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WORKING PAPER

Endogenous Wage Indexation and Aggregate Shocks

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Abstract

Empirical and institutional evidence finds considerable time variation in the degree of wage indexation to past inflation, a finding that is at odds with the assumption of constant indexation parameters in most New-Keynesian DSGE models. We build a DSGE model with endogenous wage indexation in which utility maximizing workers select a wage indexation rule in response to aggregate shocks and monetary policy. We show that workers index wages to past inflation when output fluctuations are primarily explained by technology and permanent inflation-target shocks, whereas they index to trend inflation when aggregate demand shocks dominate output fluctuations. The model's equilibrium wage setting can explain the time variation in wage indexation found in post-WWII U.S. data.

Keywords: Wage indexation, Welfare costs, Nominal rigidities

JEL Classification: E24, E32, E58

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1 Introduction

Price and wage inflation are very persistent. To replicate this feature, New-Keynesian dynamic stochastic general equilibrium (NK-DSGE) models typically assume the partial indexation of wages and prices to past inflation in addition to staggered wage and price setting. Moreover, the degree of wage and price indexation are hard wired as constant and policy invariant parameters (see Erceg, Henderson and Levin, 2000; Christiano, Eichenbaum and Evans, 2005; Smets and Wouters, 2007). The assumption of a constant degree of indexation, however, has been rejected by institutional and empirical evidence, in particular for wages. Figure (1) shows the coverage of private sector workers by cost-of-living adjustment (COLA) clauses, a measure often used as a proxy for wage indexation to past inflation (henceforth, *wage indexation*) in the United States (U.S.).¹ From the late 1960s onwards, COLA coverage steadily increased from 25% to levels of around 60% in the mid 1980s, after which there was again a decline towards 20% in the mid 1990s. Also Hofmann, Peersman and Straub (2012) document considerable time variation in the degree of wage indexation.² They find a degree of wage indexation of 0.91 during the *Great Inflation*, compared to 0.30 and 0.17 before and after this period.

The degree of wage indexation is very important for macroeconomic fluctuations and policymakers. For example, when wage indexation is high, inflationary shocks can trigger mutually reinforcing feedback effects between wages and prices, i.e. so-called second-round effects, that amplify the effects of the shock on inflation. Accordingly, a larger shift in the policy rate is required to bring inflation back to the target. The degree of wage indexation is thus crucial for the inflationary consequences of shocks hitting the economy, the costs of disinflation and the volatility of output and prices. Hofmann *et al.* (2012) find, for instance, that the decline of wage indexation from 0.91 during the *Great Inflation* to 0.17 during the *Great Moderation* implies a reduction in the long-run impact of a supply and demand shock on prices by respectively, 44% and 39%.

In this paper, we build a standard NK-DSGE model, where the level of wage indexa-

¹The COLA index, discontinued in 1995, measures the proportion of cost-of-living adjustment clauses in major collective bargaining agreements, i.e. contracts covering more than 1000 workers. Although the sample covers less than 20% of the U.S. labor force (see Devine, 1996), Holland (1988) showed that other wages reacted to price shocks in a manner similar to the COLA index.

²Hofmann *et al.* (2012) estimate in a first step a time-varying parameters Bayesian structural vector autoregressive (TVP-BVAR) model to assess time variation in wage dynamics from aggregate supply and demand shocks. In a second step, the parameters of a standard DSGE model for specific periods of time (i.e., 1960Q1, 1974Q1 and 2000Q1) are estimated using an impulse response matching procedure. Ascari *et al.* (2011) find a similar pattern of time-variation in wage indexation using rolling techniques to estimate a reduced form wage equation.

tion is endogenously determined using sound micro-foundations, to study changes in wage indexation over time.³ The novelty of our model is that, in periods when a worker’s wage is re-optimized, we let him choose between indexing his wage to past inflation or the inflation target of the central bank (i.e. trend inflation, which may vary). The worker’s indexation choice is based on the highest expected utility he would obtain from the two indexation schemes, given the average length of the labor contract and the specific economic regime. We define an economic regime as an environment with specific market structures, stochastic shock distributions, and monetary policy rule.⁴ The decisions of workers are hence micro-founded in our framework. Furthermore, we assume that wage setting takes place at a decentralized level, e.g. the individual worker or firm level, which is consistent with the institutional evidence for wage bargaining in the U.S. (e.g. Calmfors and Driffill, 1988). Similar to Schmitt-Grohé and Uribe (2007), we solve the non-linear model to compute the welfare criterion of workers. The sum of all workers’ decisions determines the degree at which nominal wages are indexed to past inflation, which we denote as the degree of **aggregate indexation** in the economy. We implement an algorithm that computes the equilibrium level for aggregate indexation, given the economic regime.

There are three primary results. First, we find that workers index wages to past inflation when permanent shocks to technology and the inflation target are important drivers of output fluctuations. In contrast, when aggregate demand and temporal inflation target shocks dominate, workers index wages to the inflation target. Thus, aggregate indexation is high in the former regime, and low in the latter. The intuition behind these results is that nominal wage rigidities cause welfare losses because the labor supply of each worker does not adapt optimally to economic events. Wage indexation rules could then lower welfare costs by closing the gap between the desired and the actual labor supply. The preferred indexation rule thus closes the labor-supply gap faster and features a more stable expected labor supply. As workers are risk averse in leisure, they prefer the labor contract with smaller variations in expected hours worked.

Second, we show that the model with endogenous wage indexation explains very well the observed changes in wage indexation over time. More specifically, we assess whether the equilibrium degree of wage indexation matches the stylized facts reported in Hofmann *et al.*

³The standard New-Keynesian model ingredients are nominal rigidities in price and wage setting, optimizing households and firms, a public sector with a balanced budget, and a central bank that sets the nominal interest rate and the inflation target. We only consider endogenous wage indexation to keep the model tractable. Endogenous price indexation is a subject left for future research.

⁴Although there is also government spending in the model, we omit any active role for public debt or fiscal policy rule.

(2012) by calibrating the model for respectively the *Great Inflation* and *Great Moderation* regimes and performing a series of counterfactual exercises. Consistent with the stylized facts, our model predicts a high degree of wage indexation for the *Great Inflation*, characterized by very volatile - in particular technology - shocks and drifting trend inflation, and a low degree for the *Great Moderation* period. The counterfactual exercises reveal that the high degree of wage indexation in the 1970s was primarily the result of very volatile supply-side shocks, whereas wage indexation vanished when supply-side shocks became less volatile - relative to demand-side shocks - in more recent periods. Changes in the monetary policy rule or the stability of the inflation target, in contrast, only played a minor role in the determination of aggregate indexation for the two periods.

Third, we find a *coordination failure*, i.e. the decentralized equilibrium of wage indexation, in general, does not coincide with the social planner's choice. More precisely, the social planner's solution is indexation to target inflation in regimes driven by technology and permanent inflation-target shocks and indexation to past-inflation in regimes driven by aggregate-demand shocks. The social planner's solution is consistent with the seminal work of Gray (1976) and Fischer (1977) on optimal wage indexation. Gray (1976) and Fischer (1977) show that, to reduce output fluctuations, wage indexation should decline in the face of real (or supply-side) shocks, whereas it should increase when nominal (or demand-side) shocks hit the economy.⁵ More recent studies find similar conclusions.⁶ We show that, at the margin, a worker has an incentive to deviate from the social planner's solution because this increases individual utility. Because all workers act similarly and do not internalize the effects of their indexation choice on others, the resulting decentralized equilibrium is inefficient. For the U.S., the assumption of decentralized wage setting is more realistic to endogenize wage indexation. According to the literature on cross-country differences in wage-setting institutions, wage bargaining in the U.S. primarily takes place at the enterprise level (see, e.g., Calmfors and Driffill, 1988; Bruno and Sachs, 1985). There is no involvement by central organizations in bargaining, and there exist no central employer organizations. In addition, the social planner's choice for the degree of wage indexation would have been low indexation

⁵Gray (1976) and Fischer (1977) show that a high degree of wage indexation stabilizes the economy under nominal shocks but destabilizes it under real shocks. The reason for this result is that indexed nominal wages imply sticky real wages, which is desirable in the former case but not in the latter.

⁶Several extensions, most of them without fully optimizing agents, are reviewed in Cover and van Hoose (2002); Calmfors and Johansson (2006). For DSGE models with a welfare criterion, see Cho (2003) and Amano *et al.* (2007). Related work is Minford *et al.* (2003), who find that coordinated equilibrium indexation is not driven by the size but by the *persistence* of shocks, a finding that is shared by Mash (2007) for price contracts by firms. The difference from our study is that we establish the *decentralized* equilibrium and compare it with the socially optimal degree of indexation. Also, we seek to explain an empirical phenomenon rather than deriving the welfare maximizing indexation rule (see Le and Minford, 2007a,b).

in the 1970s and high indexation during the *Great Moderation* period, which is at odds with the stylized facts. The (inefficient) decentralized equilibrium, in contrast, is consistent with the changes in wage indexation over time.

The remainder of the paper is organized as follows. Section 2 presents the model, Section 3 the aggregate indexation equilibria, Section 4 the validation and counterfactual exercises and Section 5 the conclusions.

