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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 driven 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.

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1 Introduction

Price and wage inflation are very persistent. To replicate this feature, New-Keynesian *dynamic stochastic general equilibrium* (DSGE) models typically assume 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 et al., 2000; Christiano et al., 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 et al. (2012) document considerable time variation in the degree of wage indexation.[2] They find a degree of wage indexation of 91% during the *Great Inflation*, compared to 30% and 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. the so-called second-round effects, that amplify the effects of shocks on inflation. Accordingly, larger changes in the policy interest rate are 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 the *Great Inflation* to the *Great Moderation* implies a reduction in the long-run impact of a supply and demand shocks on prices of 44% and 39%, respectively.

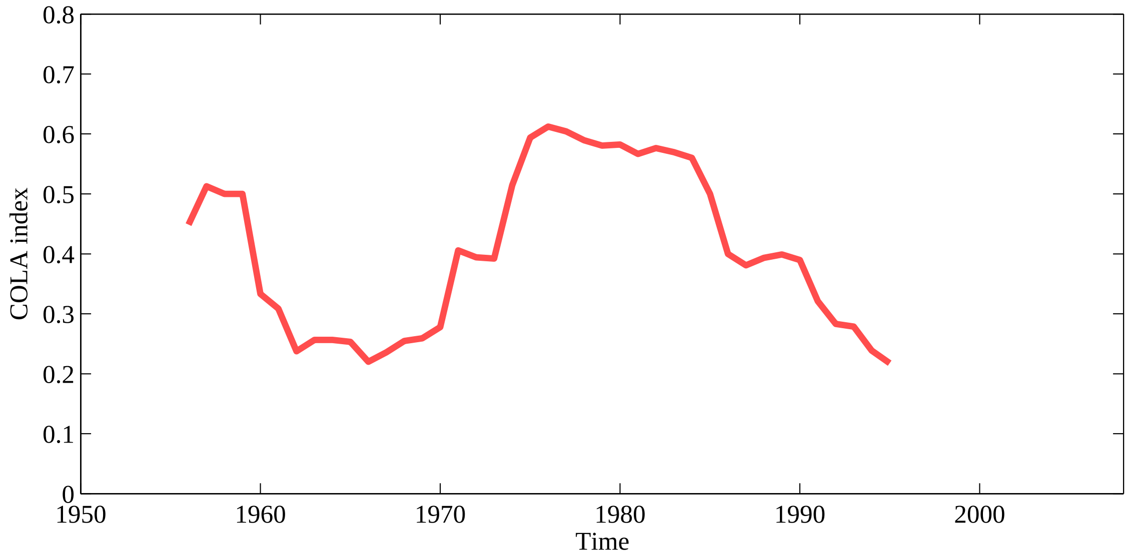
In this paper, we build a standard NK-DSGE model, where the level of wage indexation is endogenously determined using sound micro-foundations, to study changes in wage indexation over time.[3] The novelty of our model is that, in periods when a worker's wage is re-optimized,

[1]The 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 nonunion wages reacted more to price-level shocks the more indexed were union wage contracts, which suggests the existence of implicit indexation for nonunion wages.

[2]Hofmann 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.

[3]The 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

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).

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, subject to 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, i.e. at 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

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.

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

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 aggregate indexation matches the stylized facts reported in Hofmann et al. (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 often find a *coordination failure* among workers' decisions, i.e. the decentralized equilibrium of wage indexation does not, in general, 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. Interestingly, the social planner's solution is consistent with the seminal work of Gray (1976) and Fischer (1977) on optimal wage indexation. These authors 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

[5]Gray (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.

[6]Several 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

incentive to deviate from the social planner's solution because this increases individual utility. As all workers act similarly and do not internalize the externality that their indexation choice causes 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 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.,

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

Le and Minford, 2007a,b).

[7] A full description of the model can be found in the online technical appendix, which is available at Julio Carrillo's website: https://sites.google.com/site/julioart/research.

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

$$c_{i,T} + \frac{b_{i,T}}{R_T} \leq \frac{W_{i,T}}{P_T}\ell_{i,T} + \frac{b_{i,T-1}}{1+\pi_T} + \frac{\Upsilon_{i,T}}{P_T} \qquad \forall T = t, t+1, t+2, ... \tag{2}$$

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

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

The parameters γ^h and ω are respectively, the degree of consumption habits and the inverse Frisch elasticity of 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 an individual 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 a 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 $W_{i,t}^{k,\star}$ for either contract $k = trend$ or contract $k = past$. Thus, in period $T > t$, worker i's wage is updated to either $W_{i,T}^{trend} = \delta_{t,T}^{trend} W_{i,t}^{trend,\star}$ or $W_{i,T}^{past} = \delta_{t,T}^{past} W_{i,t}^{past,\star}$, where

$$\delta_{t,T}^{trend} = \left(1 + \pi_T^\star\right)\delta_{t,T-1}^{trend} \text{ and } \delta_{t,T}^{past} = \left(1 + \pi_{T-1}\right)\delta_{t,T-1}^{past} \text{ with } \delta_{t,t}^{k} = 1 \; \forall k.$$

$\pi_T^\star$ 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.

[8] Wieland (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.

Wage setting. We first describe the problem of choosing the optimal wage conditional on $\delta^k_{t,T}$, 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

$$W^{k,\star}_{i,t} \in \arg\max_{W^k_{i,t}} \quad \mathrm{E}_t \left(\sum_{T=t}^{\infty} (\beta\alpha_w)^{T-t} \left[\lambda_T \frac{\delta^k_{t,T} W^k_{i,t}}{P_T} \ell^k_{i,t,T} - \frac{\psi}{1+\omega} \left(\ell^k_{i,t,T}\right)^{1+\omega} \right] \right), \tag{3}$$

subject to the labor-specific demand of firms

$$\ell^k_{i,t,T} = \left(\frac{\delta^k_{t,T} W^k_{i,t}}{W_T} \right)^{-\theta_w} \ell_T. \tag{4}$$

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, $\ell^k_{i,t,T}$, may differ across workers due to nominal wage rigidities. We define $rw^{k,\star}_t \equiv \frac{W^{k,\star}_t}{W_t}$ as the optimal wage relative to the aggregate wage level for workers that chose indexation rule δ^k. Thus, according to the F.O.C. of the worker's problem, $rw^{k,\star}_t$ is given by

$$\left[rw^{k,\star}_t \right]^{1+\omega\theta_w} = \psi\mu_w \frac{\mathrm{num}^{\mathrm{w}}_{k,t}}{\mathrm{den}^{\mathrm{w}}_{k,t}}, \tag{5}$$

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

$$\begin{aligned} \mathrm{num}^{\mathrm{w}}_{k,t} &\equiv (\ell_t)^{1+\omega} + \beta\alpha_w \mathrm{E}_t \left(\left(\frac{1+\pi^w_{t+1}}{\delta^k_{t,t+1}} \right)^{\theta_w(1+\omega)} \mathrm{num}^{\mathrm{w}}_{k,t+1} \right), \\ \mathrm{den}^{\mathrm{w}}_{k,t} &\equiv \lambda_t w_t \ell_t + \beta\alpha_w \mathrm{E}_t \left(\left(\frac{1+\pi^w_{t+1}}{\delta^k_{t,t+1}} \right)^{\theta_w - 1} \mathrm{den}^{\mathrm{w}}_{k,t+1} \right), \end{aligned}$$

and $\pi^w_{t+1} \equiv \frac{W_{t+1}}{W_t} - 1$ 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 $rw^{k,\star}_t = 1$). 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.,

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

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 $\Xi_t = \mathrm{E}_t \left(\left\{ \left[\xi_{t+h},\ \Sigma_{t+h} \right]' \right\}_{h=0}^{\infty} \right)$. 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.,

$$\delta_{i,t}^{\star}\left(\Xi_t\right) \in \underset{\delta_i \in \left\{\delta^{trend}, \delta^{past}\right\}}{\arg\max} \ \mathbb{W}_{i,t}\left(\delta_i, \Xi_t\right) \text{ subject to } \wp\left(\Xi_t\right), \tag{7}$$

where

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

$\wp\left(\Xi_t\right)$ 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 $\Omega\left(\delta_i, \Xi_t\right)$. In formal terms, $\delta_{i,t}^{\star}\left(\Xi_t\right)$ also satisfies the problem

$$\delta_{i,t}^{\star}\left(\Xi_t\right) \in \underset{\delta_i \in \left\{\delta^{trend}, \delta^{past}\right\}}{\arg\min} \ \Omega\left(\delta_i, \Xi_t\right), \text{ subject to } \wp\left(\Xi_t\right),$$

where

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

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

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

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 $\xi^\star$, 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 $\int_{i\in I_t^k}\ell_{i,t}\mathrm{d}i = \ell_t \mathrm{disp}_{\mathrm{w},t}^k$, where $\mathrm{disp}_{\mathrm{w},t}^k = \int_{i\in I_t^k}\left(\frac{W_{i,t}}{W_t}\right)^{-\theta_w}\mathrm{d}i$. Recursive expressions for the wage dispersion measures are given by

$$\begin{aligned}\mathrm{disp}_{\mathrm{w},t}^k &= (1-\alpha_w)\chi_t^k\left(rw_t^{k,\star}\right)^{-\theta_w} + \alpha_w\left(\frac{1+\pi_t^w}{\delta_{t-1,t}^k}\right)^{\theta_w}\mathrm{disp}_{\mathrm{w},t-1}^k, & (11)\\ \text{where } \chi_t^k &= \begin{cases}\chi_t & \text{if } k = past\\ 1-\chi_t & \text{if } k = trend.\end{cases} & (12)\end{aligned}$$

