$  denotes the household's consumption and  $N_{h,t+j}$  hours worked.<sup>29</sup> Working hours supplied by households (indexed  $h$ ) constitute a differentiated input that firms combine into a composite labor factor  $N_t$  according to

$$N_t = \left[ \int_0^1 N_{h,t}^{\frac{1}{\theta_w}} dh \right]^{\theta_w}, \quad (25)$$

where  $1 \leq \theta_w < \infty$  denotes the elasticity of substitution across  $N_{h,t+j}$ . Firms take the nominal wage of each household's labor as given and adjust demand so as to minimize the cost of labor. The resulting demand for household  $h$ 's hours is given by

$$N_{h,t} = \left( \frac{W_{h,t}^n}{W_t^n} \right)^{\frac{\theta_w}{1-\theta_w}} N_t, \quad (26)$$

where  $W_{h,t}^n$  is the nominal wage charged by household  $h$  and  $W_t^n$  is the aggregate nominal wage of the composite labor factor. The specification of the nominal wage contract follows Calvo (1983) and is similar to the adjustment mechanism for intermediate goods firms' prices spelled out in Section 3. In each period, a given household may reoptimize its nominal wage with probability  $\kappa_w$ . This probability is constant over the business cycle and independent of the household's wage setting history. With probability  $1 - \kappa_w$ , households cannot reoptimize and instead adjust their nominal wage according to

$$W_{h,t}^n = \pi_{t-1}^{\omega_w} \pi^{1-\omega_w} \mu_C W_{h,t-1}^n,$$

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<sup>29</sup>Erceg, Henderson and Levin (2000) and Woodford (1996) show that consumption levels and asset holdings across households are identical provided there exists a complete set of state-contingent securities. We follow ACEL (2004) and adopt this hypothesis thus bypassing heterogeneity issues.

where  $\mu_C \equiv \mu_A \mu_V^{(1-\alpha)/\alpha}$  is the steady state growth rate of consumption. The household's optimization problem thus consists of maximizing (24) subject to its budget constraint (which is identical to the corresponding constraint in Section 3), the firm's labor demand (26) and the nominal wage adjustment constraint described above.

The implicit assumption behind this nominal wage contracting scheme is that households supply any quantity of labor demanded at their posted wage. Barro (1977) and Hall (1980) were highly critical of this hypothesis during an earlier period of research on this type of model. Indeed the allocative role of nominal wages thus postulated implies potentially important inefficiencies as households are consistently pushed off their labor supply schedule.

## 6.2 Empirical performance

As before, we calibrate a number of parameters to fit salient long-run facts. The remaining parameters are estimated.<sup>30</sup> The first two columns of Table 2 report the point estimates and standard errors. The estimates are similar to those reported in ACEL (2004). In particular, we estimate an average wage contract duration of  $1/(1 - \hat{\kappa}_w) = 3.1$  quarters, slightly below the 3.6 quarters estimated by ACEL. Also note that the estimation results in both prices and wages being completely indexed to past inflation (i.e.  $\hat{\omega}_p = \hat{\omega}_w = 1$ ).<sup>31</sup> The largest differences occur with respect to the estimates of the exogenous shock processes. These differences are not surprising given that we specify a somewhat alternative transmission mechanism for monetary policy.

The estimates of the marginal cost coefficient in the NKPC and the inflation indexation parameter are very similar to the baseline estimates obtained for the reciprocity model in the first column of Table 1. Likewise, the estimates for the curvature of the variable capital utilization  $\xi$ , the external habit  $b$ , and the investment adjustment cost  $\chi$  are reasonably close. The only big difference occurs with respect to the parameters pertaining to the characteristics of the neutral technology shock; i.e.,  $\rho_{\mu_A}$ ,  $\sigma_{\mu_A}$  and  $\phi_{\mu_A}$ . Whereas in the reciprocity model the growth rate of the neutral technology

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<sup>30</sup>As in ACEL (2004), we fix the curvature parameter of the disutility of hours worked  $\eta$  and the elasticity of substitution among differentiated labor inputs  $\theta_w$  to 2 and 1.05, respectively. When we estimate them, instead, we find values that are very close to this calibration but are also highly uncertain.

<sup>31</sup>ACEL (2004) fix both  $\omega_p$  and  $\omega_w$  to 1. As before, we refrain from reporting standard errors for these two parameters as they are estimated to be at their upper bound.

shock is estimated to be very persistent but subject to small innovations, the same process in the nominal wage contracts model is only moderately persistent but subject to innovations that are on average about 5 times larger. Furthermore, the accommodation coefficient in the money growth rule is estimated to be roughly four times larger in the wage contracts model than in the reciprocity model, meaning that monetary policy allows technology shocks to have much larger short term real effects. The general equilibrium effect of these differences in estimates for the IRFs with respect to a neutral technology shock are difficult to gauge analytically (since a larger persistence parameter  $\rho_{\mu_A}$  increases the unconditional volatility of the actual shock  $\mu_A$ ). We therefore perform some numerical comparisons that are discussed at the end of this section.