2 The model

Our analysis is based on a standard New-Keynesian model with nominal rigidities in both prices and wages and no capital. The model economy is populated by a continuum of households and firms, with respectively differentiated labor and goods supply, which are aggregated by a competitive labor intermediary and a final goods producer. The main ingredients of the model are discussed below.⁷

2.1 Households

Households are indexed by $i \in [0, 1]$. Each household is endowed with a unique labor type, $\ell_{i,t}$, and uses its monopolistic power to set its wage, $W_{i,t}$. A household chooses consumption, $c_{i,t}$, one-period-maturity bond holdings, $b_{i,t}$, and $W_{i,t}$ to maximize its discounted lifetime utility, i.e.,

$$\max_{c_{i,T}, b_{i,T}, W_{i,T}} \mathbb{E}_t \left(\sum_{T=t}^{\infty} \beta^{T-t} \mathcal{U}(c_{i,T}, \ell_{i,T}) \right), \quad (1)$$

subject to a *no Ponzi* schemes condition, labor-specific demand by firms, and a sequence of budget constraints of the form

$$c_{i,T} + \frac{b_{i,T}}{R_T} \leq \frac{W_{i,T}}{P_T} \ell_{i,T} + \frac{b_{i,T-1}}{1 + \pi_T} + \frac{\Upsilon_{i,T}}{P_T} \quad \forall T = t, t + 1, t + 2, \dots \quad (2)$$

\mathbb{E}_t denotes the expectation operator conditional on information available in period t . R_t is the risk free gross nominal interest rate. The inflation rate is given by $\pi_t \equiv P_t/P_{t-1} - 1$, with P_t as the aggregate price level. A lump sum measure $\Upsilon_{i,t}$, which includes net transfers, profits from monopolistic firms and Arrow-Debreu state-contingent securities, ensures that households start each period with equal wealth. The instantaneous utility function is given by

$$\mathcal{U}(c_{i,t}, \ell_{i,t}) = \log(c_{i,t} - \gamma^h c_{i,t-1}) - \psi \frac{\ell_{i,t}^{1+\omega}}{1+\omega}.$$

⁷A full description of the model can be found in a technical appendix, which is available upon request.

The parameters γ^h and ω are respectively, the degree of consumption habits and the inverse Frisch elasticity of the labor supply. The normalizing constant ψ ensures that labor equals $\frac{1}{3}$ at the deterministic steady-state. There are two decision-making units within a household: a consumer, who chooses consumption and savings, and a worker, who sets the labor contract. The latter specifies the nominal wage and an indexation rule. The decision rules for the consumer are standard and not reported for brevity reasons (see the technical appendix for details).

Labor contracts We follow Calvo (1983) and assume that the worker re-optimizes his labor contract in each period with probability $1 - \alpha_w$. The optimization happens in two stages. In a first stage, the worker chooses the indexation scheme that dictates how his nominal wage must be updated in periods in which no optimization takes place. In the second stage, the worker sets his optimal wage conditional on the selected indexation rule. In both stages, workers maximize their expected utility. For simplicity, we allow only two indexation rules: one based on the inflation target of the central bank (i.e., *trend*), and the other based on lagged inflation (i.e., *past*).⁸ Suppose that the last wage re-optimization of worker i occurred in period t , in which he selected wage $W_{i,t}^{k,*}$ for either contract $k = \textit{trend}$ or contract $k = \textit{past}$. Thus, in period $T > t$, worker i 's wage is updated to either $W_{i,T}^{\textit{trend}} = \delta_{t,T}^{\textit{trend}} W_{i,t}^{\textit{trend},*}$ or $W_{i,T}^{\textit{past}} = \delta_{t,T}^{\textit{past}} W_{i,t}^{\textit{past},*}$, where

$$\delta_{t,T}^{\textit{trend}} = (1 + \pi_T^*) \delta_{t,T-1}^{\textit{trend}} \quad \text{and} \quad \delta_{t,T}^{\textit{past}} = (1 + \pi_{T-1}) \delta_{t,T-1}^{\textit{past}} \quad \text{with} \quad \delta_{t,t}^k = 1 \quad \forall k.$$

π_T^* represents the time T inflation target of the central bank, which determines trend inflation. For simplicity, we assume that everybody knows this target. Each indexation rule allows the worker to smooth adjustments in his labor supply, which is otherwise fixed due to nominal wage rigidities.

Wage setting We first describe the problem of choosing the optimal wage conditional on $\delta_{t,T}^k$, which takes the familiar setting of a sticky-wage model *à la* Erceg *et al.* (2000). Specifically, given δ^k , a worker selects his wage by solving

$$W_{i,t}^{k,*} \in \arg \max_{W_{i,t}^k} E_t \left(\sum_{T=t}^{\infty} (\beta \alpha_w)^{T-t} \left[\lambda_T \frac{\delta_{t,T}^k W_{i,t}^k}{P_T} \ell_{i,t,T}^k - \frac{\psi}{1 + \omega} (\ell_{i,t,T}^k)^{1+\omega} \right] \right), \quad (3)$$

⁸Wieland (2009) analyzes the indexation decisions of firms in a model with learning and proposes similar indexation rules. However, he does not use an objective-maximizing criterion for choosing the indexation rule but uses a forecasting rule for the true process of inflation.

subject to the labor-specific demand of firms

$$\ell_{i,t,T}^k = \left(\frac{\delta_{t,T}^k W_{i,t}^k}{W_T} \right)^{-\theta_w} \ell_T. \quad (4)$$

λ_t is the marginal utility of wealth associated with the household budget constraint, ℓ_t is aggregate labor, and the coefficient θ_w denotes the elasticity of substitution between any two labor types, as implied by a Dixit-Stiglitz aggregator used by the labor intermediary. Note that, since we have assumed no inequalities in wealth (due to the Arrow-Debreu securities), λ_t is common to all households. In contrast, a worker's labor mapping, $\ell_{i,t,T}^k$, may differ across workers due to nominal wage rigidities. We define $rw_t^{k,*} \equiv \frac{W_t^{k,*}}{W_t}$ as the optimal wage relative to the aggregate wage level. Thus, according to the F.O.C. of the worker's problem, $rw_t^{k,*}$ is given by

$$\left[rw_t^{k,*} \right]^{1+\omega\theta_w} = \psi \mu_w \frac{\text{num}_{k,t}^w}{\text{den}_{k,t}^w}, \quad (5)$$

where $\mu_w \equiv \frac{\theta_w}{\theta_w - 1}$ is the gross wage markup,

$$\begin{aligned} \text{num}_{k,t}^w &\equiv (\ell_t)^{1+\omega} + \beta \alpha_w \mathbb{E}_t \left(\left(\frac{1 + \pi_{t+1}^w}{\delta_{t,t+1}^k} \right)^{\theta_w(1+\omega)} \text{num}_{k,t+1}^w \right), \\ \text{den}_{k,t}^w &\equiv \lambda_t w_t \ell_t + \beta \alpha_w \mathbb{E}_t \left(\left(\frac{1 + \pi_{t+1}^w}{\delta_{t,t+1}^k} \right)^{\theta_w - 1} \text{den}_{k,t+1}^w \right), \end{aligned}$$

and $\pi_{t+1}^w \equiv \frac{W_{t+1}}{W_t} - 1$ is the wage inflation rate. We drop the subindex i because workers with indexation rule k who can re-optimize in period t will choose the same wage. Notice that in the case of fully flexible wages, wage dispersion vanishes along with the differences in individual labor supplies (so $rw_t^{k,*} = 1$). Accordingly, equation (5) collapses to the familiar welfare-maximizing condition in which the marginal rate of substitution between consumption and leisure equals the real wage (re-scaled by a wage markup), i.e.,

$$\psi \frac{(\ell_t)^\omega}{\lambda_t} = w_t \times \frac{1}{\mu_w}. \quad (6)$$

Nominal wage rigidities impose welfare losses on workers because they cannot adapt their labor supply quickly or optimally when shocks hit the economy. Thus, after a shock, there is a wedge between a worker's desired labor supply, given by equation (6), and his actual labor supply, given by equation (5). An indexation rule may help to close this wedge and reduce welfare losses. Workers prefer the rule associated with the lowest welfare losses. The optimal rule is conditional on the economic regime, as we show next.

Indexation rule selection Let ξ_t denote the time t total proportion of workers who have selected past-inflation indexation for their most recent wage contract, i.e. ξ_t represents the degree of **aggregate indexation** to past inflation at time t . Furthermore, let Σ_t be an information set describing the economy's market structure, the distribution of stochastic shocks, and the policy rules, i.e. the *economic regime* in period t . Finally, let vector Ξ collect present and future levels for aggregate indexation and economic regimes, so $\Xi_t = \mathbb{E}_t \left(\left\{ [\xi_{t+h}, \Sigma_{t+h}]' \right\}_{h=0}^{\infty} \right)$. We can now formalize the workers indexation-rule decision as follows: when worker i re-optimizes his labor contract at time t , he selects the rule that maximizes his conditional expected utility, i.e.,

$$\delta_{i,t}^*(\Xi_t) \in \arg \max_{\delta_i \in \{\delta^{trend}, \delta^{past}\}} \mathbb{W}_{i,t}(\delta_i, \Xi_t) \text{ subject to } \wp(\Xi_t), \quad (7)$$

where

$$\mathbb{W}_{i,t}(\delta_i, \Xi_t) = \mathbb{E}_t \left(\sum_{T=t}^{\infty} (\beta\alpha_w)^{T-t} \mathcal{U}(c_T(\xi_T, \Sigma_T), \ell_{i,T}(\delta_i, \xi_T, \Sigma_T)) \right). \quad (8)$$

$\wp(\Xi_t)$ is a system of equations that summarizes all relevant general-equilibrium constraints that determine the allocation of the economy. Notice that $\mathbb{W}_{i,t}$ is constrained by the expected duration of the labor contract (as the effective discount factor is $\beta\alpha_w$). Furthermore, because of the state-contingent securities, individual consumption equals the aggregate level and does not depend on the individual indexation choice δ_i . Individual consumption does, in contrast, depend on aggregate indexation ξ_t and the current economic regime Σ_t . Finally, notice that, given worker i 's atomistic size relative to the aggregate, his choice of indexation rule has a negligible effect on aggregate indexation. Worker i thus takes ξ_t , Σ_t , and c_t as given and selects the indexation rule δ_i that minimizes his individual expected labor disutility, given by $\Omega(\delta_i, \Xi_t)$. In formal terms, $\delta_{i,t}^*(\Xi_t)$ also satisfies the problem

$$\delta_{i,t}^*(\Xi_t) \in \arg \min_{\delta_i \in \{\delta^{trend}, \delta^{past}\}} \Omega(\delta_i, \Xi_t), \text{ subject to } \wp(\Xi_t),$$

where

$$\Omega(\delta_i, \Xi_t) = \frac{\psi}{1+\omega} \mathbb{E}_t \left(\sum_{T=t}^{\infty} (\beta\alpha_w)^{T-t} [\ell_{i,T}(\delta_i, \xi_T, \Sigma_T)]^{1+\omega} \right). \quad (9)$$

Labor market aggregation The degree of aggregate indexation ξ_t is determined as follows: each period, only a fraction $1 - \alpha_w$ of workers re-optimize their wages. Let χ_t denote the time t proportion of workers from subset $(1 - \alpha_w)$ that select δ^{past} . Accordingly, ξ_t is given by

$$\xi_t = (1 - \alpha_w) \sum_{h=0}^{\infty} \chi_{t-h} (\alpha_w)^h, \quad (10)$$

which can be written recursively as $\xi_t = (1 - \alpha_w) \chi_t + \alpha_w \xi_{t-1}$. The equilibrium solution for aggregate wage indexation ξ^* , which is a function of the economic regime Σ , will be characterized in section 3. We first describe useful measures of wage dispersion and discuss aggregation details of the labor market.

