Real Wage Rigidities and the New Keynesian Model*

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Abstract

The standard new Keynesian framework is often criticised for its lack of intrinsic inflation inertia, and the absence of a tradeoff between inflation and output gap stabilization. We argue that the introduction of real wage rigidities is a natural way to overcome those shortcomings. We propose a tractable modification of the new Keynesian framework that incorporates these rigidities and examine some of its implications. We also derive the model's implied relation between inflation and unemployment, and estimate it using US data.

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1 Introduction

A standard New Keynesian model has emerged. On the supply side it consists of Calvo price and/or wage staggering. On the demand side, it is composed of an Euler equation and a Taylor rule. With more explicit microeconomic foundations than its Keynesian ancestor, and more relevance than its RBC predecessor, it has become the workhorse in discussions of fluctuations, policy and welfare.

A central, albeit controversial, block in that standard framework is the so-called New Keynesian Phillips curve (NKPC), which, in its simple form, has the following representation:

$$\pi = \beta \ E\pi(+1) + \kappa \ (y - y^*)$$

where π is inflation, y is (log) output, and y^* is (log) natural or output. The NKPC has, in this standard form, two implications that many researchers view as unsatisfactory:

- It lacks a source of intrinsic inflation inertia, i.e. a source of inflation persistence beyond that inherited from the output gap $(y - y^*)$ itself. As a result, past inflation has no effect per se on current inflation. That implication stands at odds with a substantial body of empirical evidence.

- It lacks a meaningful trade-off between stabilization of inflation and the output gap, even in the presence of supply shocks. Since in the baseline model it is optimal to fully stabilize both variables, the problem facing the central bank becomes rather trivial, with the optimal policy being independent on the relative weight given to the stabilization of each variable in the central banker's preferences. This property, which we shall refer to as the "divine coincidence," contrasts with a widespread consensus on the undesirability of policies that seek to fully stabilize inflation at all times and at any cost in terms of output loss, a consensus that underlies the medium-term orientation adopted by most inflation targeting central banks.

In this paper, we offer a solution to these twin problems. We do so by incorporating what we see as a relevant and important *real* imperfection to the standard NK model: The slow adjustment of real wages to underlying labor market conditions. The existence of such real wage rigidities has been pointed to by many authors as a feature needed to account for a number of labor market facts (for example, Hall 2005). We show that, once the NK model is extended to take account of this imperfection, it naturally delivers both inflation inertia and a meaningful trade-off between inflation and welfare–relevant output gap stabilization. Thus, the resulting model fits the data better, and in our view, has more plausible policy implications, in particular when it comes to understanding the dilemmas central banks face in response to supply shocks.

More generally, we view the proposition developed in this paper as an example of a broader theme: The optimal design of macroeconomic policy depends very much on the interaction between real distortions and shocks. In the standard NK model, these interactions are limited. Put simply, the shocks typically considered in these models do not affect the relative distance of the natural level of output to the efficient level of output. This has strong implications for policy, one of them being the "divine coincidence" between inflation and output gap stabilization. In reality, distortions are likely to interact with shocks, leading to different optimal macroeconomic policies. Understanding these interactions should be high on macroeconomists' research agendas.[1]

The paper is organized as follows. In Section 2 we lay out a baseline new Keynesian model, with staggered price setting and no labor market distortions, and use it to illustrate the two shortcomings mentioned above. In Section 3 we introduce real wage rigidities, and show how this yields both intrinsic inflation persistence and a meaningful inflation output gap stabilization trade-off. Section 4 looks at policy trade-offs. Section 5 derives a relation between inflation, unemployment and observable supply shocks implied by our framework, and provides some evidence on its ability to fit the data. Section 6 relates our results to the literature. Section 7 concludes.

2 The Standard New Keynesian Model

The baseline framework below is standard, with one exception: In order to discuss "supply shocks" we introduce a non-produced input, with exogenous supply M. We interpret shocks to M as supply shocks. For simplicity, we

[1] See Galí, Gertler and López-Salido (2005) for some evidence suggesting the presence of important cyclical variations in the size of aggregate distortions.

leave out technological shocks, but, in our model, they would have exactly the same implications as supply shocks (the only difference, relevant when going to the data, is that supply shocks are directly observable, and technological shocks are not.)