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

$$\tilde{w}_t^k = (1-\alpha_w)\chi_t^k\left[rw_t^{k,\star}\right]^{1-\theta_{w,t}} + \alpha_w\left(\frac{1+\pi_t^w}{\delta_{t-1,t}^k}\right)^{\theta_w-1}\tilde{w}_{t-1}^k. \tag{13}$$

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 the 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 detrended output at the deterministic steady state equals one, and z_t is a permanent technology shock that obeys

$$z_t = z_{t-1} + \varepsilon_{z,t}, \tag{14}$$

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 $P_{j,T} = \delta^p_{t,T} P_{j,t}$, where $t < T$ denotes the period of last reoptimization and $\delta^p_{t,T} = (1+\pi^*_T)^{1-\gamma_p}(1+\pi_{t-1})^{\gamma_p}\,\delta_{t,T-1}$ for $T > t$ and $\delta^p_{t,t} = 1$.[9] The firm sets $P_{j,t}$ by maximizing its profits, so

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

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

where the real cost function is given by $S(y_{j,t}) = w_t \left[y_{j,t} / (A \exp(z_t)) \right]$, 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

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

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:

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

[9] We 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.

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

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

where $R_t^\star = \beta^{-1}\left(1+\pi_{t+1}^\star\right)$ 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

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

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 $\ell_t = \int_0^1 n_{j,t} \mathrm{d}j$. Using the input-specific demand function, it follows that $\ell_t = y_t A^{-1} \exp(-z_t)\, \mathrm{disp}_t^{\mathrm{p}}$, where $\mathrm{disp}_t^{\mathrm{p}} = \int_0^1 \left(\frac{P_{j,t}}{P_t}\right)^{-\theta_p} \mathrm{d}j$ 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 (2004).[11] We use this method because we are interested in the welfare effects of different indexation schemes.[12] Then, given an economic regime, we implement an algorithm to find the equilibrium level for aggregate indexation. The model is solved using Dynare, version 4.

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

[11]The stochastic steady state is defined as the point where, in the absence of shocks, agents choose to remain while expecting shocks in the future. It is also referred to as the "ergodic mean in the absence of shocks", or EMAS for short, (see Born and Pfeifer, 2014), or the "risky steady state" (see Juillard, 2011). To compute the EMAS, we start from the deterministic steady state, set all shocks to zero, and simulate the system forward until convergence (see Born and Pfeifer, 2014, footnote 2 in their technical appendix, for an illustration). We use the EMAS solution for all the figures and tables of this paper. We obtain similar results if we instead compute the analytical risky steady state as in Andreasen et al. (2013), or if we compute the ergodic mean after long simulations.

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

For the analysis in the next section, we calibrate the model according to the estimation results of the *Great Moderation* period of Hofmann et al. (2012).[13] These authors 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 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 $\pi_0^\star = 0$, 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 ($\sigma_{\pi^\star} = .049$). Note that all parameters lie within the ballpark of empirical findings (see Smets and Wouters, 2007; Cogley et al., 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.

The demonstrations shown in this section rely exclusively on the second-order approximation solution method of the model. They thus focus on the unconditional welfare implications for workers when choosing a particular indexation rule. In the Annex, at the end of the paper, we provide an easy-to-digest intuition of the results found in this section, were we use a simplified version of the model and focus on their IRFs computed through a first-order approximation solution method. We advise the reader to cover sections 3.1 to 3.4, and then move to the Annex for further intuition.

[13] See their estimation for the first quarter of 2000.

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 $\mathbb{W}_{ss}\left(\delta^k, \xi, \Sigma\right) \equiv \mathrm{E}\left\{\mathbb{W}_{i,t}\left(\delta^k, \xi,\ \Sigma\right)\right\}$ (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:

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

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

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

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

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

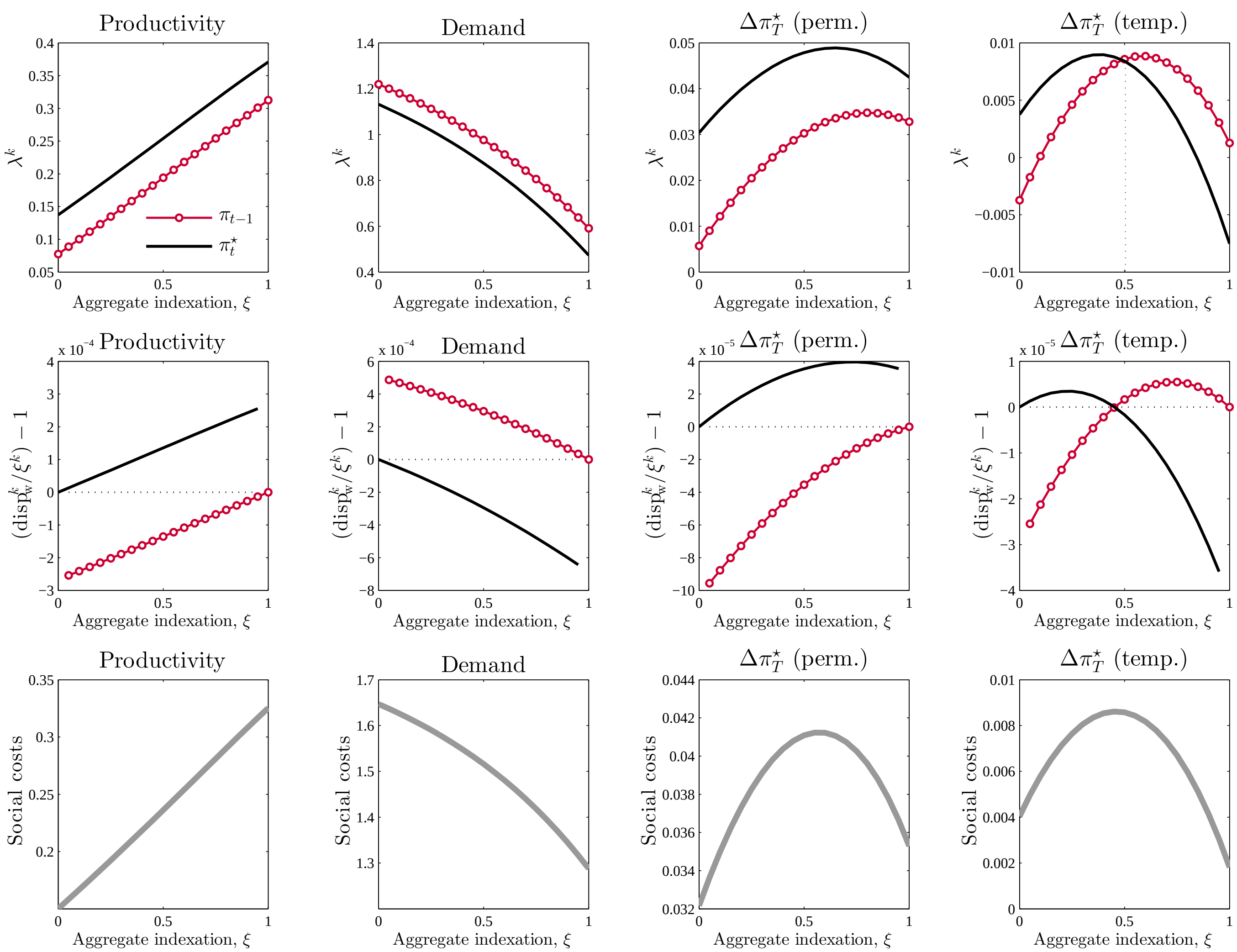
3.2 Aggregate indexation in the decentralized equilibrium

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 $\xi^\star$, is then obtained according to equation (10). Notice that at the stochastic steady state, it should be the case that $\xi_t = \chi_t = \xi^\star$.

There are two types of solutions for the aggregate equilibrium level $\xi^\star$. The corner solution $\xi^\star = 0$ 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, $\xi^\star = 1$ 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 $\xi^\star$ 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 ($\Sigma^{\pi^\star,\text{P}}$, where $\rho_\pi = 1$, so trend inflation is a random walk), while in the latter, these are temporary shocks ($\Sigma^{\pi^\star,\text{T}}$, 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).

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



Note: In the first row, we show the labor-based welfare costs for each indexation rule conditional on specific shocks. The second row displays the relative wage dispersion measures for each contract. Finally, the third row presents the social welfare costs as a function of aggregate indexation.

In the first three cases (Σ^{prod}, Σ^{dem}, and $\Sigma^{\pi^\star,\text{P}}$), 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.[14] It follows that aggregate indexation is high for regimes Σ^{prod} and $\Sigma^{\pi^\star,\text{P}}$ (in equilibrium $\xi^\star = 1$), and it is low for regime Σ^{dem} (in equilibrium $\xi^\star = 0$).[15] The temporary trend-inflation shock regime has an interior solution, since for $\xi^\star = .5$ we have that $\lambda^{trend} = \lambda^{past}$.