Figure 5 displays the IRFs for the two models together with the empirical responses from the VAR.

With regards to the monetary shock and the investment-specific shock, the two models generate virtually identical dynamics and closely replicate the VAR evidence. In particular, the reaction of nominal wage growth is very modest and smooth for both models. In the wage contracts model, this nominal rigidity is imposed exogenously. In the reciprocity model by contrast, nothing a priori prevents inflation and thus nominal wages from adjusting sharply on impact. Instead, the smooth dynamics of nominal wages is the general equilibrium outcome of the estimated rent-sharing and wage endowment factors. In other words, nominal wage rigidity arises endogenously following monetary and investment-specific shocks.<sup>32</sup>

Turning now to the neutral technology shock, both the wage contracts model and the reciprocity model fail to generate the observed persistent decrease of inflation and nominal wage growth. The reciprocity model gets somewhat closer to replicating the VAR responses in this instance but the improvement is minimal. The wage contract model is more successful in matching the pronounced and slightly hump-shaped response of output and hours over the first 10 quarters. As the objective values of 837.014 in Table 1 and 849.53 in Table 2 indicate, the overall fit of the two models over all IRFs is almost identical.

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<sup>32</sup>The endogenous nominal wage rigidity in the reciprocity model is enhanced, of course, by the estimated inflation indexation by non-reoptimizing firms. As we see below, however, even when we set inflation indexation to zero, the reciprocity model still manages to generate a substantial amount of endogenous nominal wage rigidity in the case of monetary and investment-specific technology shocks.



Furthermore and as discussed above, the ability of the wage contracts model to generate a better fit in the response of output and hours to the neutral technology shock may be due to the different estimates for  $\rho_{\mu_A}$ ,  $\sigma_{\mu_A}$  and  $\phi_{\mu_A}$ . To evaluate this possibility, we set  $\rho_{\mu_A}$ ,  $\sigma_{\mu_A}$  and  $\phi_{\mu_A}$  to the values estimated for the reciprocity model and resimulate the IRFs. In that case, the wage contracts model indeed delivers a substantially worse performance (results are reported in the appendix). This indicates that our reciprocity-based mechanism of wage setting provides a stronger internal amplification mechanism for the neutral technology shocks than the wage contracts model. This is noteworthy because DSGE models are often criticized for their reliance on implausibly large technology shocks.

### 6.3 The response of prices and wages revisited

Before closing, we inquire to what extent the reciprocity model and the wage contract model are capable of generating a sharp fall on impact for inflation and nominal wage growth in response to a neutral technology shock. This question is interesting because a number of recent DSGE studies intervene on this issue. ACEL (2004), for example, argue that their wage contract model generates a drop of inflation under the restriction that monetary policy does not accommodate the neutral technology shock (i.e.  $\phi_{\mu_A} = 0$ ). They do not report quantitative results, however, and the fall in inflation seems to come at the cost of a weak output response and a fall in hours worked. Liu and Phaneuf (2006) also argue that a simplified version of ACEL's model with modest monetary policy accommodation can generate a fall in inflation as well as a fall in nominal wage growth. However, their model abstracts from important features such as capital accumulation, they do not formally estimate their model, and the fall in nominal wage growth is quantitatively small. Finally, Dupor, Han and Tsai (2007) find that a model with little price rigidity, flexible wages and long durability in preferences instead of habit persistence is best capable of replicating the fall in inflation after a neutral technology shock. Dupor, Han and Tsai's model also abstracts from capital accumulation and their estimation focuses exclusively on fitting IRFs conditional on a neutral technology shock.<sup>33</sup>

Dupor, Han and Tsai's (2007) finding raises a challenge for New Keynesian models: the importance of nominal frictions for macroeconomic dynamics appears to depend crucially on whether the

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<sup>33</sup>Other studies reporting on the downward jump in inflation after a neutral technology shock are Cogley and Nason (1994) and Edge, Laubach and Williams (2003).

parameters are identified by monetary policy shocks or by neutral technology shocks. Our strategy to shed light on this issue consists of restricting past inflation indexation to zero (i.e.  $\omega_p = 0$ ) and reestimating the structural parameters on the same IRFs as before. This restriction is motivated by a host of single equation and full-information DSGE estimations of the NKPC, which invariably find that backward looking inflation behavior (i.e.  $\omega_p > 0$ ) is quantitatively unimportant.<sup>34</sup> One explanation for this difference in estimates is that the IRF matching estimation method employed here attributes equal importance to the dynamics conditional on the different shocks. Most empirical investigations find, however, that monetary shocks are quantitatively less important than other shocks. Since it is exactly the inflation response after a monetary shock that requires smooth, backward-looking behavior, the IRF matching method is likely to overestimate  $\omega_p$ .