Without loss of generality, assume that workers are sorted according to the indexation rule they have chosen. Workers in the interval $i \in I_t^{past} = [0, \xi_t]$ use δ^{past} , while those in the interval $i \in I_t^{trend} = [\xi_t, 1]$ use δ^{trend} . Measures of wage dispersion for each of the two sectors can be computed by adding up total hours worked, given by the set of labor-specific demands. Hence, we have $\int_{i \in I_t^k} \ell_{i,t} di = \ell_t \text{disp}_{w,t}^k$, where $\text{disp}_{w,t}^k = \int_{i \in I_t^k} \left(\frac{W_{i,t}}{W_t} \right)^{-\theta_w} di$. Recursive expressions for the wage dispersion measures are given by

$$\text{disp}_{w,t}^k = (1 - \alpha_w) \chi_t^k \left(r w_t^{k,*} \right)^{-\theta_w} + \alpha_w \left(\frac{1 + \pi_t^w}{\delta_{t-1,t}^k} \right)^{\theta_w} \text{disp}_{w,t-1}^k, \quad (11)$$

$$\text{where } \chi_t^k = \begin{cases} \chi_t & \text{if } k = \textit{past} \\ 1 - \chi_t & \text{if } k = \textit{trend} \end{cases}. \quad (12)$$

Finally, given the Dixit-Stiglitz technology of the labor intermediary, the aggregate wage level is given by $W_t^{1-\theta_w} = \int_0^1 W_{i,t}^{1-\theta_w} di$. This expression can be rewritten in terms of the sum of relative wages within each indexation-rule sector, which are given by $\tilde{w}_t^k \equiv \int_{i \in I_t^k} \left(\frac{W_{i,t}}{W_t} \right)^{1-\theta_w} di$. Thus, it follows that

$$\tilde{w}_t^{past} + \tilde{w}_t^{trend} = 1.$$

Notice that these weights may change over time due to variations in $r w_t^k$ and χ_t . The recursive law of motion of \tilde{w}_t^k is given by

$$\tilde{w}_t^k = (1 - \alpha_w) \chi_t^k \left[r w_t^{k,*} \right]^{1-\theta_w} + \alpha_w \left(\frac{1 + \pi_t^w}{\delta_{t-1,t}^k} \right)^{\theta_w - 1} \tilde{w}_{t-1}^k. \quad (13)$$

The rest of the model is standard, so we describe it briefly.

2.2 Firms and price setting

A perfectly competitive firm produces a homogeneous good, y_t , by combining a continuum of intermediate goods, $y_{j,t}$ for $j \in [0, 1]$, using a typical Dixit-Stiglitz aggregator. Each intermediate good is produced by a single monopolistic firm using linear technology

$$y_{j,t} = A \exp(z_t) n_{j,t},$$

where $n_{j,t}$ is the composite labor input, A is a normalizing constant that ensures that the de-trended output at the deterministic steady state equals one, and z_t is a permanent technology shock that obeys

$$z_t = z_{t-1} + \varepsilon_{z,t}, \quad (14)$$

where $\varepsilon_{z,t}$ is a zero-mean white noise. Each period, an intermediate firm re-optimizes its price with a fixed probability $1 - \alpha_p$. If the firm is unable to re-optimize in period T , then its price is updated according to a rule-of-thumb of the form $P_{j,T} = \delta_{t,T}^p P_{j,t}$, where $t < T$ denotes the period of last reoptimization and $\delta_{t,T}^p = (1 + \pi_T^*)^{1-\gamma_p} (1 + \pi_{t-1})^{\gamma_p} \delta_{t,T-1}$ for $T > t$ and $\delta_{t,t}^p = 1$.⁹ The firm sets $P_{j,t}$ by maximizing its profits, so

$$P_{j,t}^* \in \arg \max_{P_{j,t}} \hat{E}_t \sum_{T=t}^{\infty} (\beta \alpha_p)^{T-t} \varphi_{t,T} \left[\frac{\delta_{t,T}^p P_{j,t}}{P_T} y_{j,t,T} - S(y_{j,t,T}) \right],$$

$$\text{subject to } y_{j,t,T} = \left(\frac{\delta_{t,T}^p P_{j,t}}{P_T} \right)^{-\theta_p} y_T,$$

where the real cost function is given by $S(y_{j,t}) = w_t [y_{j,t} / (A \exp(z_t))]$, and $\theta_p > 1$ is the price elasticity of demand for intermediate good j .

2.3 Policymakers

The government budget constraint is balanced at all times (i.e. lump-sum taxes finance government expenditures). Public spending is given by

$$g_t = g \exp(\varepsilon_{g,t}) y_t \quad (15)$$

where $0 < g \exp(\varepsilon_{g,t}) < 1$ is the public-spending-to-GDP ratio and $\varepsilon_{g,t}$ is a stochastic disturbance with mean zero, following an AR(1) process:

$$\varepsilon_{g,t} = \rho_g \varepsilon_{g,t} + \eta_{g,t}.$$

Similar to Smets and Wouters (2007) and Hofmann *et al.* (2012), we assume that the central bank sets the gross nominal interest rate according to the rule

$$R_t = [R_{t-1}]^{\rho_R} [R_t^*]^{1-\rho_R} \left[\frac{1 + \pi_t}{1 + \pi_t^*} \right]^{a_\pi(1-\rho_R)} [y_t]^{a_y(1-\rho_R)} \left[\frac{y_t}{y_{t-1}} \right]^{a_{\Delta y}} \quad (16)$$

⁹We could have assumed that firms also endogenously select their price indexation rule. However, we keep the model as simple and tractable as possible to study the determination and implications of wage indexation.

where $R_t^* = \beta^{-1} (1 + \pi_{t+1}^*)$ denotes the long-term level for the nominal interest rate. This rule has shown good empirical properties, and we use it in our counterfactual exercises in section 4. The inflation target evolves as

$$\pi_{t+1}^* = \rho_\pi \pi_t^* + \varepsilon_{\pi,t+1}.$$

Unless explicitly mentioned, we assume $\rho_\pi = 1$, implying that inflation-target shocks are permanent.

2.4 Equilibrium, model solution and calibration

Equilibrium in the goods market satisfies the resource constraint, so $y_t = c_t + g_t$, where $c_t \equiv \int_0^1 c_{i,t} di$. In the labor market, the composite labor-input supply equals the aggregate intermediate-firms labor demand, or $\ell_t = \int_0^1 n_{j,t} dj$. Using the input-specific demand function, it follows that $\ell_t = y_t A^{-1} \exp(-z_t) \text{disp}_t^p$, where $\text{disp}_t^p = \int_0^1 \left(\frac{P_{j,t}}{P_t}\right)^{-\theta_p} dj$ is a measure of price dispersion. In equilibrium, there exists a set of prices $\{\lambda_t, P_t, P_{j,t}, W_t, W_{i,t}, R_t\}$ and a set of quantities $\{y_t, g_t, c_{i,t}, b_{i,t}, n_{j,t}, \ell_t, \ell_{i,t}, \chi_t\}$, for all i and j , such that all markets clear at all times, and agents maximize their utility and profits. It is worth mentioning that when ξ_t is given with an exogenous constant in the interval $[0, 1]$, the model is observationally equivalent to a standard New Keynesian model with fixed indexation coefficients.¹⁰

Given an economic regime Σ , we use a second-order perturbation method to solve the model and find the stochastic steady state, as proposed by Schmitt-Grohé and Uribe (2007). We use this method because we are interested in the welfare effects of different indexation schemes.¹¹ Then, given an economic regime, we implement an algorithm to find the equilibrium level for aggregate indexation.

For the analysis in the next section, we calibrate the model according to the results of the *Great Moderation* period of Hofmann *et al.* (2012).¹² Hofmann *et al.* (2012) fix the discount rate β to 0.99; the Frisch elasticity ω equals 2; and θ_p and θ_w are both set to 10. Using a minimum distance estimator to fit the impulse responses of a permanent technology shock and a government spending shock from a time-varying SVAR, Hofmann *et al.* (2012) estimate the degree of external habits ($\gamma^h = .37$), inflation inertia ($\gamma^p = .17$), the degree of rigidities in prices and wages ($\alpha_p = .78$ and $\alpha_w = .54$), the monetary rule

¹⁰We demonstrate in the technical appendix how this model collapses to a representative agent model in the New Keynesian framework.

¹¹Such effects vanish in the linear version of the model (see Kim and Kim, 2003; Schmitt-Grohé and Uribe, 2007).