Notice that $\xi^\star$ is an equilibrium for all regimes, since workers have no incentive to change their rule at this level of aggregate indexation. Also, $\xi^\star$ is globally stable because, for any initial $\xi_0 \neq \xi^\star$, workers choose the contract with the lowest expected losses, and aggregate indexation ξ_t converges towards $\xi^\star$.[16]

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^k_{ss}, can be approximated as follows:

$$\Omega^k_{ss} \approx \frac{\psi}{1-\beta\alpha_w}\left(R^k_{ss} + V^k_{ss}\right), \tag{17}$$

where

$$R^k_{ss} = \frac{1}{1+\omega}\left[\frac{\text{disp}^k_{\text{w},ss}}{\xi^k} \times \ell_{ss}\right]^{1+\omega}, \text{ and } V^k_{ss} = \frac{\omega}{2}\left[R^k_{ss}\left(1+\omega\right)\right]^{\frac{\omega-1}{\omega+1}} \text{var}\left(\ell^k_t\right)$$

[14]The 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.

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

[16]It is worth mentioning that in every single exercise we have performed, either with an interior or a corner solution, $\xi^\star$ 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 then λ^{trend}, it happens that $\delta\left(\lambda^{past}\right)/\delta\xi$ is steeper or parallel to $\delta\left(\lambda^{past}\right)/\delta\xi$. The opposite holds when $\lambda^{past} \leq \lambda^{trend}$. It follows that the $\lambda^{k\prime}s$ can cross at most only once.

with

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

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, $\mathrm{disp}_{\mathrm{w},ss}^k \times \left(\xi^k\right)^{-1}$. 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.[17] In the technical appendix, we show that wage dispersion can be written as a function of hours worked as follows[18]

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

where

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

The vector $\overline{\ell}_t^k$ contains the log difference between the individual hours worked in an indexation-rule sector and the economy's average. The function $\mathrm{D_k}$ takes the average of the squared values in $\overline{\ell}_t^k$.[19] Thus, R_{ss}^k increases with the average squared deviation of hours worked in sector k with respect to the *reference* level of hours worked. That is, differences with respect to this reference level causes disutility. 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.[20]

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 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.[21]

[17] See the definition of wage dispersion per sector in equation (11).

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

[19] In fact, $\mathrm{D_k}$ is proportional to the square of the Euclidean norm of vector $\overline{\ell}_t^k$, i.e. $\mathrm{D_k}\left(\overline{\ell}_t^k\right) = \frac{1}{\xi^k}\left\|\overline{\ell}_t^k\right\|^2$.

[20] Notice 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., $W_t = \left[\int_0^1 W_{i,t}^{1-\theta_w}\mathrm{d}i\right]^{\frac{1}{1-\theta_w}}$). However, within each labor sector, some deviations may occur at the stochastic steady state.

[21] For 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 $\mathrm{var}\left(\ell_t^k\right)$.

In sum, the disutility of workers increases with the volatility in their expected labor supply in general, $\mathrm{var}\left(\ell_t^k\right)$, as well as with the relative variance of hours, $\mathrm{D_k}\left(\bar{\ell}_t^k\right)$. 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. In support of this claim, the second row of the Figure shows the relative wage dispersion measures as represented by $\mathrm{Rdisp}_{\mathrm{w}}^k = \mathrm{disp}_{\mathrm{w},ss}^k \times \left(\xi^k\right)^{-1}$. Notice that $\mathrm{disp}_{\mathrm{w},ss}^k$ 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 in determining the aggregate level of wage indexation. For now, the main message of this section is that a greater variance of working hours within an indexation contract, that is a greater $\mathrm{D_k}\left(\bar{\ell}_t^k\right)$, implies a larger disutility of labor and makes that contract less attractive. The intuition is simple, if workers believe that an indexation contract implies higher volatility of their labor disutility, they will avoid this contract. These sectorial differences among contracts generate an externality that makes the choices of workers and that of a social planner to differ.

3.4 Social *versus* private welfare

The equilibrium aggregate indexation $\xi^\star$ 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, $\xi^\star$ differs from the socially optimal level, as we show next.

Social welfare is obtained by adding up all households' welfare, i.e.,[22]

$$\mathbb{SW}_t = \mathrm{E}_t \left\{ \sum_{T=t}^{\infty} \beta^{T-t} \int_0^1 \mathcal{U}\left(c_T, \ell_{i,T}\right) \mathrm{d}i \right\},$$

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 $\mathbb{SW}_{ss}\left(\xi, \Sigma\right) \equiv \mathrm{E}\left(\mathbb{SW}_t\right)$. Notice that $\mathbb{SW}_{ss}$ varies with aggregate indexation and the economic regime. The upper bound in social welfare is achieved when there are no shocks to

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

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 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.,

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

where $\mathbb{SW}_d = \frac{1}{1-\beta}\mathcal{U}\left(c_d, \ell_d\right)$. 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 $\Sigma^{\pi^\star,\text{T}}$). In contrast, full indexation is optimal in response to aggregate spending shocks and permanent inflation shocks (regimes Σ^{dem} and $\Sigma^{\pi^\star,\text{P}}$).

Interestingly, $\xi^\star$ 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 relative variance measures should remain roughly the same and therefore we should not see important changes in equilibrium wage indexation.

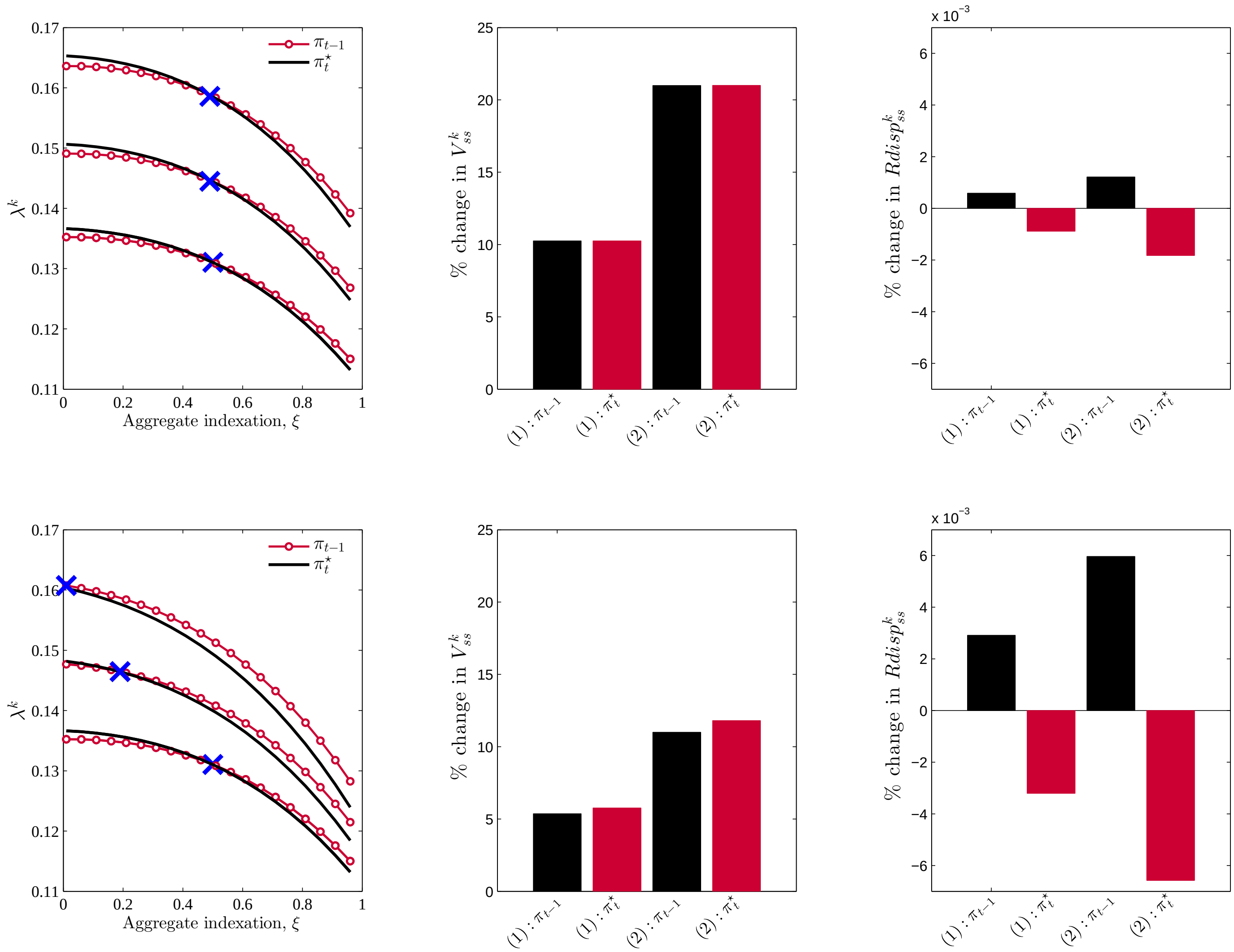
The first row of Figure 3 shows the effects of this experiment and confirms our intuition. The first panel uses three crosses to depict the wage indexation equilibria. The bottom cross represents the baseline and the two others show that increasing the shock variances raises welfare costs (y-axis) but 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 $\pi_t^\star$-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 steps 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

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.