The third and fourth columns of Tables 3 and 4 display the reestimated parameters of the reciprocity model and the wage contract model, respectively, under the restriction that  $\omega_p = 0$ . For the reciprocity model, the estimates change relatively little and remain plausible. In particular, the slope of the NKPC increases only slightly. External employment conditions remain negligible whereas wage entitlement becomes even more important relative to rent-sharing. Furthermore, monetary accommodation of neutral technology shocks completely vanishes.

The estimates for the wage contracts model, by contrast, change quite dramatically and become considerably less plausible. In particular, the average wage contract duration increases to  $1/(1 - \hat{\kappa}_w) = 6.4$  quarters, which is substantially above the reported micro-evidence (e.g. Taylor, 1998); capital utilization becomes constant ( $\xi \rightarrow \infty$ ) and investment adjustment costs become very large. Hence, the restriction of  $\omega_p = 0$  seems to have important effects and requires implausible estimates for the wage contracts model to fit the VAR evidence.

Figure 6 illustrates the empirical performance of the two reestimated models. Unsurprisingly, both models now have inflation jump up on impact of the monetary shock. However, this jump is relatively modest and the IRFs are back within the confidence bands after 2 periods. Both models also generate a fall in inflation after a neutral technology shock that is just within the confidence bounds of the VAR. Hence, as long as we impose  $\omega_p = 0$ , the reciprocity model generates acceptable inflation dynamics without implying implausible estimates.

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<sup>34</sup>See Galí and Gertler (1999) and Kurmann (2007) among many others for single-equation estimates; Ireland (2004) or Smets and Wouters (2007) for full-information DSGE estimates.

The reciprocity model also implies a substantial drop of nominal wage growth in response to the monetary policy shocks whereas the estimated wage change inertia of the contract model forces wage inflation to adjust sluggishly in response to all shocks. Contrary to the reciprocity model, the wage contracts model therefore generates a nominal wage growth response with respect to a neutral technology shock that is inconsistent with the available VAR evidence.<sup>35</sup>

Overall, the results illustrate that for the reasonable case where  $\omega_p = 0$ , our reciprocity model produces more plausible estimates and replicates the IRFs better than the wage contracts model. This raises doubts on the conclusions of ACEL (2004) and Liu and Phaneuf (2006) mentioned above. The results also suggest that the identification challenge for New Keynesian models raised by Dupor, Han and Tsai (2007) is not as important as it may seem. In fact, the reciprocity model performs well in response to all three shocks. As for the jump of inflation and nominal wage growth after the monetary shock, several recent studies (e.g. Mackowiak and Wiederholt, 2006) argue that they are due to informational frictions leading to firms recognizing real productivity shocks more quickly than aggregate nominal shocks (e.g. monetary policy shocks). Since these information frictions are absent from the current DSGE framework, we should not expect to replicate the sluggish, initial response of inflation and nominal wage growth in response to a monetary shock.

## 7 Conclusion

In this paper, we incorporate a reciprocity-based model of wage determination into a modern DSGE framework. We estimate the structural parameters of the model and assess its ability to generate the distinct dynamics of prominent macroeconomic aggregates in response to various exogenous shocks. Several results stand out. First, our estimation suggests that workers' past wage level (a factor we associate with a sense of wage entitlement) but also firms' ability to pay (resulting from rent-sharing considerations) are the most important determinants of wage setting. Aggregate labor market conditions – the wage reference typically emphasized in standard efficiency wage formulations

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<sup>35</sup>One may expect that nominal wage growth in the wage contracts model is prevented from falling on impact of the neutral technology shock because of the estimated backward-looking wage setting behavior (i.e.  $\hat{\omega}_w = 1$ ). However, when we reestimate the wage contracts model with  $\omega_w = 0$ , nominal wage growth *jumps up* on impact of a neutral technology shock, thus rendering the model even more inconsistent with the VAR evidence. See the appendix for details.

– are estimated to be of minor importance. These findings accord well with a large number of survey studies on reciprocity in labor relations and wage setting in general. The reason often given in these studies for the relative unimportance of firm-external labor market conditions is that individuals have only little knowledge of the market value of their work and thus resort to alternative reference points. While our model stops short from formalizing this information problem, we find the match between our estimates of the determinants of wage setting and the survey evidence intriguing and suggestive of interesting avenues for future research.