¹²See their estimation for the first quarter of 2000.

parameters ($\rho_R = .78$, $a_\pi = 1.35$, $a_y = .10$ and $a_{\Delta y} = .39$), and the size of the technology and the government spending shock ($\sigma_z = .31$ and $\sigma_g = 3.25$). Finally, the authors find a degree of wage indexation equal to $\xi = .17$. In section 4, we show that the endogenous indexation criterion that we have described predicts an indexation value consistent with the estimated value. Furthermore, we assume that the level of initial trend inflation is $\pi_0^* = 0$, the public-spending ratio g is $.2$, and the parameters A and ψ are set at levels that put output and labor equal to 1 and $\frac{1}{3}$, respectively, in the deterministic steady state. Finally, for completeness, we set the variance of the trend-inflation shock equal to the estimated value of Cogley *et al.* (2010) for the period 1982-2006 ($\sigma_{\pi^*} = .049$). Note that all parameters lie within the ballpark of empirical findings (see Smets and Wouters, 2007; Cogley, Primiceri and Sargent, 2010).

3 Equilibrium aggregate indexation

This section characterizes the aggregate indexation level that prevails in the long-run equilibrium for a given economic regime. We show that workers decide to index wages to past inflation when technology and (permanent) trend-inflation shocks explain a large proportion of output fluctuations. When demand-side shocks (such as exogenous government spending shocks) dominate the aggregate dynamics, workers prefer to index to trend inflation. We demonstrate how the relationship between wage dispersion and volatility in expected hours explains our results. In addition, we show that equilibrium indexation does not coincide with the socially desired level.

3.1 Welfare costs at the stochastic steady state

At the steady state, worker i 's expected welfare equals his or her unconditional expected value, given by $\mathbb{W}_{ss}(\delta^k, \xi, \Sigma) \equiv E\{\mathbb{W}_{i,t}(\delta^k, \xi, \Sigma)\}$ (see equation 8). Notice that, in general, \mathbb{W}_{ss} varies with the selected indexation rule δ^k , aggregate indexation ξ , and the economic regime Σ . However, if the economic regime contains no stochastic shocks, consumption and labor (and thus welfare) will be invariant to ξ and δ^k . Define this scenario as the deterministic regime Σ_d , and define its associated steady-state welfare \mathbb{W}_d as follows:

$$\mathbb{W}_d = \frac{1}{1 - \beta\alpha_w} \mathcal{U}(c_d, \ell_d).$$

Our calibration implies that $c_d = 0.8$ and $\ell_d = \frac{1}{3}$. It is common in the literature to measure the welfare costs from stochastic regimes in terms of proportional losses in deterministic

steady-state consumption (see Schmitt-Grohé and Uribe, 2007). But these costs could also be measured using leisure, as we do next. Let λ^k for $k \in \{past, trend\}$ denote the required percentage change in ℓ_d that makes a household with indexation rule δ^k indifferent between the deterministic and the stochastic regime. Formally, given δ^k , ξ and Σ , the term λ^k is implicitly defined by

$$\mathbb{W}_{ss}(\delta^k, \xi, \Sigma) = \frac{1}{1 - \beta\alpha_w} \mathcal{U}(c_d, \ell_d(1 + \lambda^k)).$$

Put differently, λ^k measures the increase in *deterministic* labor so that a worker is indifferent between the *deterministic* and the *stochastic* scenario. For the utility function that we have used, it is straightforward to show that

$$\lambda^k = \left[\frac{\mathbb{W}_{ss} \times (1 - \beta\alpha_w) - \log(c_d(1 - \gamma^h))}{\mathbb{W}_d \times (1 - \beta\alpha_w) - \log(c_d(1 - \gamma^h))} \right]^{\frac{1}{1+\omega}} - 1.$$

3.2 Aggregate indexation in the decentralized equilibrium

Assume that the economy is at its stochastic steady state at time t , and that worker i is drawn to re-optimize. According to the indexation-rule selection criterion of page 7, worker i prefers the indexation rule associated with the lowest λ^k . The equilibrium degree of aggregate indexation, denoted by ξ^* , is then obtained according to equation (10). Notice that at the stochastic steady state, it should be the case that $\xi_t = \chi_t = \xi^*$.

There are two types of solutions for the aggregate equilibrium level ξ^* . The corner solution $\xi^* = 0$ is achieved when, for any $\xi \in [0, 1]$, the trend-inflation indexation rule yields the lowest welfare costs (i.e. $\lambda^{trend} < \lambda^{past}$). Similarly, $\xi^* = 1$ when $\lambda^{trend} > \lambda^{past}$ for any $\xi \in [0, 1]$. An interior solution exists if there is at least one $\xi \in [0, 1]$ for which $\lambda^{trend} = \lambda^{past}$; in such a case, workers are indifferent between the indexation rules. Next, we use an array of examples to show that ξ^* is an *equilibrium state* and is *globally stable*.

Let us consider four different regimes, each including *only* one type of shock. The first contains permanent productivity shocks (Σ^{prod}), while the second is driven by government spending shocks (Σ^{dem}). The third and fourth regime display trend-inflation shocks, but in the former, these are permanent shocks ($\Sigma^{\pi^*,P}$, where $\rho_\pi = 1$, so trend inflation is a random walk), while in the latter, these are temporary shocks ($\Sigma^{\pi^*,T}$, where $\rho_\pi = 0.7$, so trend inflation is mildly persistent and stationary). The first row of Figure 2 shows the long-run welfare costs associated with labor contracts with a trend-inflation indexation rule (λ^{trend} is the plain line) and those with a past-inflation rule (λ^{past} is the line with circles).

[Insert Figure 2 here]

In the first three cases (Σ^{prod} , Σ^{dem} , and $\Sigma^{\pi^*,\text{P}}$), there is a corner solution, i.e. for any level of ξ , worker i has a clear preference: he chooses the past-inflation indexation rule when the economy is driven by either productivity shocks or permanent trend-inflation shocks, and he chooses the trend-inflation rule when the aggregate-demand shock drives the economy.¹³ It follows that aggregate indexation is high for regimes Σ^{prod} and $\Sigma^{\pi^*,\text{P}}$ (in equilibrium $\xi^* = 1$), and it is low for regime Σ^{dem} (in equilibrium $\xi^* = 0$).¹⁴ The temporary trend-inflation shock regime has an interior solution, since for $\xi^* = .5$ we have that $\lambda^{\text{trend}} = \lambda^{\text{past}}$.

Notice that ξ^* is an equilibrium for all regimes, since workers have no incentive to change their rule at this level of aggregate indexation. Also, ξ^* is globally stable because, for any initial $\xi_0 \neq \xi^*$, workers choose the contract with the lowest expected losses, and aggregate indexation ξ_t converges towards ξ^* .¹⁵

3.3 Explaining the decentralized equilibrium

To explain workers' indexation choices, recall from the wage-setting problem that nominal rigidities result in welfare losses because they create a wedge between the desired and the actual labor supply schedules. The intuition behind this wedge is straightforward. If nominal wages cannot freely react to macroeconomic shocks, then most of the adjustment in the labor market must come through changes in hours worked. We can thus expect a higher variance of hours in an economic regime with nominal wage rigidities than in a flexible wage regime. In addition, the variance of working hours for each worker depends on the chosen indexation rule.

To see why, it is instructive to decompose the expected labor disutility at the stochastic steady state into its main determinants. In the technical appendix, we show that the labor disutility associated with labor contract k at the stochastic steady state, Ω_{ss}^k , can be approximated as follows:

$$\Omega_{ss}^k \approx \frac{\psi}{1 - \beta\alpha_w} (R_{ss}^k + V_{ss}^k), \quad (17)$$

¹³The aggregate-demand shocks we have analyzed, apart from government spending, are a preference shock, a risk-premium shock *à la* Smets and Wouters (2007), or a high frequency monetary-policy shock (i.e. a temporary deviation from the policy rule). In all cases, we find similar results.

¹⁴A similar picture emerges if we measure welfare costs in terms of the deterministic steady-state consumption instead of leisure.

¹⁵It is worth mentioning that in every single exercise we have performed, either with an interior or a corner solution, ξ^* is globally stable. Our exercises cover several combinations of shocks, such as productivity, preferences, monetary policy, government spending, price-markup, etc. Global stability is achieved because when λ^{past} is greater than λ^{trend} , it happens that $\delta(\lambda^{\text{past}})/\delta\xi$ is steeper or parallel to $\delta(\lambda^{\text{past}})/\delta\xi$. The opposite holds when $\lambda^{\text{past}} \leq \lambda^{\text{trend}}$. It follows that the λ^k 's can cross at most only once.

where

$$R_{ss}^k = \frac{1}{1 + \omega} \left[\frac{\text{disp}_{w,ss}^k}{\xi^k} \times \ell_{ss} \right]^{1+\omega}, \text{ and } V_{ss}^k = \frac{\omega}{2} [R_{ss}^k (1 + \omega)]^{\frac{\omega-1}{\omega+1}} \text{var}(\ell_t^k)$$

with

$$\xi^k = \begin{cases} \xi & \text{if } k = \textit{past} \\ 1 - \xi & \text{if } k = \textit{trend}. \end{cases}$$

The term R_{ss}^k is a *relative measure of variance* that depends on the economy's average level of hours worked, ℓ_{ss} , and the wage dispersion associated with labor contract k , $\text{disp}_{w,ss}^k \times (\xi^k)^{-1}$. The latter term equals 1 when all wages in sector k are equal (no wage dispersion) and it is different from one when at least one worker has a wage (and working hours) different from his sector peers.¹⁶ In the technical appendix, we show how wage dispersion can be written as a function of hours worked¹⁷

$$\frac{\text{disp}_{w,ss}^k}{\xi^k} = 1 + \frac{1}{2\theta_w} \text{E} \{ D_k(\bar{\ell}_t^k) \} - \mu_w \left(\frac{\xi^k - \tilde{w}_{ss}^k}{\xi^k} \right), \quad (18)$$

where

$$\begin{aligned} D_k(\bar{\ell}_t^k) &= \frac{1}{\xi^k} \int_{i \in IR_k} (\ln \ell_{i,t} - \ln \ell_t)^2 di, \text{ and} \\ \bar{\ell}_t^k &= \{ \ln \ell_{i,t} - \ln \ell_t : i \in IR_k \}. \end{aligned}$$

The vector $\bar{\ell}_t^k$ contains the log difference between the individual hours worked in an indexation-rule sector and the economy's average. The function D_k takes the average of the squared values in $\bar{\ell}_t^k$.¹⁸ Thus, R_{ss}^k increases with the average squared deviation of hours worked in sector k with respect to the *reference* hours worked. The third term on the right hand side of equation (18) is a small correction term associated with the difference between the weight of relative wages, \tilde{w}_{ss}^k , and its deterministic steady state level ξ^k .¹⁹

The second term in equation (17), V_{ss}^k , is proportional to a measure of the *total variance* in contract-specific hours, which depends on the stochastic economic environment and is

¹⁶See the definition of wage dispersion per sector in equation (11).