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 estimation results of Hofmann et al. (2012), where a New-Keynesian model similar to ours is taken to the data.[23] Hofmann et al. (2012) estimate the model with U.S. data 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 estimated 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 ($\sigma_{\pi^\star} = 0$). In case 2, we use the estimated posterior median values for trend inflation volatility from Cogley et al. (2010) for the two regimes.[24] 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.[25] 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 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

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

[24] Cogley 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 $\sigma_{\pi^\star}$ for both subperiods for respectively the *Great Inflation* and the *Great Moderation* calibrations.

[25] See Boivin and Giannoni (2006) or Smets and Wouters (2007).

Table 1. Validation exercises

		Great Moderation 2000 (benchmark)	Great Inflation 1974
	Common parameters		
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
	Specific parameters		
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
	Case 1: $\sigma_{\pi^\star} = 0$		
$\xi^\star$	Implied equilibrium indexation	0	.89
ξ^S	Implied social optimum	1	0
	Case 2: $\sigma_{\pi^\star} > 0$		
σ_{π^*}	Std. dev. inflation target	.049	.081
$\xi^\star$	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), who estimated an isomorphic model to ours with U.S. data for 1974Q1 and 2000Q1. For more details about their estimation procedure, see Section 3.2 of Hofmann et al. (2012). The standard deviations for trend inflation are taken from the estimation results of Cogley et al. (2010). The *implied* indexation values are computed using the analysis provided in section 3.

are reported at the bottom of Table (1). For case 1, with constant trend inflation, the model predicts an aggregate degree of wage indexation $\xi^{\star}$ 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 $\xi^{\star}$ 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.[26]

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.[27] The implied equilibrium $\xi^{\star}$ 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 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 $\xi^{\star}$. We first discuss the effect of changes in the volatility of shocks, followed by the monetary policy rule and finally structural changes.

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

[27]The 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.

Table 2. Counterfactual exercises

		2000's $\xi^{\star}$ is 0, applying 1974 value to: $\xi^{counterfactual}$ (1)	1974's $\xi^{\star}$ is $.89$, applying 2000 value to: $\xi^{counterfactual}$ (2)
	I - Shocks		
σ_z	Std. dev. Tech. shock	1	0
σ_g	Std. dev. Dem. shock	0	1
σ_{π^*}	Std. dev. inflation target	.6	.89
	II - Policy parameters		
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
	III - Structural parameters		
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.

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, $\xi^\star$ 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 $\xi^\star$ 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 $\xi^\star = 1$, whereas a regime driven by demand shocks results in an equilibrium with $\xi^\star = 0$. 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 of Table (1).

A cross check with column (2) of Table (2) shows that there is no inconsistency. The column shows how $\xi^\star$ 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.[28]

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 $\xi^\star$ from 0 to .05 for

[28] In 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.

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 $\xi^\star$, 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 $\xi^\star$ from 0 to .49 in column (1). However, column (2) predicts that a *decrease* in this parameter leads to an *increase* in $\xi^\star$ from .89 to .95, which is a strong indication that non-linearities are at play.[29] 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 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.

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

[29] In the technical appendix, we show that the changes in the nominal rigidities parameters result in highly nonlinear effects on equilibrium $\xi^\star$

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.

Annex: Economic Intuition Behind Workers' Indexation Choice[30]

Our research paper builds a model which endogenizes the wage indexation choice of workers. Specifically, we consider a New-Keynesian DSGE model in which workers set their wages for contracts with random duration. The novelty of our model is that workers can also select an *indexation scheme* when they re-optimize their wages for a new contract. This indexation scheme, which is either indexing to past or to trend inflation, but not both, determines how the worker's wage evolves until she gets the chance to reset it.

The results from the main text can be summarized as follows: workers index their wages to past inflation if the economy is driven by permanent shocks to productivity or the inflation target. However, they index to trend inflation when temporal aggregate-demand shocks are the most important drivers. These results are robust to different parameter values within the New Keynesian tradition, at least to a second-order approximation. To provide more intuition for these results, this document presents a simplified framework which resembles a real-business-cycle model in which the only rigidity is that wages are sticky. The rest of the economy features linear technology in labor and flexible prices.

The remainder of the document is structured as follows. Section B describes the simplified model and Section C discusses the indexation choices which are made under three types of shocks.

A A Simple Sticky-Wage Model

A.1 Households and Wage Setting

The model in this document is very similar but simpler than that of Section 2 from the main text. We introduce heterogeneity in labor types to keep dispersion on wages. However, we add a labor subsidy τ_w to eliminate any steady-state distortion in labor allocations generated by workers' monopolistic power. The instantaneous utility function takes a logarithmic form for consumption and a quadratic form for labor. As before, $1-\alpha_w$ is the probability of re-optimizing a wage contract any given period and it is independent across time and types. Thus, the expected duration of a labor contract is $1/(1-\alpha_w)$ periods. Under these conditions, household $i \in [0,1]$ selects consumption $c_{i,t}$, one-period-maturity real bond holdings $b_{i,t}$, a nominal wage $W_{i,t}$, and an indexation rule $\delta_{i,t}$,

[30]This Annex greatly benefit from discussions and comments during the Seventh BIS-CCA Research Conference in Lima, in May 2016. In particular, we are deeply grateful to Giorgio Primiceri and his inspiring discussion, which help us greatly in writing this section.

in order to maximize its expected discounted lifetime utility

$$\max_{c_{i,T},b_{i,T},W_{i,T},\delta_{i,T}} \mathrm{E}_t \left\{ \sum_{T=t}^{\infty} \beta^{T-t} \left(\log c_{i,T} - \frac{\psi}{2} \ell_{i,T}^2 \right) \right\}, \tag{Objective}$$

subject to

$$\begin{aligned}
c_{i,T} + \frac{b_{i,T}}{(1+R_T)\exp(d_T)} &\leq (1+\tau_w)\frac{W_{i,T}}{P_T}\ell_{i,T} + \frac{b_{i,T-1}}{1+\pi_T} + \frac{\Upsilon_{i,T}}{P_T}, && \text{(Budget constraint)} \\
\ell_{i,T} &= \left(\frac{W_{i,T}}{W_T}\right)^{-\theta_w} \ell_T && \text{(Labor demand for type-}i\text{)} \\
\delta_{i,T} &\in \left\{ \delta_{t,T}^{past}, \delta_{t,T}^{trend} \right\}, && \text{(Indexation rules)} \\
\text{where } \delta_{t,T}^{past} &= (1+\pi_{T-1})\,\delta_{t,T-1}^{past}, \text{ and } \delta_{t,T}^{trend} = (1+\pi_T^\star)\,\delta_{t,T-1}^{trend},
\end{aligned}$$

with $\delta_{t,t}^k = 1$ for $k \in \{past, trend\}$. As in the main text, R_t is the risk-free nominal interest rate, P_t denotes the price of the final good, $1 + \pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate, and $\Upsilon_{i,t}$ is a lump sum including net fiscal transfers and Arrow-Debreu state-contingent securities which guarantee that households start each period with equal wealth. Aggregate hours ℓ_t are built by a labor packer according to $\ell_t = \left(\int_0^1 \ell_{i,t}^{(\theta_w-1)/\theta_w} \mathrm{d}i\right)^{\theta_w/(\theta_w-1)}$, where $\theta_w > 1$ is the elasticity of substitution between any two labor types. The aggregate wage level is given by $W_t^{1-\theta_w} = \int W_{i,t}^{1-\theta_w} \mathrm{d}i$. The parameter ψ is a normalizing constant which ensures that labor equals 1/3 at the non-stochastic steady-state, while $1 + \tau_w = \theta_w/(\theta_w - 1)$. Finally, the aggregate-demand shock d_t, which follows the stationary process $d_t = \rho_d d_{t-1} + \varepsilon_{d,t}$, creates a spread between the return on bonds and the risk free rate (cf. risk-spread shock in Smets and Wouters, 2007).

A.2 Rest of the Economy

A representative final goods producer uses a linear technology on labor:

$$y_t = A \exp(z_t)\, \ell_t,$$

where z_t is a permanent productivity shock that follows the process $z_t = z_{t-1} + \varepsilon_{z,t}$. The linear technology and flexible prices imply that the firm's demand for the aggregate labor input is completely flat, which pins down the real wage at

$$w_t = A \exp(z_t).$$

To close the economy, the central bank sets its nominal policy interest rate according to

$$1 + R_t = \frac{1+\pi_t^\star}{\beta} \times \left(\frac{1+\pi_t}{1+\pi_t^\star}\right)^{a_\pi},$$

where the inflation target $1+\pi_t^\star$ may vary over time. For simplicity, we assume that variations in $\pi_t^\star$ are permanent, i.e. $\pi_t^\star = \pi_{t-1}^\star + \varepsilon_{\pi,t}$. This version of the model omits government spending, so the resource constraint is given by $y_t = c_t$.