The second important result is that the proposed reciprocity-based wage setting model is capable of fitting the empirical VAR dynamics at least as well as a model postulating nominal wage contracts. In particular, the estimated reciprocity model implies substantial structural rigidity in real wages that is manifest across the various types of shock hitting the economy. This is consistent with the presented VAR evidence. Nominal wage contracts, on the other hand, imply a form of rigidity that makes it hard to replicate the immediate, large response of nominal wage growth to a neutral technology shock. In addition, as argued by Barro (1977) and Hall (1980), the allocative role of nominal wage contracts implies potentially important inefficiencies if one assumes that the underlying labor supply schedule is neoclassical. The reciprocity-based wage setting mechanism is based on a very different view of the labor market, one where firms set wages so as to elicit optimal effort. It is, by construction, not subject to the Barro-Hall critique. Our analysis suggests that, in a low inflation environment, nominal wages often remain unchanged for several quarters because firms find it optimal to keep real wage adjustments relatively small rather than because recontracting is expensive.

Why should we be concerned about the nature of wage setting in DSGE models? One important reason is normative. Blanchard and Gali (2006) show, for example, that the optimal monetary policy implications of a model with nominal wage contracts differ substantially from those of a reduced-form model of real wage rigidity. Our reciprocity model takes this argument one step further by providing an explicit, utility-based, theory for why past wages matter in wage setting. Likewise, our analysis of optimal firm behavior suggests possible externalities stemming from rent-sharing considerations. These structural modeling features result in potentially relevant trade-offs between inflation and output that should be taken into account when formulating monetary policy.<sup>36</sup>

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<sup>36</sup>A point emphasized by Akerlof (2007) in his AEA Presidential Address.

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Table 1

Estimation results for reciprocity model

Parameter	Baseline estimates with $\omega_p$ unrestricted		Estimates with $\omega_p = 0$	
	Point estimate	Standard error	Point estimate	Standard error
$\varphi_2$	0.072	0.000	0.055	0.054
$\varphi_3$	0.621	0.170	0.890	0.016
$\gamma$	0.040	0.311	0.051	0.049
$\omega_p$	1.000	<i>n.a.</i>	0.000	<i>n.a.</i>
$\xi$	2.260	0.961	7.160	0.305
$b$	0.719	0.029	0.722	0.017
$\chi$	5.227	0.029	7.121	0.054
$\varsigma$	2.603	0.238	2.425	0.061
$\rho_{\mu_A}$	0.989	0.008	0.993	0.001
$\sigma_{\varepsilon_{\mu_A}}$	0.032	0.404	0.030	0.055
$\rho_{\mu_V}$	0.437	0.295	0.473	0.058
$\sigma_{\varepsilon_{\mu_V}}$	0.241	0.123	0.222	0.048
$\sigma_{\varepsilon_{\mu_M}}$	0.375	0.081	0.362	0.048
$\phi_{\mu_A}$	0.316	3.162	0.000	5.325
$\phi_{\mu_V}$	2.321	0.138	2.656	0.040
Objective value	837.014		940.209	

Standard errors are computed by bootstrap simulation of the estimated model. See ACEL (2004) for details.

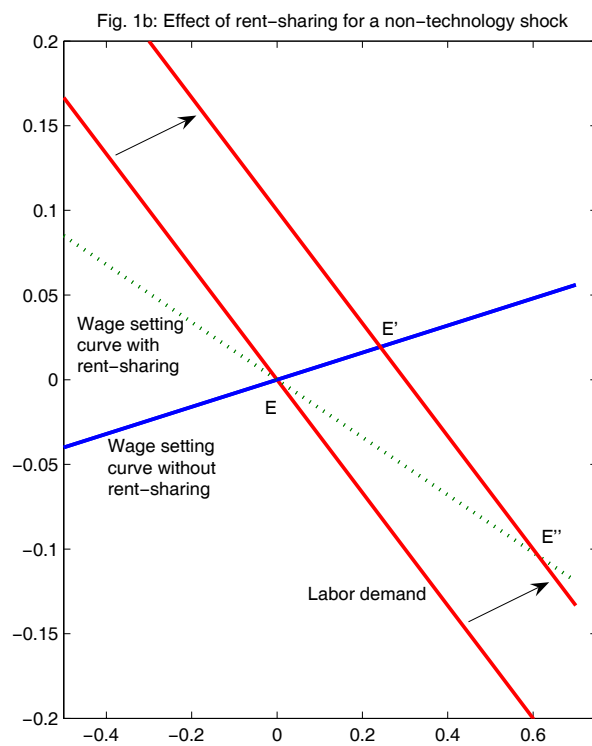
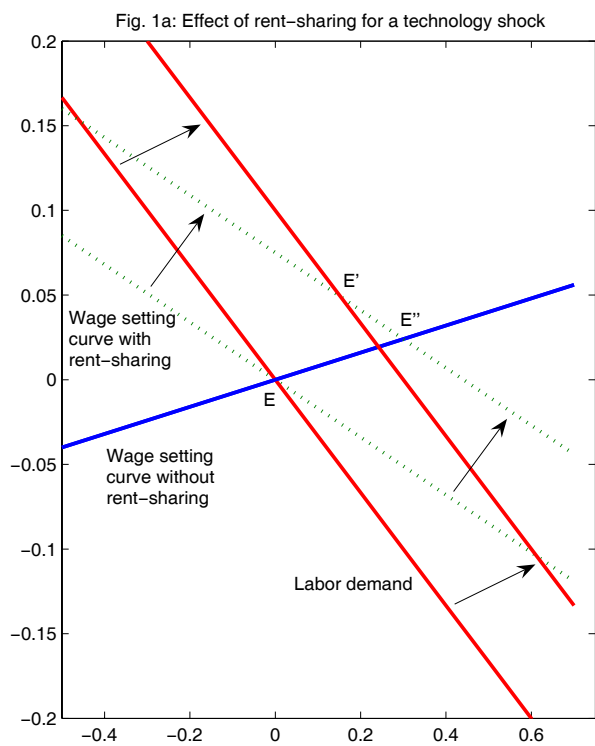
Table 2