¹⁷Similar expressions for total wage dispersion can be found in Erceg *et al.* (2000) or Galí and Monacelli (2004).

¹⁸In fact, D_k is proportional to the square of the Euclidean norm of vector $\bar{\ell}_t^k$, i.e. $D_k(\bar{\ell}_t^k) = \frac{1}{\xi^k} \|\bar{\ell}_t^k\|^2$.

¹⁹Notice that the sum of all relative wages, $\tilde{w}_{ss}^1 + \tilde{w}_{ss}^2$, must be equal to 1 due to the zero-profit condition of the labor intermediary (i.e., $W_t = \left[\int_0^1 W_{i,t}^{1-\theta_w} di \right]^{\frac{1}{1-\theta_w}}$). However, within each labor sector, some deviations may occur at the stochastic steady state.

independent of any reference point. Note that although R_{ss}^k also appears in the definition of V_{ss}^k , it plays only a minor role.²⁰

In sum, the disutility of workers increases with the volatility in their expected labor supply in general, $\text{var}(\ell_t^k)$, as well as with the relative variance of hours, $D_k(\bar{\ell}_t^k)$. However, it is this second term that explains the equilibrium aggregate wage indexation levels that we found for each single-shock regime depicted in Figure 2. The second row of the Figure shows the relative wage dispersion measures as represented by $\text{Rdisp}_w^k = \text{disp}_{w,ss}^k \times (\xi^k)^{-1}$. Notice that $\text{disp}_{w,ss}^k$ may be either above or below ξ^k , while the population average lies fairly close to 1 (light dashed line). For a given level of ξ , workers prefer the contract with the lowest wage dispersion, which is consistent with the welfare cost analysis shown in the plots of the first row. In Section 3.5, we re-assess the importance of the relative versus the total variance in hours in a multiple-shock regime.

3.4 Social *versus* private welfare

The equilibrium aggregate indexation ξ^* described above corresponds to a set of uncoordinated decisions among workers; it is thus a decentralized equilibrium and it might not reflect the socially desired indexation level. In fact, in most cases, ξ^* differs from the socially optimal level, as we show next.

Social welfare is obtained by adding up all households' welfare, i.e.,²¹

$$\text{SW}_t = E_t \left\{ \sum_{T=t}^{\infty} \beta^{T-t} \int_0^1 \mathcal{U}(c_T, \ell_{i,T}) di \right\},$$

which differs from private welfare in two main respects. First, social welfare is the weighted sum of every single household in the economy, regardless of their last wage re-optimization. In contrast, the individual measure $\mathbb{W}_{i,t}$ refers only to the welfare of those workers drawn to reset their wage contract in period t . Second, social welfare is not conditional on the average duration of a labor contract, so the discount factor is closer to 1 than for private welfare.

At the stochastic steady state, social welfare converges to its unconditional expected level, defined as $\text{SW}_{ss}(\xi, \Sigma) \equiv E(\text{SW}_t)$. Notice that SW_{ss} varies with aggregate indexation and the economic regime. The upper bound in social welfare is achieved when there are no shocks to the economy and there is no chance that they will ever happen, i.e. the deterministic scenario. In all other stochastic regimes, there will be welfare losses, which can

²⁰For instance, if the Frisch elasticity ω equals 1, then R_{ss}^k drops out from the definition of V_{ss}^k . At the actual calibration of $\omega = 2$, only a third of the percent changes in R_{ss}^k are passed through as percent changes in V_{ss}^k , where most variations are due to the total variance term $\text{var}(\ell_t^k)$.

²¹Because there are no differences in wealth or consumption, each household has a similar weight.

be measured in the same way as private welfare. Let λ^S denote the increase in deterministic hours worked that leaves the *representative* household indifferent between the deterministic and the stochastic regime, i.e.,

$$\lambda^S = \left[\frac{\mathbb{S}W_{ss} \times (1 - \beta) - \log(c_d(1 - \gamma^h))}{\mathbb{S}W_d \times (1 - \beta) - \log(c_d(1 - \gamma^h))} \right]^{\frac{1}{1+\omega}} - 1,$$

where $\mathbb{S}W_d = \frac{1}{1-\beta} \mathcal{U}(c_d, \ell_d)$. Gray (1976) and Fischer (1977) show that the socially optimal degree of aggregate indexation depends on the structure of shocks prevailing in the economy, i.e. on the economic regime Σ . They argue that full indexation to past inflation ($\xi = 1$) is optimal when only nominal shocks prevail, and that no indexation to past inflation ($\xi = 0$) is optimal when only real shocks occur. Gray and Fischer's results hold in a New Keynesian model such as ours, as we show in the third row of figure 2 (see also Amano *et al.*, 2007). Let ξ^S be the level of aggregate indexation to past inflation that minimizes social welfare losses. It follows that no indexation is socially optimal when the economy is driven by permanent productivity shocks and temporal inflation-target shocks (regimes Σ^{prod} and $\Sigma^{\pi^*,\text{T}}$). In contrast, full indexation is optimal in response to aggregate spending shocks and permanent inflation shocks (regimes Σ^{dem} and $\Sigma^{\pi^*,\text{P}}$).

Interestingly, ξ^* and ξ^S differ substantially for regimes Σ^{prod} and Σ^{dem} . They indeed oppose each other from corner to corner. The reason is that the socially optimal indexation level aims to stabilize the real wage, thus avoiding excessive fluctuations in both aggregate labor and consumption (see Gray, 1976). However, even if the economy starts at ξ^S , individual workers have the incentive to change their indexation rules because, at the margin, they can obtain gains in terms of a lower wage dispersion. Indeed, in the decentralized equilibrium, workers neglect the effect that their own indexation-rule decision imposes on others, given their atomistic size with respect to the entire population. The decentralized equilibrium is therefore inefficient because the externalities caused by workers' uncoordinated decisions create unnecessary fluctuations and higher welfare costs.

3.5 Comparison of *total* and *relative* variance in hours

In the single-shock regimes described above, the differences in labor disutility are almost exclusively driven by R_{ss}^k , the *relative measure of variance*, while the measure of *total variance in hours* V_{ss}^k is negligible. However, in multiple-shock regimes, V_{ss}^k is larger and its importance in determining the aggregate indexation equilibrium might increase. In the following example, we show that even in an economic regime with multiple shocks, it is still the case

that at the margin, important changes in wage dispersion drive the indexation rule choice.

Let $\tilde{\Sigma}$ represent an economic regime with productivity and government spending shocks. In the baseline case, shock variances are calibrated to deliver an equilibrium where 50% of workers index to past inflation. We now consider an experiment where we increase the standard deviation of both shocks, first by 5% and then by 10% relative to the baseline. With the volatility of both shocks increased by the same factor, one would expect the total variance in hours worked to increase in both indexation-rule sectors. However, since the relative importance of the two shocks in the economy has not changed, the wage dispersion measures should remain roughly the same and therefore we should not see important changes in equilibrium wage indexation.

The first row of Figure 3 shows the effects of this experiment and confirms our intuition. The first panel uses three crosses to depict the wage indexation equilibria. The bottom cross represents the baseline and the two others show that increasing the shock variances raises welfare costs (y-axis) but leaves equilibrium indexation close to baseline, shifting from 50% to 49% (x-axis). The second and third panel show how the subcomponents of labor disutility are affected. The bars portray the average changes in V_{ss}^k and R_{ss}^k for each $\xi \in [0, 1]$. The total variance terms in the second panel increase substantially but equally when the volatility of shocks increases. In contrast, we observe in the third panel that very small changes in wage dispersion occur in each sector and that these shifts favor indexing to trend inflation (wage dispersion increases for the π_{t-1} -contracts and decreases for the π_t^* -contracts). These changes explain the marginal shift in equilibrium indexation from 50% to 49%.

We now consider a second experiment in which we keep the standard deviation of the productivity shock at the baseline value and raise the standard deviation of the government spending shock in two stages by 5 and 10% relative to the baseline. The second row of Figure 3 shows that this experiment leads to very different outcomes: equilibrium wage indexation falls sharply, the total variance measures increase unequally but less than before and the wage dispersion measures change four times more than in the previous case. These large changes in wage dispersion create important differences in labor disutility, which explains why the trend-inflation contract is now the strongly favored indexation rule.

4 Explaining the stylized facts

In this section, we first demonstrate that the model predictions for aggregate indexation are consistent with the stylized facts discussed in the introduction. Specifically, the model predicts high indexation for the *Great Inflation* and low indexation for the *Great Moderation*

periods. We then show via counterfactual analyses that high indexation during the *Great Inflation* was most likely due to volatile productivity shocks rather than loose monetary policy.

4.1 Model predictions for the *Great Moderation* and the *Great Inflation*

We build our analysis on the results of Hofmann *et al.* (2012), where a New-Keynesian model similar to ours is considered.²² Hofmann *et al.* (2012) estimate the model for three different time periods (1960Q1, 1974Q1 and 2000Q1) by minimizing the distance between the DSGE implied impulse responses and those obtained from a Bayesian structural VAR with time-varying parameters in the spirit of Cogley and Sargent (2005) and Primiceri (2005). Within the VAR, the dynamic effects of supply and demand shocks are estimated. The former is then matched with a permanent productivity shock in the DSGE model and the latter with a government spending shock. We use the estimated parameters of the DSGE model of Hofmann *et al.* (2012) for respectively the *Great Inflation* (1974Q1) and *Great Moderation* (2000Q1) periods to calculate the predictions of our model for aggregate indexation.