A.3 Aggregate Dynamics and Implications of Nominal Wage Rigidities

The equilibrium conditions of this economy are quite standard and read:

$$\begin{aligned}
\frac{1}{y_t} &= \lambda_t, \\
1 &= \beta \mathrm{E}_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} \frac{R_t \exp(d_t)}{1+\pi_{t+1}} \right\}, \\
\left(\frac{W_t^{k,\star}}{W_t} \right)^{1+\theta_w} &= \psi \frac{\mathrm{num}_t^k}{\mathrm{den}_t^k}, \text{ for } k \in \{past, trend\}, \text{ where} \\
\mathrm{num}_t^k &= \ell_t^2 + \beta \alpha_w \mathrm{E}_t \left\{ \left(\frac{\delta_{t,t+1}^k}{1+\pi_{t+1}^w} \right)^{-2\theta_w} \mathrm{num}_{t+1}^k \right\}, \text{ and} \\
\mathrm{den}_t^k &= \lambda_t w_t \ell_t + \beta \alpha_w \mathrm{E}_t \left\{ \left(\frac{\delta_{t,t+1}^k}{1+\pi_{t+1}^w} \right)^{1-\theta_w} \mathrm{den}_{t+1}^k \right\},
\end{aligned}$$

along with the production function, aggregate labor demand, and the monetary policy rule. $W_t^{k,\star}$ is the optimal nominal wage set under a δ^k labor contract in period t, $w_t \equiv W_t/P_t$ is the aggregate real wage, and while λ_t is the Lagrange multiplier of households' budget constraint, or the marginal utility of wealth. Notice that these state-contingent securities ensure that λ_t is the same for all households. While these securities simplify the model's solution, they maintain the role of λ_t as a signaling device of income effects scattered by aggregate shocks in the economy. For instance, if λ_t increases it means that households have less resources to spend and must reduce consumption and leisure. As households feel poorer and aim to smooth consumption, they will raise their labor supply in response to an increase in λ_t. The latter can be clearly observed under flexible wages ($\alpha_w = 0$), because then the household's labor supply is given by the marginal rate of substitution between leisure and consumption:

$$\ell_{i,t}^f = \frac{1}{\psi} \lambda_t^f w_{i,t}^f,$$

where $w_{i,t}^f = w_t^f$ for all i and t, and superscript f denotes quantities of a flexible-wage economy. Wage flexibility is the ideal situation for households: it allows them to respond to external shocks by selecting an optimal wage in each period, thus maximizing welfare. In contrast, staggered wages imply that the household's wage will not be re-optimized during some periods, but instead it will follow the chosen indexation rule. In these periods, the household's effective labor supply, or hours worked, might deviate from the optimal labor supply schedule, which entails welfare costs for the household.

In order to understand a household's preference towards an indexation rule, we introduce the following thought experiment. Suppose that a single worker i' has a flexible wage contract, even though all other households face staggered wages. This household's labor supply $\ell^{\star}_{i',t}$, which is determined by the individual labour demand and the household's flexible nominal wage choice $W^{\star}_{i',t}$, has the same functional form as the labor supply of the flexible-wage economy:

$$\ell^{\star}_{i\prime,t} = \frac{1}{\psi}\lambda_t w^{\star}_{i\prime,t},$$

where $w^{\star}_{i\prime,t}$ is household i''s optimal real wage. This fact is not surprising as this decision rule is an unrestricted welfare-maximizing condition for households in this economy. But even if this worker has a flexible labor contract, she faces the income effect of the sticky-wage economy, and thus her optimal hours worked will differ from those of the flexible-wage economy. For instance, if a shock induces a stronger negative income effect in the sticky-wage economy, then worker i' will increase her labor supply more strongly in this economy than under the flexible-wage version. Worker's i' optimal nominal wage can be obtained from her FOCs by setting $\alpha_w = 0$, which already takes into account worker's i' individual labour demand. Thus,

$$\begin{aligned} W^{\star}_{i\prime,t} &= \left(\psi\frac{\ell_t}{\lambda_t}\frac{1}{w_t}\right)^{\frac{1}{1+\theta_w}} W_t, \text{ or in real terms} \\ w^{\star}_{i\prime,t} &= \left(\frac{1}{M^w_t}\right)^{\frac{1}{1+\theta_w}} w_t, \end{aligned}$$

where M^w_t represents an aggregate wage markup, defined as the gap between the aggregate real wage and the average marginal rate of substitution, such that

$$w_t = \psi\frac{\ell_t}{\lambda_t}M^w_t.$$

In other words, M^w_t represents an efficiency wedge in the labor market due to sticky wages. The latter implies that when a positive wage markup emerges, $M^w_t > 1$, aggregate hours and output will be below the efficient level, prompting a negative income effect ($\Delta\lambda_t > 0$) which pushes worker i' to increase its labor supply. She will thus set her real wage below the aggregate real wage in order to work more, which implies that

$$\ell^{\star}_{i\prime,t} = {M^w_t}^{\frac{\theta_w}{1+\theta_w}}\ell_t,$$

since her labor demand at the optimal level for hours worked is $\ell^{\star}_{i',t} = \left(\frac{W^{\star}_{i',t}}{W_t}\right)^{-\theta_w} \ell_t$.

Now assume we inform worker i' that she cannot have this flexible labor contract, but instead we offer her a menu with two staggered-wage choices: the δ^{past} contract and the δ^{trend} contract. It seems reasonable to expect that household i''s preferred indexation rule minimizes the gap between its effective and its desired labor supply. In this situation, $\ell^{\star}_{i',t}$ has become a notional variable for worker i' and serves her as a signaling device on whether she should increase or decrease her labor supply when facing different shocks. Worker i' could therefore choose her nominal wage strategically under her preferred δ^k contract to get as close as possible to her desired labor supply, depending on what she expects her nominal wage dynamics looks like at in the future. The twist of this experiment is that any worker in the sticky-wage economy could be worker i', and so every household would choose the indexation rule that better helps her to close the gap between her desired and expected hours worked when allowed to do so.

B A First-Order Approximation to Endogenous Wage Indexation

B.1 Aggregate Supply and Demand Schedules

Nominal wage rigidities imply that the aggregate labor supply cannot adjust freely to shocks.[31] The latter is clearly observed using a first-order approximation to the wage Phillips curve of this economy:[32]

$$\pi^w_t - \xi\pi_{t-1} - (1-\xi)\pi^*_t = \kappa_0 \times \left(\hat{\ell}_t - \hat{\lambda}_t - \hat{w}_t\right) + \beta \mathrm{E}_t \left\{\pi^w_{t+1} - \xi\pi_t - (1-\xi)\pi^*_{t+1}\right\},$$

where $\kappa_0 = \frac{(1-\beta\alpha_w)(1-\alpha_w)}{\alpha_w(1+\theta_w)}$, ξ denote the aggregate proportion of workers indexing to past inflation, which for simplicity we assume here fixed, and hatted variables denote the percent deviation from a variable's non-stochastic steady-state level. The sluggishness in the labor market translates into an upward-sloping Phillips curve for prices, even if the latter are flexible. Using log-linear approximations for the equilibrium conditions and some algebra, the wage Phillips curve can be rewritten

[31] Sticky wages cause an efficiency wedge in the labor market, as the marginal rate of substitution between leisure and consumption cannot be satisfied when inflation or wage inflation are outside their equilibrium levels.

[32] See section D in the technical appendix for its derivation.

as a New-Keynesian Phillips curve (NKPC) for prices:[33]

$$\pi_t = \frac{\xi}{1+\beta\xi}\pi_{t-1} + \frac{2\kappa_0}{1+\beta\xi}\left(\hat{y}_t - z_t\right) + \frac{\beta}{1+\beta\xi}\mathrm{E}_t\pi_{t+1} - \frac{1}{1+\beta\xi}\varepsilon_{z,t} + \frac{(1-\beta)(1-\xi)}{1+\beta\xi}\pi_t^*.$$

Wage indexation to past inflation not only increases the intrinsic persistence of inflation (first right-hand-side term), but also makes the NKPC flatter (second term), which reduces the responsiveness of inflation to changes in real activity. Also, notice that a negative productivity shock shifts the NKPC curve upwards and to the left in the $(\hat{y}_t, \pi_t)$-plane. Notice that under flexible wages ($\kappa_0 \to \infty$), the aggregate supply curve is given by $\hat{y}_t^f = z_t$.

Aggregate demand is given by the IS curve, which in log-linear terms is

$$\begin{aligned}
\hat{y}_t &= \mathrm{E}_t\left\{\hat{y}_{t+1} - \left(d_t + \hat{R}_t - \pi_{t+1}\right)\right\}, \text{ or} \\
\hat{y}_t &= \mathrm{E}_t\left\{\hat{y}_{t+1} - \left(d_t + \pi_t^\star + a_\pi\left(\pi_t - \pi_t^\star\right) - \pi_{t+1}\right)\right\}.
\end{aligned}$$

A positive risk-spread shock ($d_t > 0$) boosts savings and decreases current consumption, which shifts the IS curve downwards. The effect of a decrease in the inflation target depends on how fast inflation adjusts to the new objective. A fast adjustment leaves the IS curve intact, while a slow adjustment triggers an increase in the policy rate R_t as the central bank tries to steer inflation towards the target.