Estimation results for nominal wage contract model

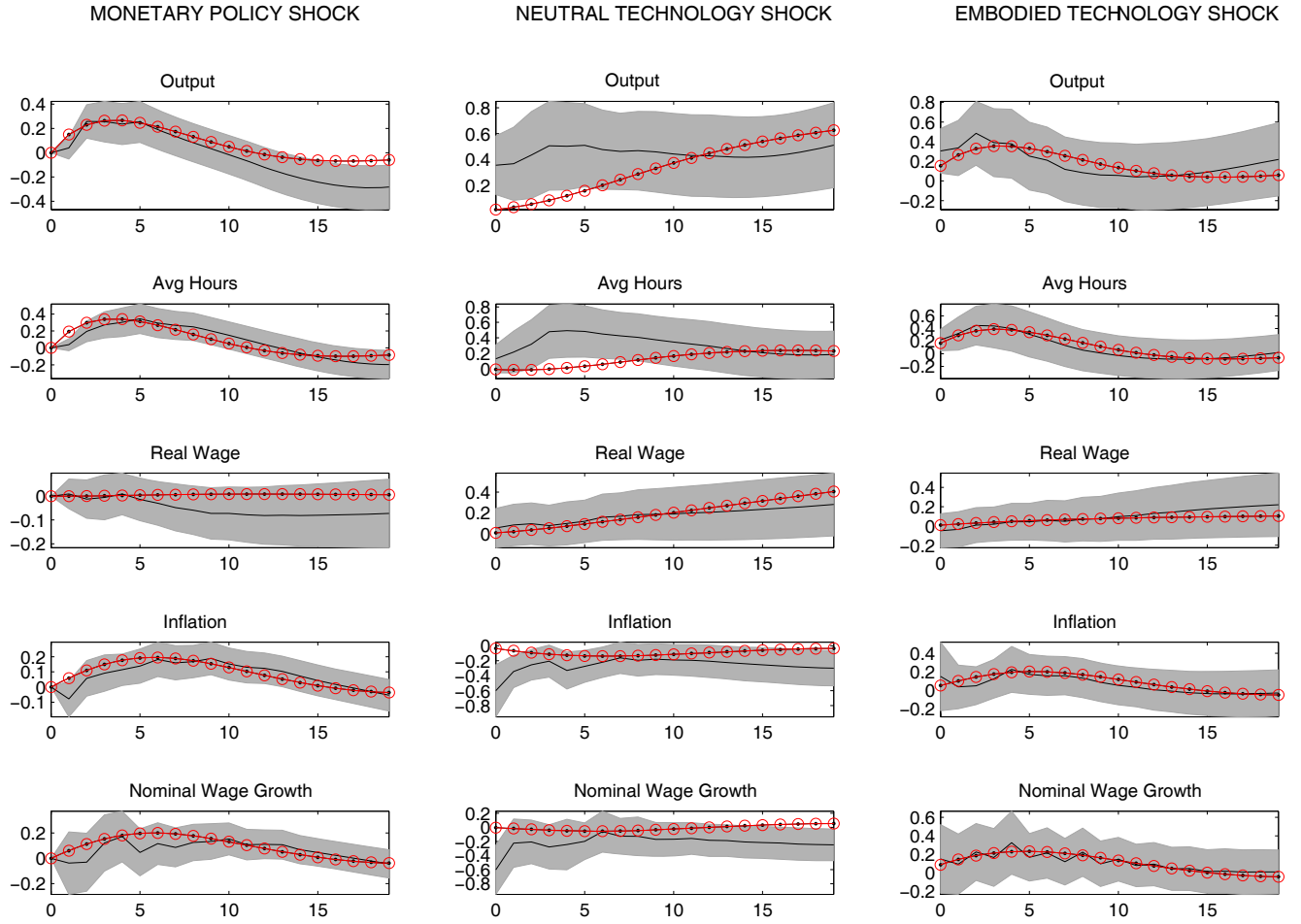
Parameter	Baseline estimates with $\omega_p$ unrestricted		Estimates with $\omega_p = 0$	
	Point estimate	Standard error	Point estimate	Standard error
$\kappa_w$	0.672	0.278	0.843	0.008
$\omega_w$	1.000	<i>n.a.</i>	1.000	<i>n.a.</i>
$\gamma$	0.035	0.452	0.143	0.098
$\omega_p$	1.000	<i>n.a.</i>	0.000	<i>n.a.</i>
$\xi$	3.079	2.036	$4.7 * 10^9$	5.215
$b$	0.699	0.202	0.685	0.026
$\chi$	3.237	1.520	158.544	0.329
$\varsigma$	2.555	0.285	2.027	0.099
$\rho_{\mu_A}$	0.615	0.056	0.792	0.036
$\sigma_{\varepsilon_{\mu_A}}$	0.164	0.058	0.107	0.097
$\rho_{\mu_V}$	0.463	0.424	0.613	0.063
$\sigma_{\varepsilon_{\mu_V}}$	0.240	0.176	0.200	0.084
$\sigma_{\varepsilon_{\mu_M}}$	0.361	0.150	0.294	0.073
$\phi_{\mu_A}$	1.057	0.131	0.337	0.189
$\phi_{\mu_V}$	2.215	0.062	1.878	0.052
Objective value	849.532		933.293	