Table (1) shows the parameters for the two periods that we consider. A set of calibrated parameters common for both periods is shown in the first part of the table. For the specific parameters of each regime, we take the median values of the posterior distributions of Hofmann *et al.* (2012). Notice that Hofmann *et al.* (2012) do not consider trend inflation shocks. To accommodate this difference, we consider two cases for our predictions. In case 1, trend inflation remains constant ($\sigma_{\pi^*} = 0$). In case 2, we use the posterior median estimated values for trend inflation volatility from Cogley *et al.* (2010) for the two regimes.²³ They find that trend inflation volatility is higher in the *Great Inflation* than in the *Great Moderation* period. As can be seen in Table (1), the parameters for each regime exhibit typical patterns found in the literature.²⁴ For example, the persistence parameters such as habits (γ^h) and inflation inertia (γ^p) were higher during the *Great Inflation* period, while the response of the Federal Reserve to inflation deviations from target in the Taylor rule (a_π) was lower. We also report the estimated degree of wage indexation ($\hat{\xi}$) from Hofmann *et al.* (2012) for both regimes, which should be compared with our predicted aggregate indexation measures. The

²²The only difference is that in the framework of Hofmann *et al.* (2012), the wage indexation coefficient is not endogenously determined, and there are no inflation target shocks.

²³Cogley *et al.* (2010) estimate a New Keynesian model with sticky prices and flexible wages using Bayesian methods over two sample periods: 1960:Q1-1979:Q3 and 1982:Q4-2006:Q4. We use the estimated σ_{π^*} for both subperiods for respectively the *Great Inflation* and the *Great Moderation* calibrations.

²⁴See Boivin and Giannoni (2006) or Smets and Wouters (2007).

estimated degree of wage indexation is high in the 1970s and low in the 2000s.

The model predictions of the aggregate degree of wage indexation conditional on each regime are reported at the bottom of Table (1). For case 1, with constant trend inflation, the model predicts an aggregate degree of wage indexation ξ^* of 0 for the *Great Moderation* and .89 for the *Great Inflation*. The model's endogenous predictions are thus consistent with the estimated degree of wage indexation from Hofmann *et al.* (2012) and also the COLA index reported in the introduction. Somewhat surprisingly, adding trend inflation volatility to the analysis has no effect on the results. Specifically, allowing for time-varying trend inflation, the ξ^* estimates of case 2 remain at the same levels for both regimes. The reason for this result is that the trend-inflation shocks are relatively small compared to the other shocks in the economy, even during the *Great Inflation*, when trend-inflation volatility was twice as high. According to the model, trend inflation only explains approximately .79 percent of the long-run total output fluctuations in the 1974 regime. For the 2000 regime, they explain 1.25 percent. Notably, Ireland (2007) reports a similar explanatory power for trend-inflation shocks at impact in a New Keynesian model estimated with Bayesian methods including several shocks.²⁵

The bottom parts of Table (1) also report the model-based socially optimal rate of aggregate indexation ξ^S . Notice that the social optimum diametrically differs from the decentralized equilibrium presented above. Indeed, the social planner would have opted for high indexation during the *Great Moderation* and low indexation during the *Great Inflation*. As discussed in the previous section, these are the recommendations elicited from the seminal contributions of Gray (1976) and Fischer (1977), which appear to be at odds with the stylized facts.

4.2 Counterfactual analysis

In a next step, we conduct a counterfactual analysis to detect the primary drivers of the changes in wage indexation presented above. The exercise is divided in two parts. First, we run a series of counterfactuals, where we take the calibrated parameters for 2000 from Table (1) and then set each parameter one-by-one to its 1974 value.²⁶ The implied equilibrium ξ^* values from these counterfactuals are shown in column (1) of Table (2). For the second part, we do the opposite: we start from the 1974 calibration and substitute each parameter with

²⁵In Ireland's estimation, the long-run contribution of trend-inflation shocks to output fluctuations is even lower, converging to zero as the horizon increases.

²⁶The entry in the first row and first column of Table (2) thus corresponds to the 2000 calibration except for σ_z , which is set to its 1974 value. The entry below corresponds to the 2000 calibration with σ_g at its 1974 value, etc.

its 2000 value. These results are shown in column (2) of Table (2). The results reported in both columns should allow us to assess whether there was a dominant factor explaining the changes in ξ^* . We first discuss the effect of changes in the volatility of shocks, followed by the monetary policy rule and finally structural changes.

The relative importance of shocks Several studies have documented a substantial difference in the volatility of aggregate shocks between the *Great Inflation* and the *Great Moderation* periods (see e.g. Sims and Zha, 2006). The consequences of changes in the volatility of shocks on changes in wage indexation in both periods are shown in part I of Table (2). Starting from the 2000 parameter values in column (1) and substituting the standard deviation of the technology shocks (σ_z) by its 1974 value has a strong effect on the degree of wage indexation. In particular, ξ^* shifts from 0 to 1. Replacing the volatility of the trend-inflation shock (σ_{π^*}) by its 1974 value has a smaller but still substantial impact as ξ^* increases to .6. However, substituting the volatility of the government spending shocks leaves ξ at zero. The direction of these changes is consistent with the results reported in section 3.2. Specifically, we showed that a regime driven by either productivity or permanent inflation target shocks results in an equilibrium where $\xi^* = 1$, whereas a regime driven by demand shocks results in an equilibrium with $\xi^* = 0$. What is surprising, however, is that raising the inflation target shock volatility to its 1970s value has a large effect on the predicted degree of wage indexation, while σ_{π} only had a small effect on the level of indexation in the model predictions.

A cross check with column (2) of Table (2) shows that there is no inconsistency. The column shows how ξ^* changes from its value of .89 in 1974 when we substitute the volatility of each shock by its value in 2000. Technology shocks are again important, as they drive ξ to zero. Replacing the volatility of trend inflation, however, has no effect, as ξ remains .89. This result occurs because technology shocks had such a large variance in 1974 that the variance of trend inflation becomes unimportant in relative terms. We interpret this result as evidence that technology shock volatility was the key driver of changes in wage indexation over time and not trend inflation. This exercise illustrates that the consequences of changes in some of the parameters depend on the other parameters in the calibration. In this case, the trend-inflation shock volatility in 1974 was simply too small to have a relevant effect on wage indexation. Finally, it is clear that changes in the government spending shock variance cannot explain the stylized facts.²⁷

²⁷In the technical appendix, we show that changes in the variance of monetary policy shocks (the non-systematic part of monetary policy) have a negligible effect on the equilibria.

Changes in Monetary Policy The good-policy hypothesis for the *Great Moderation* asserts that macroeconomic fluctuations have become more stable in the post-*Great Inflation* period as a result of a shift in the monetary policy rule (see e.g. Clarida *et al.*, 2000). Such a shift could have changed inflation dynamics and hence indexation practices. However, the second part of Table (2) shows that substituting the values of the 2000 policy rule by their 1974 counterparts has no significant effect on the equilibrium of wage indexation. There is only a slight increase of ξ^* from 0 to .05 for the substitution of the output gap coefficient, but the cross-checks in column (2) mostly predict an *increase* in wage indexation when we replace the policy rule parameters of 1974 by the values of the 2000 rule. This exercise clearly shows that changes in the conduct of monetary policy cannot explain the observed variations in wage indexation.

Structural change Finally, we check whether other structural changes in the economy could have caused changes in indexation practices. It is clear that habit formation (γ^h), Calvo-price rigidity (α_p) and the persistence of demand shocks (ρ_g) cannot explain the stylized facts. In column (1), these parameters have no effect on ξ , and in column (2), they predict either little change or the wrong direction of change for ξ .

The interpretation of changes in inflation inertia (γ^p) and Calvo-wage rigidity (α_w) is more challenging. Column (1) shows that setting inflation inertia to its 1974 value in the 2000 benchmark has a large effect, i.e. ξ increases from 0 to .78. However, in column (2), changing this parameter from its 1974 value to its 2000 value only has a small effect on ξ^* , which decreases from .89 to just .77. We can therefore conclude that the effect of this parameter depends on the entire set of parameters in the calibration. Concerning Calvo-wage rigidity, it predicts a moderate increase of ξ^* from 0 to .49 in column (1). However, column (2) predicts that a *decrease* in this parameter leads to an *increase* in ξ^* from .89 to .95, which is a strong indication that non-linearities are at play.²⁸ We conclude that there is no clear indication that changes in γ^p and α_w or the other structural parameters have been important contributors to the observed changes in wage indexation.

5 Conclusion

In this paper, we have proposed a novel microfounded approach to endogenize wage indexation in a standard New-Keynesian DSGE model with sticky wages and prices. In the

²⁸In the technical appendix, we show that the changes in the nominal rigidities parameters result in highly nonlinear effects on equilibrium ξ^*

model, workers can choose to index their wages either to trend inflation or past inflation to minimize *individual* welfare losses coming from wage rigidities. The selection of a specific wage indexation rule could essentially lower welfare costs by reducing the gap between the desired and the actual labor supply. We find that workers index their wages to past inflation when permanent shocks to technology and the inflation target are important drivers of output fluctuations. In contrast, when aggregate demand and temporal inflation target shocks dominate, workers index wages to the inflation target.

Furthermore, we find that the decentralized equilibrium of wage indexation, which is the aggregate of individual worker's decisions, is very different from the socially optimal level of indexation, which minimizes the *average* welfare losses across workers. Specifically, we find that at the individual level, workers have an incentive to deviate from the social optimum. Because workers do not take the externalities of their decisions into account, a decentralized equilibrium emerges that is, in general, different from the social optimum and therefore inefficient.