Next, we discuss the impulse responses to a productivity shock, a risk-spread shock, and an inflation-target shock. We use the following calibration: $\beta = 0.99$, $\xi = 0.5$, $\theta_w = 10$, $\rho_d = 0.5$, $a_\pi = 1.5$, and $\alpha_w = 0.5$; the latter implies that the average duration of a wage contract is 2 periods.

B.2 Technology Shock

Figure B.1 shows the impulse responses of the flexible-wage and sticky-wage economies to a 1 percent permanent fall in productivity. Starting point $t = 0$ represents the economy in a state where no shocks have occurred for a long time. In period $t = 1$, a single shock occurs. The upper two rows show how aggregate quantities react to this shock, and the third graph in row 2 also shows the desired labor supply evolution (see the example of household i' in Section A.3). The bottom two rows focus on the behavior of the sub-populations of households who index to either past or trend inflation. The first plot in the third row compares the expected and desired hours worked for households re-optimizing their wage contracts at the impact period ($t = 1$) in the sticky-wage economy.

[33] We have used again the fact that $\mathrm{E}_t\varepsilon_{z,t+1} = 0$. The equilibrium conditions used to obtain this equation are $\hat{w}_t = z_t$ for the aggregate labor demand, $\hat{y}_t = z_t + \hat{\ell}_t$ for the production function, $\hat{\lambda}_t = -\hat{y}_t$ for the FOC of consumption, and $\pi_t^w = \hat{w}_t - \hat{w}_{t-1} + \pi_t$ as a mere definition of nominal wage inflation.

The remaining 4 panels show all possible trajectories of hours and relative wages ($W_{i,t}/W_t$) for the subgroups who re-optimized in any given period. In these dispersion plots, the size of circles and squares are proportional to the population size of the subgroups. We first discuss what happens to an economy with flexible wages, and then turn to one with sticky wages.

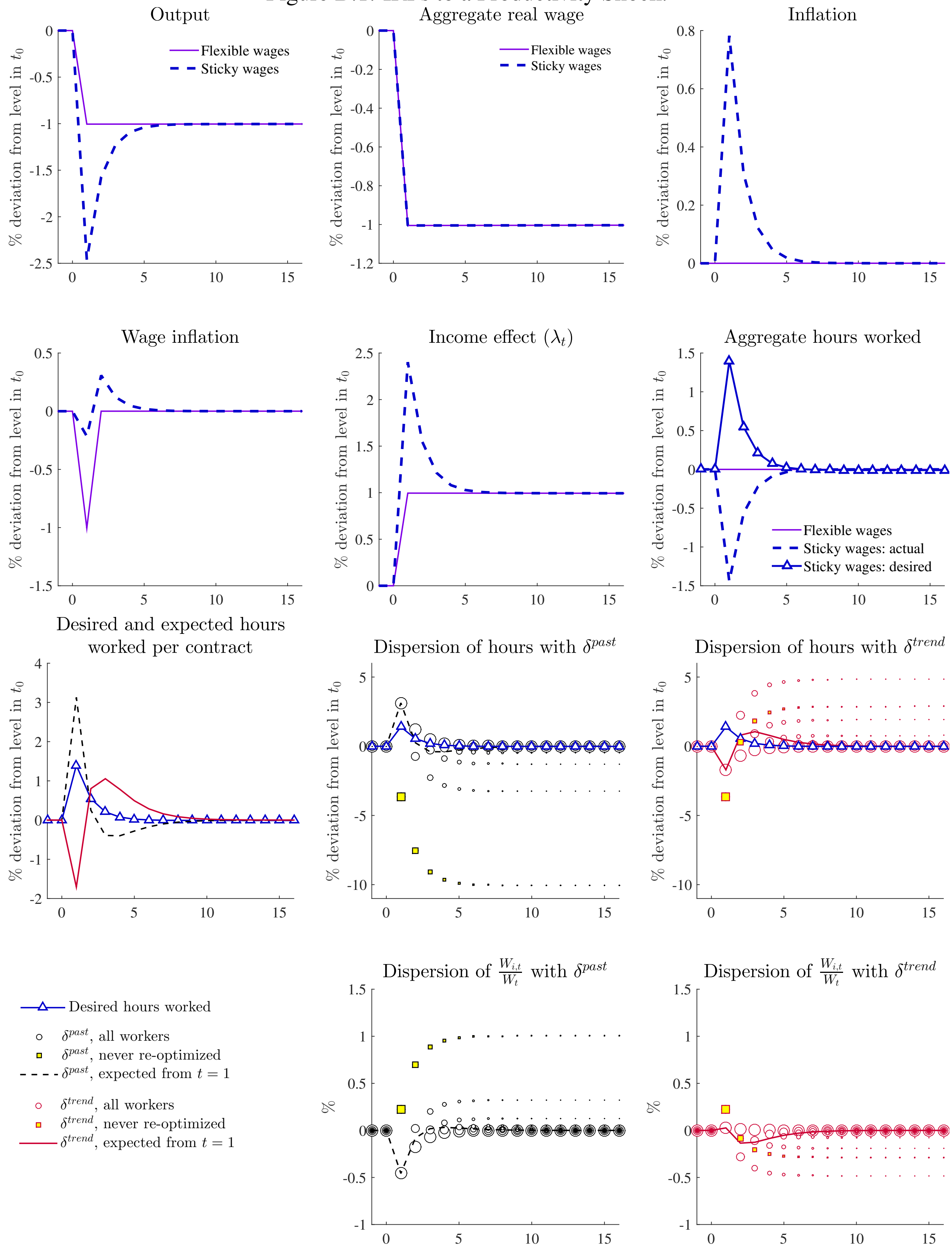
Under flexible wages, the negative productivity shock causes output and the real wage to decrease immediately to their new steady-state levels (see plain lines in the figures from rows 1 and 2). Marginal utility of wealth λ_t^f increases because households have less resources to spend for consumption and leisure. Concerning the aggregate labor market, lower productivity implies a permanent drop in aggregate labor demand, while the negative income effect pushes households to increase their labor supply. In equilibrium, the shifts in aggregate labor demand and supply balance, such that the real wage is lower and aggregate hours worked remain unchanged. In the flexible-wage economy, the necessary decline of the real wage is achieved by a drop of nominal wages and a steady price level. The transition dynamics occur immediately after the shock.

The transition to a new equilibrium is much slower, however, when households cannot freely adjust their wages in a staggered wage economy. These dynamics are shown by the dashed lines in the first two rows of Figure B.1. Since the technology in labor is linear, it remains the case that aggregate labor demand falls in order to lower the real wage.[34] Nominal wage rigidities impede households from increasing their labor supply sufficiently in response to their permanent income loss. In consequence, aggregate hours fall and output drop more strongly on impact than before. This implies that the negative income effect, as portrayed by λ_t, is larger when wages are sticky. Since households are poorer under sticky-wages, their desired labor supply increases at impact and then decreases slowly, as shown by the line with triangles in the third plot in row 2. Households will select the indexation rule which helps them close the gap between their expected hours worked and their desired hours worked. In the third row of the figure, we observe that, from the perspective of households choosing their wage contract at the impact period, the gap is smaller if they select the δ^{past} contract (black dashed line) compared to the δ^{trend} contract (red plain line).

The rationale behind this result is the following. Nominal wages under the δ^{past} contract tend to overshoot the general wage index W_t in periods of no re-optimization (see row 4), because past inflation will be temporarily higher due to the shock. This effect is clearer for the subgroup of households who never get the chance to re-optimize their wages, as shown by the yellow squares in

[34] The adjustment now comes through an increase in inflation and an initial moderate fall in wage inflation, followed by a subsequent increase due to a group indexing to π_{t-1}.

Figure B.1: IRFs to a Productivity Shock.



the dispersion graphs. A higher relative wage implies that a household works less than the average (since labor demand $\ell_{i,t} = (W_{i,t}/W_t)^{-\theta_w}\, \ell_t$). Moreover, demand for specific labor is also pushed down by lower aggregate demand. However, the desired labor hours of households has *increased* rather than decreased. Therefore, a rational household who indexes to past inflation and can re-optimize in period $t = 1$ will cut his wage in order to counter both the drop in aggregate hours and the expected increase in relative wages in non re-optimizing periods. By strategically setting their nominal wage, households with δ^{past} contracts are able to raise working hours in the impact period, which reduces the gap between desired and expected hours worked. By the same token, wages under the δ^{trend} contract tend to undershoot W_t in no re-optimizing periods. The δ^{trend} contract updates nominal wages according to trend inflation, which remains fixed at zero. Thus, setting a very low $W_1^{trend,\star}$ in $t = 1$ implies that expected hours worked are too high in subsequent periods (as relative wages will be too low). To keep the expected path of hours worked as close as possible to the desired level, $W_1^{trend,\star}$ is raised in order to offset future expected decreases in relative wages. In consequence, $W_1^{trend,\star}$ cannot counter the drop in aggregate hours, so hours worked under the δ^{trend} contract fall in period $t = 1$, which increases the gap between desired and expected hours worked in period t.[35] Workers prefer the contact which, in expectation, brings expected hours the closest to the desired hours worked.