Standard errors are computed by bootstrap simulation of the estimated model. See ACEL (2004) for details.

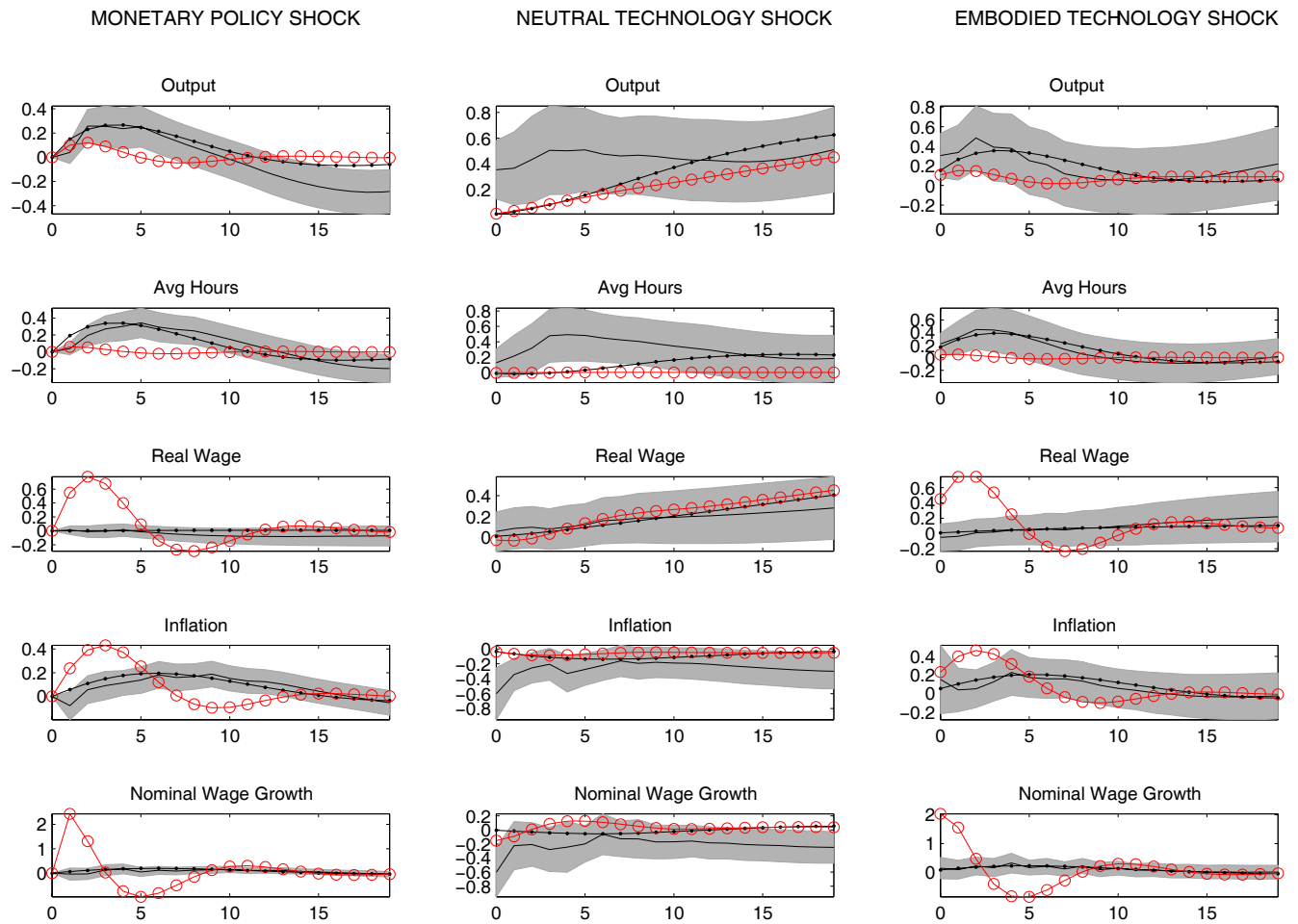
**Figure 1**  
**The effects of rent-sharing**