Firms. We assume a continuum of monopolistically competitive firms, each producing a differentiated product and facing an isoelastic demand. The production function for each firm is given by:

$$Y = M^{\alpha} N^{1-\alpha} \tag{1}$$

where Y is output, and M and N are the quantities of the two inputs hired by the firm (in order to keep the notation simple we ignore firm-specific and time subscripts when not strictly needed).

Letting lower case letters denote the natural logarithms of the original variables, the real marginal cost is given by:

$$\begin{aligned} mc &= w - mpn \\ &= w - (y - n) - \log(1 - \alpha) \end{aligned} \tag{2}$$

where w is the (log) real wage, assumed to be taken as given by the firm.

Each good is non-storable and is sold to households, who consume it in the same period. Hence, consumption of each good must equate output.

People. We assume a large number of identical households, with time separable preferences, constant discount factor β, and period utility given by

$$U(C, N) = \log(C) - \exp\{\xi\} \, \frac{N^{1+\phi}}{1+\phi}$$

where C is composite consumption (with elasticity of substitution between goods equal to ϵ), N is employment, and ξ is a (possibly time-varying) preference parameter.

The implied marginal rate of substitution (in logs) is given by:

$$mrs = c + \phi n + \xi \tag{3}$$

2.1 Efficient Allocation (First Best)

Let us start by assuming perfect competition in goods and labor markets. In this case we have, from the firms' side:

$$\begin{aligned} w &= mpn \qquad (4) \\ &= (y - n) + \log(1 - \alpha) \end{aligned}$$

and, from the consumer-workers' side:

$$\begin{aligned} w &= mrs \\ &= y + \phi n + \xi \end{aligned} \tag{5}$$

where we have already imposed the market clearing condition $c = y$. Combining both expressions yields the following expression for the first best level of employment n_1 (we use the subscript "1" to denote values of variables associated with the first best allocation)

$$(1+\phi)\ n_1 = \log(1-\alpha) - \xi \tag{6}$$

Notice that first best employment does not depend on the endowment of the non-produced input (because of exact cancellation of income and substitution effects implied by log utility and Cobb-Douglas technology), but it is inversely related to the preference shifter ξ.

2.2 Flexible Price Equilibrium (Second Best)

We maintain the assumption that prices and wages are flexible, but we take into account the monopoly power of firms in the goods market.

From the firms' side, optimal price setting implies $mc + \mu^p = 0$, where $\mu^p \equiv \log \frac{\epsilon}{\epsilon - 1}$ is the markup of price over cost, coming from the monopoly power of firms. Hence, using (2)

$$w = y - n + \log(1-\alpha) - \mu^p \tag{7}$$

Henceforth, we use subscript "2" to refer to the *second best* (or *natural*) levels of a variable, corresponding to the equilibrium with flexible prices. Combining (5) and (7), we can determine second best employment n_2 :

$$(1+\phi)\ n_2 = \log(1-\alpha) - \mu^p - \xi \tag{8}$$

which, under our assumptions, is independent of m, but may vary as a result of changes in the preference parameter ξ.

Note an important implication of this baseline NK model: While both first and second best employment vary over time, the (log) gap between the two remains *constant* and given by

$$n_1 - n_2 = \frac{\mu^p}{1+\phi} \equiv \delta \tag{9}$$

That property will play an important role in what follows.

2.3 Staggered price equilibrium

Assume now that price decisions are staggered à la Calvo. As is well known, in that case, in the neighborhood of the zero inflation steady state, the behavior of inflation is described by the difference equation:

$$\pi = \beta \; E\pi(+1) + \lambda \; (mc + \mu^p) \tag{10}$$

where $mc+\mu^p$ denotes the log-deviation of real marginal cost from its value in a zero inflation steady state, and $\lambda \equiv \theta^{-1}(1-\theta)(1-\beta\theta)$, with θ representing the fraction of firms not adjusting their price in any given period.