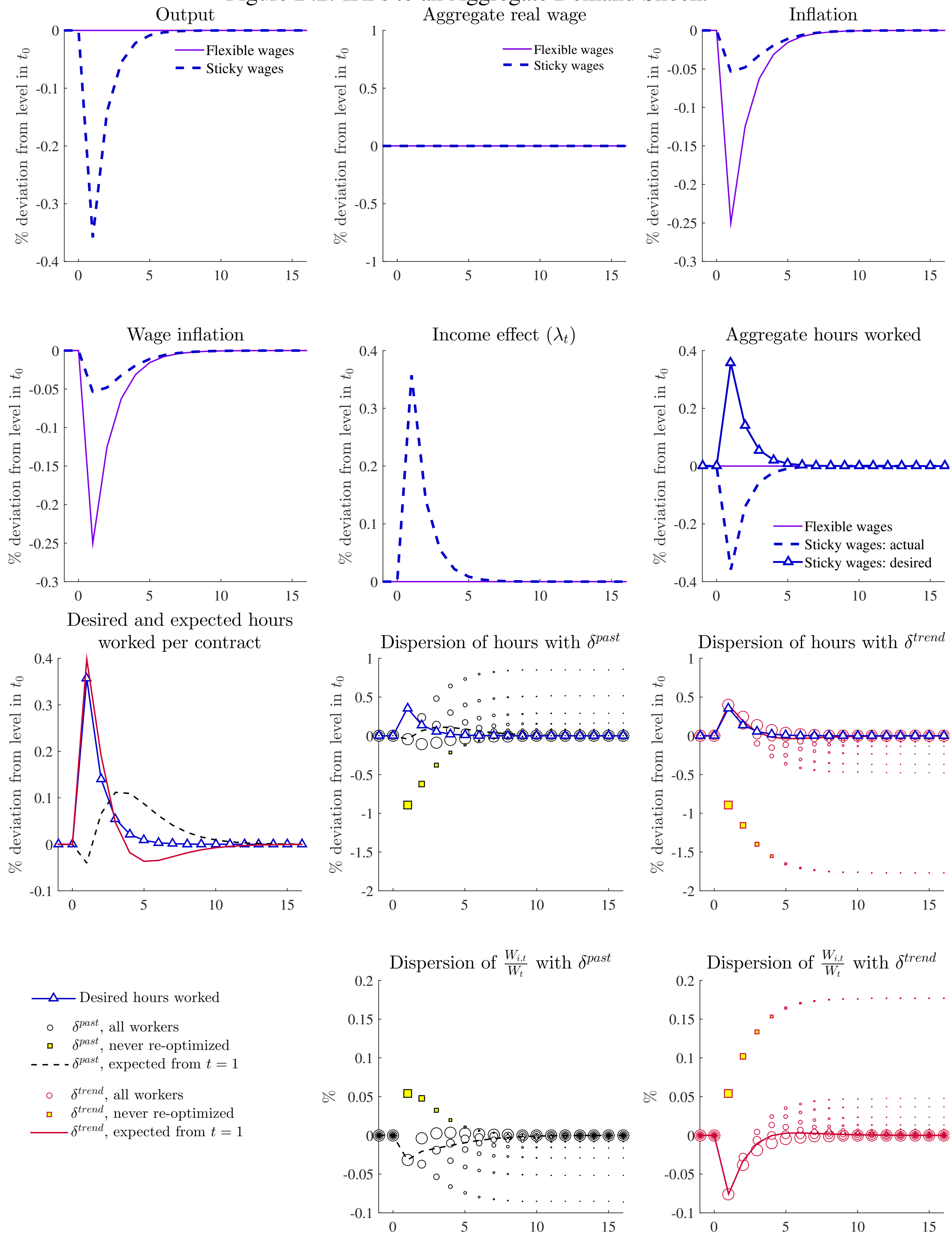
B.3 Aggregate Demand Shock

Figure B.2 shows the impulse response to an unexpected increase of 25 basis points in the spread between the returns of bonds and the risk-free rate. This shock stimulates households to save more and consume less, which lowers the IS curve. Since productivity remains stable, so do aggregate labor demand and the real wage. Under flexible wages, lower aggregate demand causes equally sized decreases in wage and price inflation, which induces stability in output, the income effect, and hours worked. But when wages are sticky, output and hours worked plummet because wages and prices cannot adjust sufficiently downwards. As a result, λ_t rises due to the negative income effect, which raises households' desired labor supply.

In this shock scenario, the δ^{trend} contract minimizes the gap between expected and desired hours worked. This choice is again driven by nominal wage dynamics in periods of no re-optimization. Since prices and the general wage index fall, nominal wages under the δ^{trend} contract tend to over-

[35]These effects prevail even if the proportion of households indexing to past-inflation indexation is zero ($\xi = 0$). In this scenario, it remains the case that cutting $W_1^{trend,\star}$ below the aggregate W_1 increases the odds of having future relative wages which are too low. In turn, expected hours worked will be too high compared to the future desired labor supply.

Figure B.2: IRFs to an Aggregate Demand Shock.



shoot W_t in no re-optimizing periods. Households who can re-optimize in period $t = 1$ will cut $W_1^{trend,\star}$ in order to balance expected increases in their future relative wages. As a result, hours worked under the δ^{trend} contract rises at impact and gets closer to current desired hours worked. In contrast, wages under the δ^{past} contract tend to undershoot W_t in no re-optimizing periods because of indexing to a falling past inflation. As such, $W_1^{past,\star}$ cannot be reduced significantly in the impact period: doing so would prompt very low relative wages in the future. Therefore, $W_1^{past,\star}$ is set to reduce the chances of overshooting the future path of desired hours worked, at a cost of not offsetting the current fall in the labor-specific demand. In consequence, hours worked under the δ^{past} contract fall at impact and create a larger gap between expected and desired hours worked.

B.4 Inflation-Target Shock

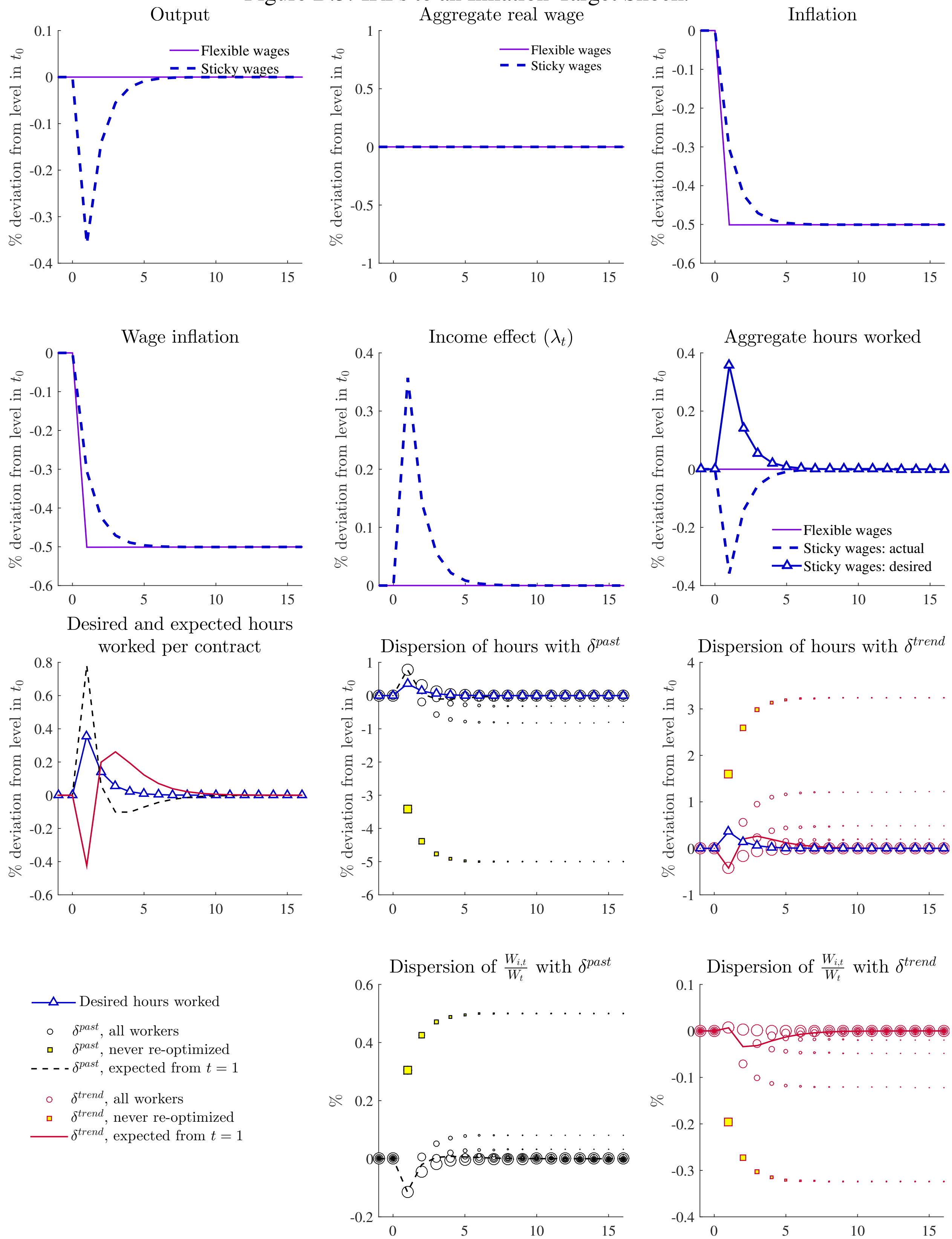
Figure B.3 shows the responses to a permanent and unexpected 50 basis points decrease in the inflation target. In the flexible-wage scenario, prices and wages adjust immediately to the new nominal anchor and there are no effects on real quantities. But staggered wage setting again implies a slow transition to the new equilibrium. As in the aggregate-demand shock case, the real wage remains stable. Since inflation and wage inflation move slow to their new targets, the central bank increases its policy rate R_t to cut aggregate demand and reduce the inflation gap ($\pi_t - \pi_t^\star$). The costly disinflation translates into a drop in output and hours worked, and a negative income effect which raises the desired labor supply.