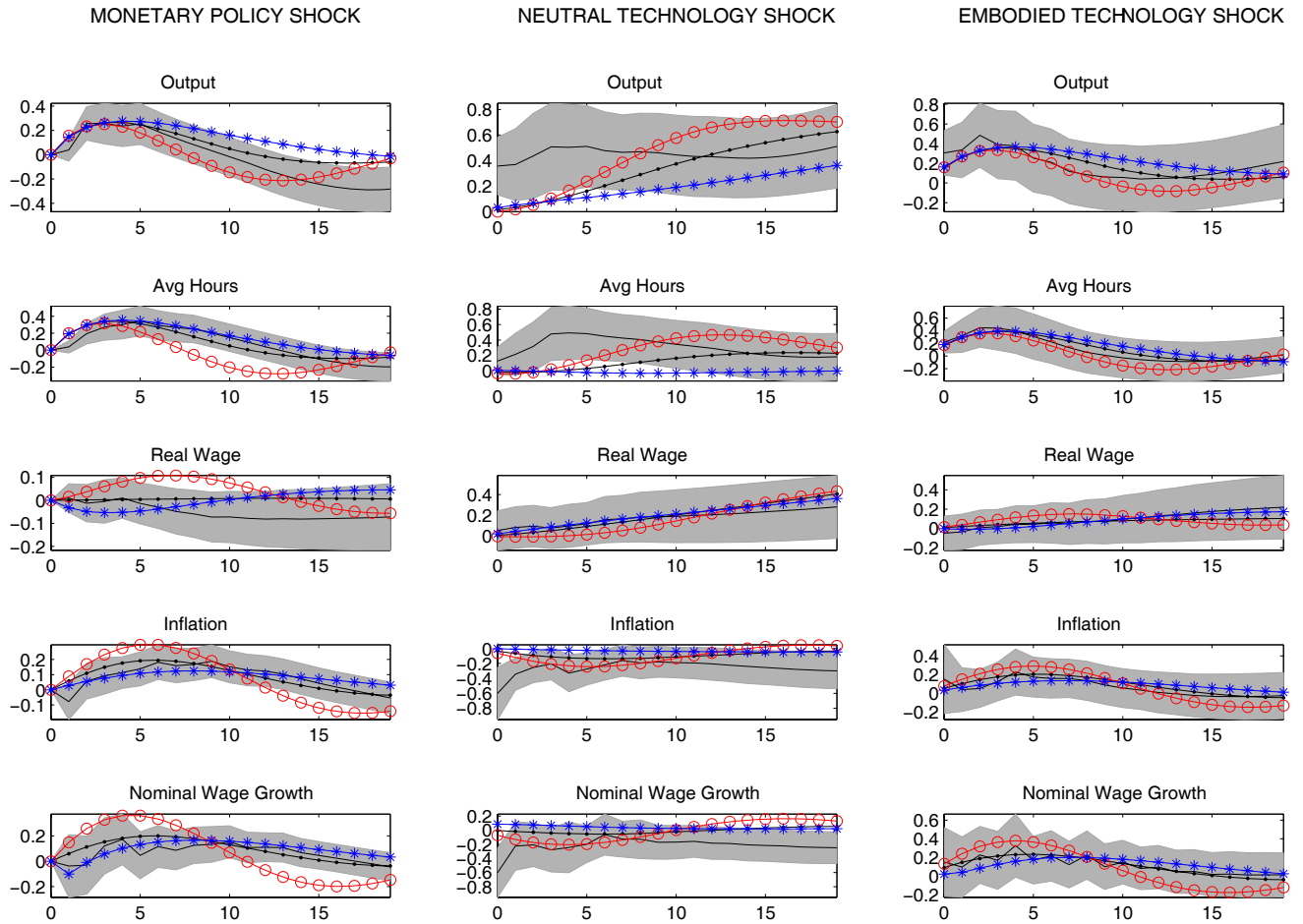
**Figure 2**  
**Impulse responses of empirical VAR model (solid lines and grey intervals)**  
**and estimated baseline model ( -o- )**