In a next step, we show that the model predictions can very well explain the degree of wage indexation in the U.S. for respectively the *Great Inflation* and the *Great Moderation* periods, as documented in Hofmann *et al.* (2012). In particular, the model predicts a high degree of wage indexation to past inflation for the *Great Inflation* and a low degree of indexation for the *Great Moderation*, which is consistent with the stylized facts. This result occurs because workers prefer past-inflation indexation in regimes dominated by strong technology shocks (like the 1970s), while they prefer target-inflation indexation in regimes driven by aggregate-demand shocks (presumably, the 2000s). We also show that the relative importance of aggregate shocks in explaining output fluctuations, and not changes in monetary policy, was a crucial determinant for the presumed variations of wage indexation in the U.S.

This paper partially responds to recent concerns about the lack of endogenous channels explaining price and wage inflation persistence (see Benati, 2008). Models with such devices are indispensable tools for the conduct of monetary policy. It is thus desirable to extend the framework to a price setting, which should be an interesting avenue for future research.

References

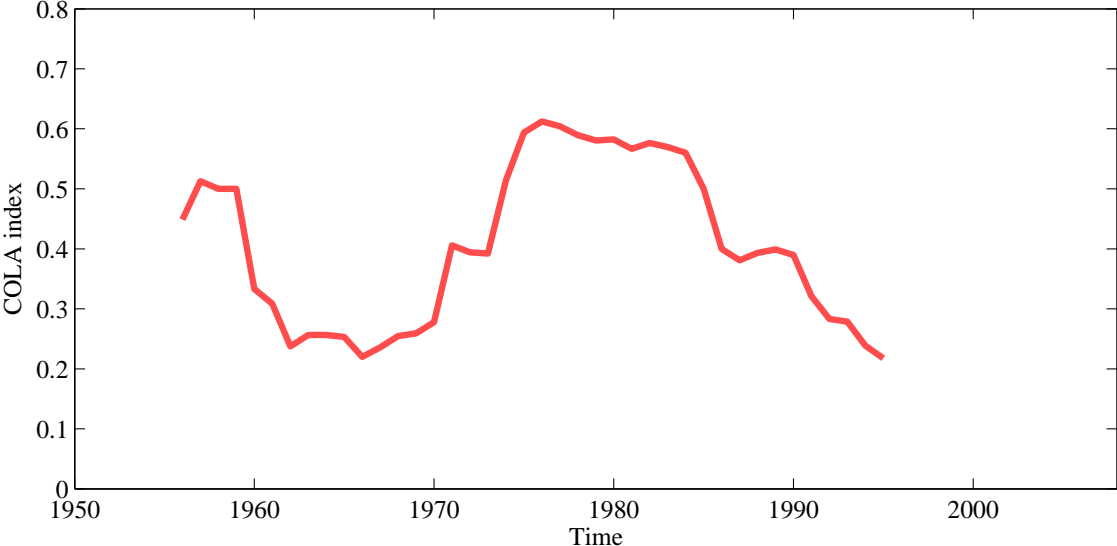
- Amano, R., Ambler, S. and Ireland, P. (2007) Price-Level Targeting, Wage Indexation and Welfare, Bank of Canada, Manuscript.
- Ascari, G., Branzoli, N. and Castelnuovo, E. (2011) Trend Inflation, Wage Indexation, and Determinacy in the U.S, Quaderni di Dipartimento 153, University of Pavia, Department of Economics and Quantitative Methods.
- Benati, L. (2008) Investigating inflation persistence across monetary regimes, *The Quarterly Journal of Economics*, **123**, 1005–1060.
- Boivin, J. and Giannoni, M. P. (2006) Has monetary policy become more effective?, *The Review of Economics and Statistics*, **88**, 445–462.
- Bruno, M. and Sachs, J. (1985) *Economics of worldwide stagflation*, Harvard University Press.
- Calmfors, L. and Driffill, J. (1988) Bargaining structure, corporatism and macroeconomic performance, *Economic policy*, pp. 14–61.
- Calmfors, L. and Johansson, A. (2006) Nominal wage flexibility, wage indexation and monetary union, *Economic Journal*, **116**, 283–308.
- Calvo, G. A. (1983) Staggered prices in a utility-maximizing framework, *Journal of Monetary Economics*, **12**, 383–398.
- Cho, J. (2003) Optimal wage indexation.
- Christiano, L. J., Eichenbaum, M. and Evans, C. L. (2005) Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy, *Journal of Political Economy*, **113**, 1–45.
- Clarida, R., Gal, J. and Gertler, M. (2000) Monetary policy rules and macroeconomic stability: Evidence and some theory, *The Quarterly Journal of Economics*, **115**, 147–180.
- Cogley, T., Primiceri, G. E. and Sargent, T. J. (2010) Inflation-Gap Persistence in the US, *American Economic Journal: Macroeconomics*, **2**, 43–69.
- Cogley, T. and Sargent, T. J. (2005) Drift and Volatilities: Monetary Policies and Outcomes in the Post WWII U.S, *Review of Economic Dynamics*, **8**, 262–302.

- Cover, J. and van Hoose, D. (2002) Asymmetric wage indexation, *Atlantic Economic Journal*, **30**, 34–47.
- Devine, J. M. (1996) Cost-of-living clauses: Trends and current characteristics, *Compensation and Working Conditions*, US Department of Labor, **24**, 29.
- Erceg, C. J., Henderson, D. W. and Levin, A. T. (2000) Optimal monetary policy with staggered wage and price contracts, *Journal of Monetary Economics*, **46**, 281–313.
- Fischer, S. (1977) Wage indexation and macroeconomics stability, *Carnegie-Rochester Conference Series on Public Policy*, **5**, 107–147.
- Galí, J. and Monacelli, T. (2004) Monetary policy and exchange rate volatility in a small open economy, Economics Working Papers 835, Department of Economics and Business, Universitat Pompeu Fabra.
- Gray, J. (1976) Wage indexation: a macroeconomic approach, *Journal of Monetary Economics*, **2**, 221–235.
- Hofmann, B., Peersman, G. and Straub, R. (2012) Time Variation in U.S. Wage Dynamics, *Journal of Monetary Economics*, **59**, 769 – 783.
- Holland, A. S. (1988) The changing responsiveness of wages to price-level shocks: Explicit and implicit indexation, *Economic Inquiry*, **26**, 265–279.
- Ireland, P. N. (2007) Changes in the Federal Reserve’s Inflation Target: Causes and Consequences, *Journal of Money, Credit and Banking*, **39**, 1851–1882.
- Kim, J. and Kim, S. H. (2003) Spurious welfare reversals in international business cycle models, *Journal of International Economics*, **60**, 471–500.
- Le, V. P. M. and Minford, P. (2007a) Calvo contracts - optimal indexation in general equilibrium, Cardiff Economics Working Papers E2007/8, Cardiff University, Cardiff Business School, Economics Section.
- Le, V. P. M. and Minford, P. (2007b) Optimising indexation arrangements under calvo contracts and their implications for monetary policy, Cardiff Economics Working Papers E2007/7, Cardiff University, Cardiff Business School, Economics Section.
- Mash, R. (2007) Endogenous Indexing and Monetary Policy Models, Kiel Working Papers 1358, Kiel Institute for the World Economy.

- Minford, P., Nowell, E. and Webb, B. (2003) Nominal Contracting and Monetary Targets - Drifting into Indexation, *The Economic Journal*, **113**, 65–100.
- Primiceri, G. E. (2005) Time varying structural vector autoregressions and monetary policy, *The Review of Economic Studies*, **72**, 821–852.
- Ragan, J. F. J. and Bratsberg, B. (2000) Un-COLA: why have cost-of-living clauses disappeared from union contracts and will they return?, *Southern Economic Journal*, **67**, 304–324.
- Schmitt-Grohé, S. and Uribe, M. (2007) Optimal simple and implementable monetary and fiscal rules, *Journal of Monetary Economics*, **54**, 1702–1725.
- Sims, C. A. and Zha, T. (2006) Were there regime switches in us monetary policy?, *The American Economic Review*, pp. 54–81.
- Smets, F. and Wouters, R. (2007) Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach, *American Economic Review*, **97**, 586–606.
- Wieland, V. (2009) Learning, Endogenous Indexation, and Disinflation in the New-Keynesian Model, in *Monetary Policy under Uncertainty and Learning* (Eds.) K. Schmidt-Hebbel and C. E. Walsh, Central Bank of Chile, vol. 13 of *Central Banking, Analysis, and Economic Policies Book Series*, chap. 11, pp. 413–450, 1 edn.