Substituting (5) into (2) and using (8) we obtain:

$$mc + \mu^p = (1+\phi)(n - n_2)$$

Combining the previous two equations gives us the New Keynesian Phillips curve (NKPC):

$$\pi = \beta E\pi(+1) + \lambda(1+\phi)(n - n_2) \tag{11}$$

Inflation depends on expected inflation and the employment gap, defined as the (log) distance of employment from its natural level (the employment gap is clearly proportional to the output gap, similarly defined. We use the employment gap throughout; the equations could be rewritten using the output gap instead.) Note that supply shocks do not appear directly in equation (11). They appear indirectly through their effect on the natural level of employment, n_2, and thus through the employment gap $(n - n_2)$.

Equation (11) exhibits the first characteristic of the NK model we discussed in the introduction, namely the *lack of intrinsic inflation inertia*, i.e. the absence of an independent role for past inflation in the determination of current inflation; the latter depends on exclusively on current and anticipated future employment gaps.

Equation (11) also implies that stabilizing inflation is equivalent to stabilizing the employment gap $(n - n_2)$. Now recall from (9) that $(n_1 - n_2) = \delta$. This implies that stabilizing the employment gap $(n - n_2)$ is equivalent to stabilizing the welfare relevant (log) distance between employment and its first best level $n - n_1$. Putting the two steps together implies that stabilizing inflation is equivalent to stabilizing the welfare relevant (log) distance of employment from first best. This is what we referred to as the *divine coincidence* in the introduction.

Note that the divine coincidence is a consequence of the constancy of δ, the (log) distance between the first and the second best levels of employment. In particular, because an adverse supply shock does not alter δ, it does not create any incentives for the monetary authority to deviate from a policy of constant inflation.

A number of recent papers have introduced a trade-off between stabilization of inflation and stabilization of the distance between employment and the first best level by assuming (directly or indirectly) exogenous stochastic variations in δ, the gap between first and second best employment.[2] We propose instead an alternative source of *endogenous* fluctuations in that gap, one that we view as more relevant empirically, and more significant from the viewpoint of policy, since it may interact with a broad range of shocks.

3 Introducing Real Wage Rigidities

We assume that real wages respond sluggishly to labor market conditions, as a result of some (unmodelled) imperfection or friction in labor markets. Specifically, we assume the partial adjustment model:

$$w = \gamma \; w(-1) + (1 - \gamma) \; mrs \tag{12}$$

where γ can be interpreted as an index of real rigidities.[3]

We view equation (12) as a parsimonious way of modeling the slow adjustment of wages to labor market conditions implied by a variety of models of real wage rigidities, without taking a stand on what the "right" model is.[4] What is important, however, is that the slow adjustment be the result of distortions rather than preferences, so the first best equilibrium is unaffected.

[2] See Woodford (2004, section 4.5) for a general discussion of that case.

[3] In principle one would want to guarantee $w \geq mrs$ at all times, to prevent workers from working more than desired, given the wage—as would be the case for example in a model where wages are set in bargaining, fluctuating but remaining above the reservation wage of workers. This would be easily achieved by introducing a (sufficiently large) positive steady state wage markup, as in

$$w = \gamma w(-1) + (1 - \gamma)(\mu_w + mrs)$$

without altering any of the conclusions below, though at the cost of burdening the notation.

[4] Other authors have adopted a similar assumption in order to model real wage rigidities. Hence, Kai and Linzert (2005) propose an analogous partial adjustment model in the context of a matching model in order to account for the response of unemployment and

Next we examine the implications of real wage rigidities on the equilibrium level of employment and inflation. Once again we find it useful to start by looking at the flexible price case.

3.1 Flexible Price Equilibrium (Second Best)

Assume that prices and wages are flexible, so we solve for the second best level of employment. Notice that the first best level is the same as before.