From the individual perspective, a household finds that the gap between desired and expected hours worked is smaller under the δ^{past} contract. As before, the expected path of relative wages explains this choice. Wages under the δ^{trend} (δ^{past}) contract tend to undershoot (overshoot) W_t in no re-optimizing periods because wages drop faster when indexed to trend inflation compared to past inflation. As a result, $W_1^{past,\star}$ can be lowered in order to counter expected increases in future relative wages, while the same cannot be said for $W_1^{trend,\star}$. Households with the δ^{past} contract reduce the gap between expected and desired hours worked in the impact period.

B.5 The tension between the choices of households and the social planner

We have shown that a δ^k contract can help the household close the gap between desired and effective hours worked after a shock. Households prefer to index to past inflation after the permanent shocks in productivity and the inflation target, while they prefer to index to trend inflation after a temporal aggregate-demand shock. In the paper, we highlighted that these preferences hold for a broad range of values for aggregate indexation ξ, from low to high levels. We obtained these re-

Figure B.3: IRFs to an Inflation-Target Shock.



sults by analyzing the welfare costs associated to each type of indexation scheme at the stochastic steady state, where we assumed that the economy was driven by one type of shock at a time (see Figure 2 in the paper). An important assumption behind our results is that households take the level of aggregate indexation as given and disregard the effect of their own indexation choice on ξ. We now show that households' choices exert a negative externality into the decentralized equilibrium, which yields excessive fluctuations in output and inflation as opposed to an scenario in which a benevolent social planner selects the economy's indexation rule.

Assume that the social planner cannot remove the nominal rigidities in this economy, but she can choose the indexation rule of each household. When doing so, the planner internalizes the effect of overall wage dynamics on output and inflation. The planner's reference point is the frictionless flexible-wage economy, which delivers the efficient allocation with the highest welfare for households. Deviations from this efficient allocation entail welfare costs for households.

Figure B.4: IRFs with maximum and minimum past-inflation indexation.

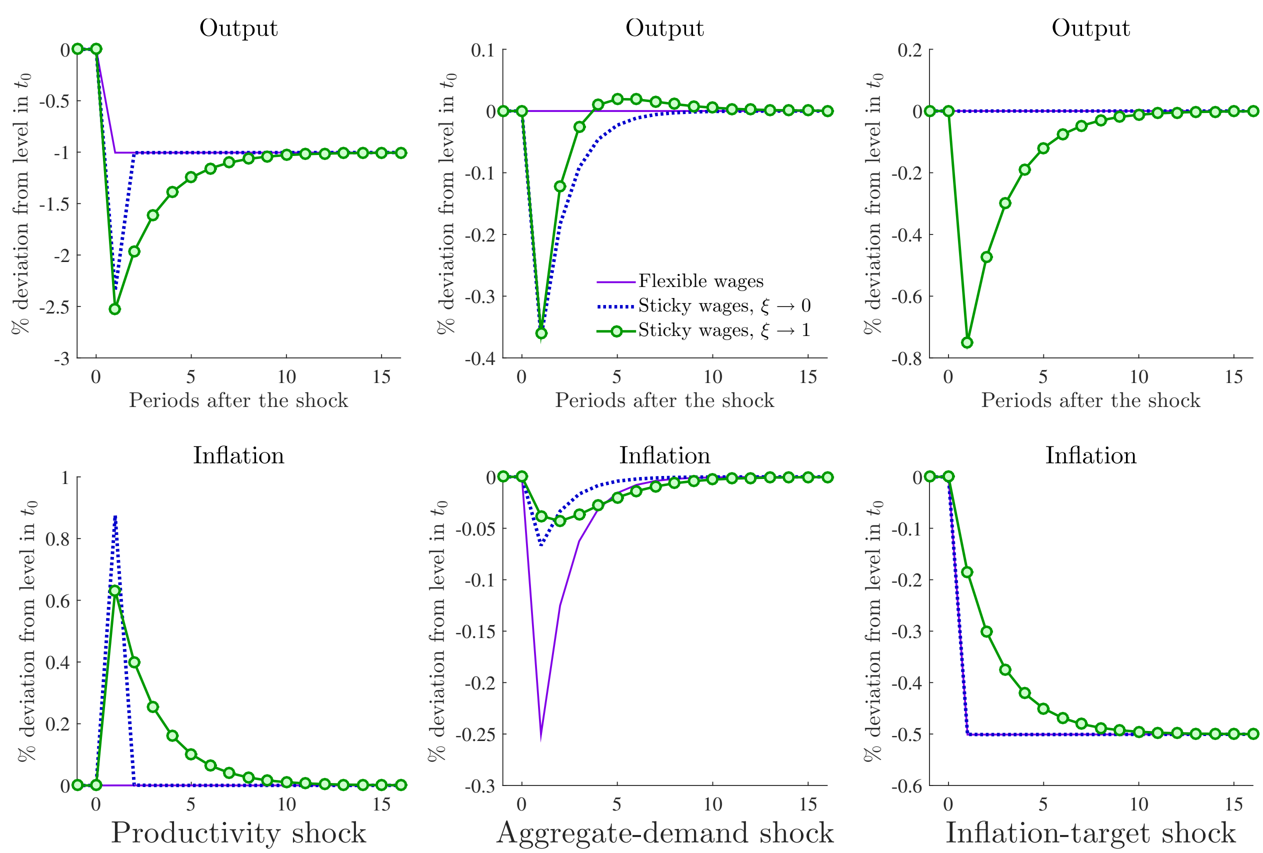


Table B.1. Discounted deviations from efficient levels.

	$\sum_{s=0}^{\infty} \beta^s \left\lvert \hat{y}_{t+s}^f - \hat{y}_{t+s} \right\rvert$		$\sum_{s=0}^{\infty} \beta^s \left\lvert \hat{\pi}_{t+s}^f - \hat{\pi}_{t+s} \right\rvert$	
	$\xi \to 0$	$\xi \to 1$	$\xi \to 0$	$\xi \to 1$
Productivity shock	1.4	4.1	0.9	1.7
Aggregate-demand shock	0.7	0.6	0.4	0.4
Inflation-target shock	0	2.0	0	0.8

Figure B.4 displays the impulse responses of output and inflation for the flexible-wage economy (plain lines), and two versions of the sticky-wage economy: one where nobody indexes to past inflation ($\xi \to 0$, dotted lines), and another where everybody indexes to past inflation ($\xi \to 1$, lines with circles). In turn, Table B.1 presents the discounted percent deviations of output and inflation from their efficient levels, i.e. the flexible-wage economy, for each of the shocks studied above.

For the productivity shock, the lowest deviations for output and inflation are clearly obtained when all households are indexing to trend inflation. In the first column of Figure B.4, we observe higher inertia when all households index to past inflation, and so the deviations with respect to the efficient allocation are the largest. The planner will thus push for the δ^{trend} contract for all households, while the latter prefer the δ^{past} contract for reasons we have explained before.

Table B.2. Social optimum *versus* decentralized equilibrium.

	Outcome from	
	Social planner choice	Households choices
Productivity shock	$\xi \to 0$	$\xi \to 1$
Aggregate-demand shock	$\xi \to 1$	$\xi \to 0$
Inflation-target shock	$\xi \to 0$	$\xi \to 1$

A similar reasoning applies for the other two shocks. After an aggregate-demand shock, the planner prefers all households to index to past inflation because it brings output closer to the efficient allocation. However, households prefer to index to trend inflation. Finally, after an inflation-target shock, the planner prefers the δ^{trend} contract because output and inflation do not deviate from the efficient allocation,[36] but households will not choose this indexation rule. Table B.2 summa-

[36] In this case, inflation drops immediately to its new level, with no costs in terms of real activity.

rizes the conflict emerging from the planner's choices and those of households. In Section 4 in the paper, we argue that it is the decentralized equilibrium, rather than the social planner's outcome, which can explain the documented changes in U.S. wage indexation from the Great Inflation to the Great Moderation.

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