**Figure 3**  
**Impulse responses of baseline model (-•-) and model with larger weight on external labor market conditions (-○-)**



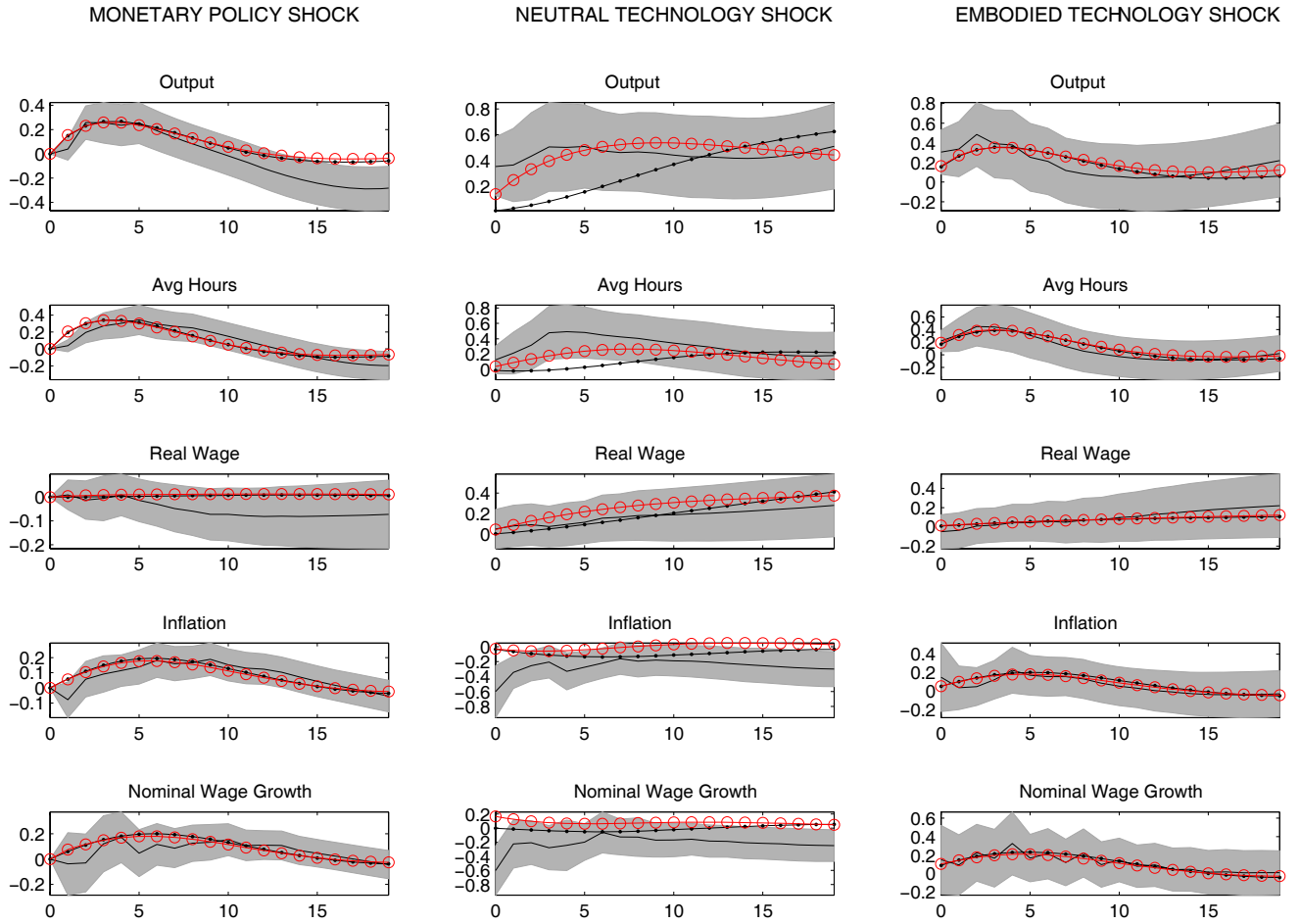
**Figure 4**  
**Impulse responses of baseline model (-•-), model with wage entitlement only (-o-), and model with rent-sharing only (-\*-)**





**Figure 5**

**Impulse responses of baseline model (-•-) and model with nominal wage contracts (-o-)**



**Figure 6**  
**Impulse responses of baseline model (-•-) and model with**  
**nominal wage contracts (-o-), both reestimated with  $\omega_p = 0$**