From above, using (3), (12), and our assumptions on technology (1), we have, from the wage setting side:

$$\begin{aligned} w &= \gamma\, w(-1) + (1-\gamma)\ (y + \phi n + \xi) \\ &= \gamma\, w(-1) + (1-\gamma)\ [\alpha(m-n) + (1+\phi)n + \xi] \end{aligned} \tag{13}$$

As before, from the firms' side:

$$\begin{aligned} w &= mpn - \mu^p \\ &= (y-n) + \log(1-\alpha) - \mu^p \\ &= \alpha(m-n) + \log(1-\alpha) - \mu^p \end{aligned}$$

Putting the two together and rearranging terms, we can solve for second best employment n_2 as a function of the first best (which remains unchanged, and given by (6)) and the two exogenous driving forces:

$$n_2 - n_1 + \delta = \Theta_\gamma\ [n_2(-1) - n_1(-1) + \delta] + \Theta_\gamma[\Delta m + (1+\phi)^{-1}\Delta\xi] \tag{14}$$

where $\Theta_\gamma \equiv (\gamma\alpha)/(\gamma\alpha + (1-\gamma)(1+\phi)) \in [0,1]$ and $\delta \equiv \mu^p/(1+\phi)$.

Equation (14) points to the key implication of the introduction of real wage rigidities: The gap between the first and second best levels of employment is no longer constant, fluctuating instead in response to both preference and supply shocks.

Notice further that Θ_γ is increasing in γ, implying that the size and persistence of deviations of the gap between second and first best employment are increasing in the degree of real rigidities. The effects of an adverse supply shock (an unexpected decrease in m) are to decrease employment (relative

inflation to monetary policy shocks. Alternative, but related, formalizations of real wage rigidities can be found in Felices (2005), in a model with variable effort and shirking, and Rabanal (2004), in a model with rule-of-thumb wage setters.

to an unchanged first best) initially by Θ_γ, with employment returning to its initial value as the wage decreases over time. On the other hand, in response to a preference shock that lowers first best employment (an increase in ξ), second best employment falls by less, since the assumed real rigidities prevent the real wage from adjusting upward sufficiently to support the lower efficient level of employment.

3.2 Staggered Price Equilibrium

We can now solve for the behavior of inflation under the assumption of price staggering a la Calvo. Combining (1), (2), and (13), and rearranging terms we obtain

$$(mc+\mu^p) = \gamma\ (mc+\mu^p)(-1)+(1-\gamma)(1+\phi)(n-n_2)+\gamma\alpha(\Delta n-\Delta n_2)) \quad (15)$$

This equation shows an immediate consequence of the interaction between real wage rigidities ($\gamma > 0$) and sticky prices ($n \neq n_2$): The inertia in real marginal cost beyond that implied by deviations of employment from its natural, second best, level.

This inertia has an important implication for the dynamics of inflation, as can be seen by combining (15) with (10) to yield:

$$\pi = \beta E\pi(+1) + \frac{\lambda}{1-\gamma L}[(1-\gamma)(1+\phi)(n-n_2)+\gamma\alpha(\Delta n-\Delta n_2)] \quad (16)$$

This is the relation between inflation and the employment gap implied by our model. It differs from the baseline NKPC relation in two important ways:

It implies *intrinsic inflation inertia*, i.e. a direct dependence of inflation on past inflation, for a given employment gap. We shall discuss this at more length in the next section when we derive an empirically testable version of (16), but this can already be seen by multiplying both sides of the equation by $1-\gamma L$ and rearranging to get:

$$\pi = \frac{\gamma}{1+\beta\gamma}\pi(-1) + \frac{\beta}{1+\beta\gamma}E\pi(+1) + \frac{\lambda}{1+\beta\gamma}\ x + \zeta \quad (17)$$

where $x \equiv ((1-\gamma)(1+\phi)(n-n_2) - \gamma\alpha(\Delta n - \Delta n_2)$ and $\zeta \equiv (\beta\gamma)/(1+\beta\gamma)\ (\pi - E(\pi|-1))$ is white noise. As γ increases, the coefficient on past inflation increases from 0 (no inflation inertia) to $1/(1+\beta)$, which is slightly greater than $1/2$. On the other hand, the coefficient on expected inflation declines from β (when $\gamma = 0$) to $\beta/(1+\beta)$ (when $\gamma = 1$), which is slightly less than $1/2$.

It implies that the *divine coincidence* no longer holds. It is still the case that there is an exact relation—although a more complex dynamic one—between inflation, expected inflation, and the employment gap (now, both level and change). So fully stabilizing inflation is still consistent with fully stabilizing the employment gap, the distance of employment from its second best level : In equation (16), $\pi = \pi(+1)$ implies a constant $(n - n_2)$.