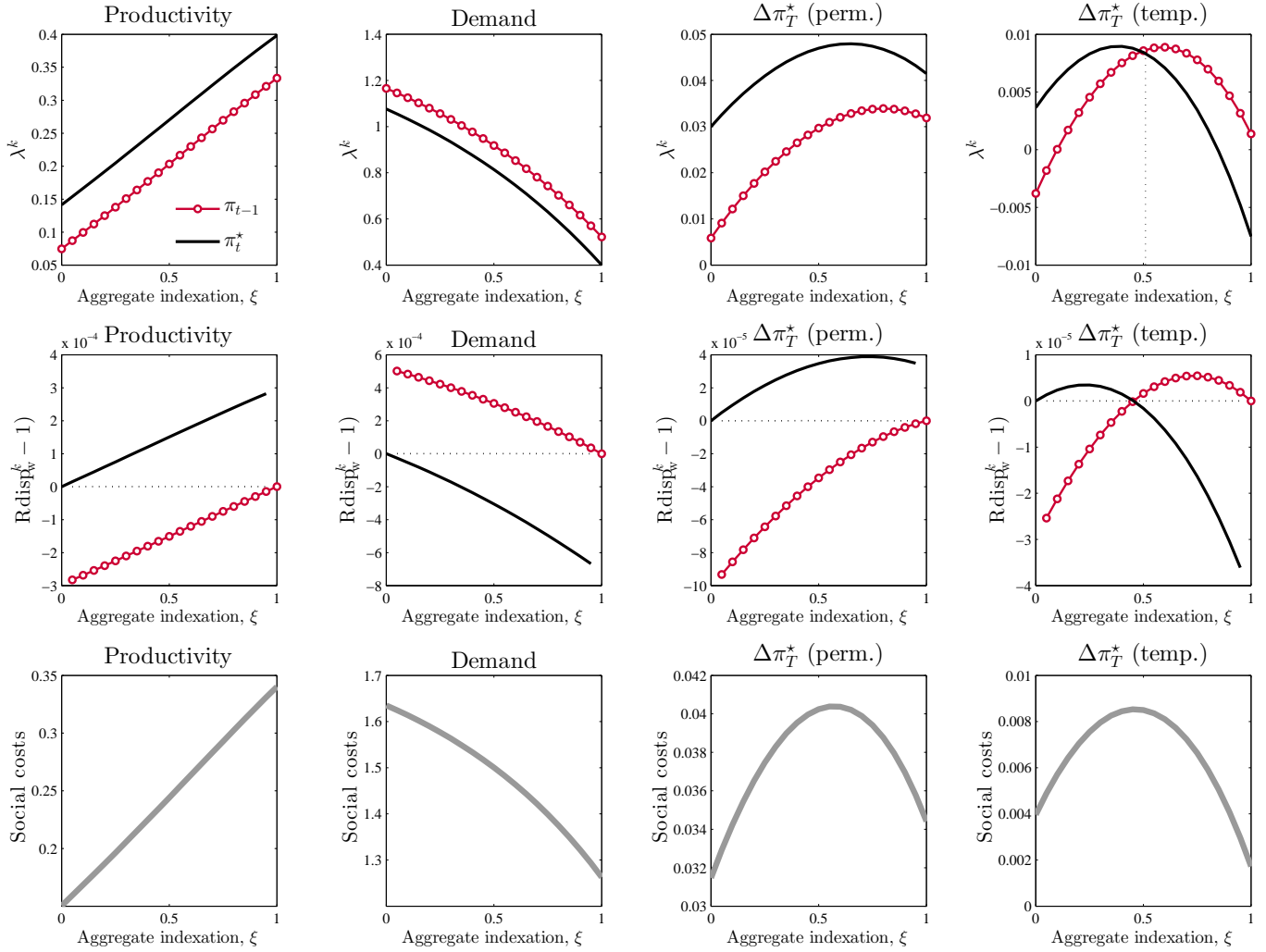
Table and figures

Figure 1: Presumed wage indexation in the U.S.



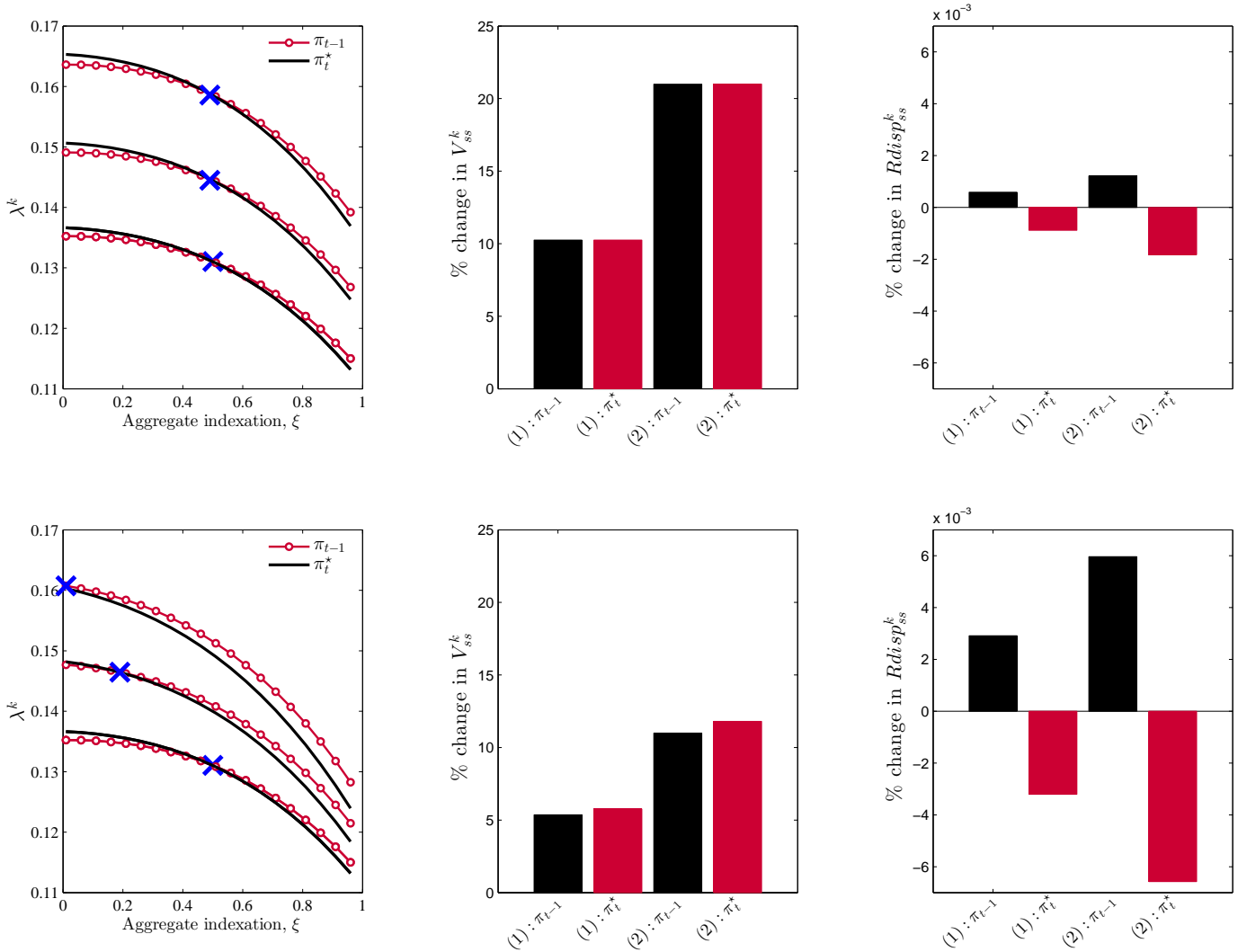
Note: The COLA index gives the proportion of union workers in large collective bargaining agreements with explicit contractual wage indexation clauses. The series is annual from 1956-1995. Source: Ragan and Bratsberg (2000).

Figure 2: Welfare costs and wage dispersion for different economic regimes.



Note: Labor-based welfare costs conditional on specific shocks. The model is solved using a Taylor expansion of order two.

Figure 3: Total and relative variance of hours worked.



Note: The figure shows the changes in aggregate indexation of two experiments. In the first experiment, depicted in row 1, we increase the standard deviation of all of the shocks in the economy (here, only technology and government spending) first by 5 percent and then by 10 percent. The first case is noted as (1) and the second as (2). In both cases, the changes in the equilibrium level of wage indexation are negligible (see the crosses in the first panel). In the second row, we only increase the standard deviation of the government spending shock by the same proportions as before. In these scenarios, the equilibrium wage indexation sharply falls, which is explained by the important changes in wage dispersion, which favor the trend inflation indexation rule.

Table 1. Validation exercises

		Great Moderation 2000 (benchmark)	Great Inflation 1974
<i>Common parameters</i>			
β	Subj. discount factor	.99	.99
σ	Intertemp. elasticity of subst.	1	1
ϕ^{-1}	Labor share	1	1
ω^{-1}	Frisch elast. of labor supply	2	2
θ_w	Elast. labor demand	10	10
θ_p	Elast. input demand	10	10
<i>Specific parameters</i>			
γ^h	Habit formation	.37	.71
γ^p	Inflation inertia	.17	.8
α_p	Calvo-price rigidity	.78	.84
α_w	Calvo-wage rigidity	.54	.64
a_π	Taylor Rule: inflation	1.35	1.11
a_y	Taylor Rule: output gap	.1	.11
$a_{\Delta y}$	Taylor Rule: output gap growth	.39	.5
ρ_R	Taylor Rule: smoothing	.78	.69
σ_z	Std. dev. Tech. shock	.31	1.02
σ_g	Std. dev. Dem. shock	3.25	4.73
ρ^g	Autocorr. Dem. shock	.91	.89
$\hat{\xi}$	Estimated indexation by HPS	.17	.91
<i>Case 1: $\sigma_{\pi^*} = 0$</i>			
ξ^*	Implied equilibrium indexation	0	.89
ξ^S	Implied social optimum	1	0
<i>Case 2: $\sigma_{\pi^*} > 0$</i>			
σ_{π^*}	Std. dev. inflation target	.049	.081
ξ^*	Implied equilibrium indexation	0	.89
ξ^S	Implied social optimum	1	0

Note : All *common* and *specific* parameter values are extracted from Hofmann *et al.* (2012). The standard deviations for trend inflation are taken from Cogley *et al.* (2010). The *implied* indexation values are computed using the tools provided in section 3.

Table 2. Counterfactual exercises

		2000's ξ^* is 0, applying 1974 value to: $\xi^{counterfactual}$ (1)	1974's ξ^* is .89, applying 2000 value to: $\xi^{counterfactual}$ (2)
<i>I - Shocks</i>			
σ_z	Std. dev. Tech. shock	1	0
σ_g	Std. dev. Dem. shock	0	1
σ_{π^*}	Std. dev. inflation target	.6	.89
<i>II - Policy parameters</i>			
a_π	Taylor Rule: inflation	0	1
a_y	Taylor Rule: output gap	.05	.89
$a_{\Delta y}$	Taylor Rule: output gap growth	0	1
ρ_R	Taylor Rule: smoothing	0	.94
<i>III - Structural parameters</i>			
γ^h	Habit formation	0	1
γ^p	Inflation inertia	.78	.77
α_p	Calvo-price rigidity	0	.89
α_w	Calvo-wage rigidity	.49	.95
ρ^g	Autocorr. Dem. shock	0	.85

Note : In this exercise, we keep all parameters at their calibrated values as indicated in the top of columns (1) and (2), and we only change the value of the parameter indicated in each row. Our aim is to evaluate the impact of the change in each parameter on wage indexation.