Stabilizing the employment gap however is no longer desirable. This is because what matters for welfare is the distance of employment not from its second best, but from its first best level. In contrast to the baseline model, the distance between the first and the second best levels of employment is no longer constant, but is instead affected by the shocks.

To see what this implies, combine (16) with (14) to obtain the relation between inflation and the distance of employment from its first best level:

$$\begin{aligned}\pi \;=\; & \beta E\pi(+1) + \frac{\lambda}{1-\gamma L}\,[(1-\gamma)(1+\phi)(n - n_1 + \delta) + \gamma\alpha(\Delta n - \Delta n_1)] \\ & -\frac{\lambda}{1-\gamma L}\,\gamma\alpha[\Delta m + (1+\phi)^{-1}\Delta\xi\,]\end{aligned} \qquad (18)$$

Inflation depends on expected inflation, a distributed lag of the distance of employment from its first best level, and a distributed lag of both supply and preference shocks. In other words, there is no longer an exact relation, however complex, between inflation and the distance of employment from first best. Thus, there is no way to stabilize both in the presence of either supply or preference shocks, and monetary policy faces a clear trade-off.

To understand the basic source of the trade-off, it is useful to look at the economy's factor price frontier. Let v be the real price of the non-produced input. Then, given the Cobb Douglas assumption:

$$mc = (1-\alpha)\; w + \alpha\; v + const.$$

Thus any shock that induces an increase in the real price of the non-produced input (say, an increase in the price of oil) must lead either to a decrease in real wages or an increase in real marginal cost. Depending on the degree of monetary policy accommodation, the outcome will be reflected in employment or inflation. This can be seen clearly by deriving the inflation equation, now expressed in terms of Δv and the distance of employment from first best (see appendix for derivation):

$$\pi = \beta \; E\pi(+1) + \frac{\lambda}{1 - \Gamma L} \; [(1-\Gamma)(1+\phi) \; (n - n_1 + \delta) + \Gamma\alpha \; \Delta v] \qquad (19)$$

where $\Gamma \equiv \gamma/(1-\alpha(1-\gamma)) \in [0,1]$ is a monotonic transformation of the index of real wage rigidities γ.

Consider now any shock that drives up the real price of the non produced input, v. Note that v is endogenous in our framework, and so an increase in v may come from either a negative supply shock (a drop in m) or a preference shock that brings down the marginal disutility of labor (a drop in ξ). Stabilizing inflation would require a proportional decline in the real wage; given real wage rigidity, this can only be delivered by a decrease in employment relative to first best. Stabilizing the distance of employment from first best will lead to higher inflation.

In the next two sections, we look first at the implications of the trade-off for monetary policy, and then at the empirical evidence the specification of the inflation equation suggested by our model.

4 Policy Tradeoffs

To illustrate the implications of the trade off faced by the monetary authority in such an economy, we look at two extreme policies. For convenience, we assume $\xi = 0$ and a random walk process for the non-labor input endowment, so that $\Delta m = \varepsilon_m$ is a white noise process. Note that, in this case, first best employment is constant.

Suppose that the central bank stabilizes the distance of employment from first best, at a level consistent with zero *average* inflation. That requires $n = n_1 - \delta$ at all times. It follows from (18) that:

$$\pi = \beta E\pi(+1) - \frac{\lambda\gamma\alpha}{1-\gamma L} \; \varepsilon_m$$

Solving under rational expectations gives:

$$\pi = \gamma\pi(-1) - \frac{\lambda\gamma\alpha}{1-\beta\gamma} \; \varepsilon_m$$

So, the employment stabilizing policy implies a potentially strong accommodation of adverse shocks through inflation, followed by a slow (if γ is high) return to normal.

Suppose that central bank stabilizes inflation instead, so $\pi = E\pi(+1) = 0$. Then:

$$(1-\gamma)(1+\phi)[n - n_1 + \delta] + \gamma\alpha(\Delta n - \Delta n_1) - \gamma\alpha\varepsilon_m = 0$$

Or equivalently:

$$n - n_1 = -(1-\Theta_\gamma)\delta + \Theta_\gamma \ [n(-1) - n_1(-1)] + \Theta_\gamma\varepsilon_m$$

Not surprisingly, this policy replicates the second best, with large fluctuations in employment.

To the extent that the central bank attaches some weight to stabilization of both inflation and the gap from first best, optimal policy will be somewhere in between. The important point is that, so long as the central bank puts some weight on activity, it may have to accommodate adverse supply shocks through potentially large and long lasting increases in inflation. How long lasting depends on the degree of real wage rigidity, γ. How large depends also on γ, but also on λ, the degree of nominal rigidity, and α, the share of the non-produced input in production.

5 Estimating the Inflation-Unemployment Relation

Equation (16) is not directly estimable, for two reasons. First, the natural level of employment, and by implication the employment gap, is not observable (a point stressed by Galí and Gertler (1999)). Second, we typically observe the price rather than the quantity of the non-produced input. Thus, in taking equation (16) to the data, we must transform it into a relation that can be estimated from actual data. We proceed in two steps.

The first is to explicitly introduce unemployment. To do so, let n^s be implicitly defined by

$$w = y + \phi n^s + \xi$$

Note that n^s measures the quantity of labor households would want to supply given the current wage and marginal utility of income.[5] Accordingly, define the (involuntary) rate of unemployment u as the (log) deviation between the desired supply of labor and actual employment:

$$u \equiv n^s - n$$

Clearly, in the absence of wage rigidities ($\gamma = 0$) there is no involuntary unemployment as the wage is equal to the marginal rate of substitution of households. For $\gamma > 0$, the previous definition and some algebraic manipulation allows us to rewrite (12) as follows:

$$\Delta w = -\frac{(1-\gamma)\phi}{\gamma}\, u$$

This implies that an equivalent way of stating our assumption of real wage rigidity is as follows: A rate of unemployment above (below) the natural rate, where the latter is implicitly normalized to zero, induces a downward (upward) adjustment of real wages. That adjustment goes on as long as the unemployment rate deviates from the natural rate, with the size of the implied response being inversely related to γ, our index of real rigidities, but positively related to ϕ, the slope of the labor supply.

The second is to rewrite the inflation equation (16) in terms of unemployment, and of the price rather than the quantity of the non-produced input. Some manipulation gives (the algebra is given in the appendix):

$$\pi = \frac{1}{1+\beta}\pi(-1) + \frac{\beta}{1+\beta}E\pi(+1) - \frac{\lambda(1-\alpha)(1-\gamma)\phi}{\gamma(1+\beta)}\, u + \frac{\alpha\lambda}{1+\beta}\, \Delta v + \zeta \quad (20)$$

As in equation (17) earlier, the term ζ is proportional to $\pi - E(\pi|-1)$ and so is white noise, orthogonal to all variables at $t-1$.

Inflation is a function of past and expected future inflation, of the unemployment rate, and of the change in the real price of the non-produced input; except for the presence of expected future inflation, this specification is indeed quite close to traditional specifications of the Phillips curve, which typically include changes in the price of oil and other supply side factors in addition to unemployment on the right hand side.[6]

[5] Note that the two conditioning variables would generally differ in a first best equilibrium, which explains why, in general, $n_s \neq n_1$

[6] See, for example, Gordon (1997), or Blanchard and Katz (1999).

This equation can be estimated using instrumental variables. To do so, we use annual U.S. data on inflation (measured by the percent change in the GDP deflator), the civilian unemployment rate, and the percent change in the PPI raw materials index (relative to the GDP deflator). Our instrument set consist of four lags of the previous three variables. The sample period is 1960-2004. The resulting estimated equation is (standard errors in brackets, constant not reported):

$$\pi = \underset{(0.09)}{0.66}\pi(-1) + \underset{(0.06)}{0.42}E\pi(+1) - \underset{(0.08)}{0.20}\ u + \underset{(0.001)}{0.018}\ \Delta v + \zeta$$

which accords, at least qualitatively, with (20). In particular all the estimated coefficients have the right sign and are statistically significant. Furthermore the theoretical restriction that the sum of coefficients on lagged and expected inflation equals one cannot be rejected at the 5 percent level (though not by much). When we impose this restriction the resulting estimated equation is:

$$\pi = \underset{(0.05)}{0.52}\pi(-1) + \underset{(0.05)}{0.48}E\pi(+1) - \underset{(0.05)}{0.08}\ u + \underset{(0.009)}{0.014}\ \Delta v + \zeta$$

which again matches well the theoretical specification, though the coefficients on unemployment and raw materials prices are significant at a level slightly above 10 percent now. The coefficients on past and expected future inflation imply a value for β of 0.92. The other structural coefficients are not identified and cannot be recovered (they would be if we estimated the full model, something we have not done).

6 Relation to the Literature and Extensions

We are not the first to offer potential solutions to either the lack of inflation inertia and the divine coincidence present in the baseline NK model. One can distinguish between at least four approaches:

- *Distortion shocks.* A standard fix has been to simply append an exogenous disturbance to the NKPC, call it a "cost-push" shock, and thus create a trade-off between inflation stabilization and employment gap stabilization (for example, [Clarida, Galí and Gertler 1999]). Taken at face value, such a fix is clearly not an acceptable solution. One needs to know where this additional disturbance comes from, and whether it belongs to the equation. As we have seen, conventional supply shocks do not appear as disturbances in the baseline NKPC. A number of authors however have shown that a potential justification for this approach is to assume the presence of "distortion shocks", for example variations in tax changes, or changes in desired markups by firms (see for example Smets and Wouters (2003), Steinsson (2003), and Clarida, Galí and Gertler (2001)). Such shocks do not affect the relation between inflation and the employment gap, the distance of employment from its second best value; they do however affect the distance of the second best—which is affected by the shock—and the first best—which, by assumption, is not affected by the shock. Thus, they create a trade-off between stabilization of inflation and stabilization of the distance of employment from first best. Such distortion shocks do probably exist, and, with respect to these shocks, the divine coincidence no longer holds. But it still holds with respect to standard supply shocks, such as movements in the price of oil. And, thus, the model extended in this way, still implies that keeping inflation constant in the face of increases in the price of oil is the right policy—a proposition which, again, seems implausible.

- *Lagged indexation and Inflation Inertia.* Another fix, aimed at generating inflation inertia, has been to simply append a lagged inflation term to the NKPC, thus giving rise to what has been known as the *hybrid* NKPC. Taken at face value, such a fix is clearly also not an acceptable solution. Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003) and Steinsson (2004), among others, have shown however that such a formulation can be derived from models in with automatic indexation of prices to past inflation by the firms that are not re-optimizing prices in any given period. We also see this as an unconvincing fix, with little basis in fact (for example Dhyne et al. 2005)) rather than a convincing explanation of inflation inertia. In addition, this approach does not remove the divine coincidence: Fully stabilizing inflation, even in the presence of supply shocks, still leads to stabilization of the distance of employment from its first best level.

- *Sticky information and Inflation Inertia:* Mankiw and Reis (2002) have proposed a model in firms adjust prices every period, according to a pre-specified plan, but revise that plan infrequently. Accordingly, current inflation is the result of decisions based on news about future demand and cost conditions obtained in previous periods, in addition to current news. A consequence of that "distributed lag" property is the emergence of inertia in inflation. Once again, we view that explanation as one at odds with the micro evidence: firms do not seem to adjust their prices continuously according to a pre-specified plan; instead they typically keep prices unchanged for long periods of time. Furthermore, recent survey-based evidence suggests that firms review their prices more often than they change them, exactly the opposite to what sticky information models assume. (see Fabiani et al. (2004)). Finally, as was the case with lagged indexation models, sticky information does not overcome in itself the divine coincidence feature: by stabilizing inflation the central bank can make the constraints on frequency of price revisions non-binding, and thus stabilizing the gap.

- *More Complex Price and Wage Setting* Yet another approach aimed at removing the divine coincidence has been to explore the implications of alternative structures of wage and price setting. Erceg, Henderson and Levin (2000; EHL, henceforth) in particular have shown for example that, under the assumption that, if both wage decisions and price decisions are staggered à la Calvo, the relation between price inflation and the output gap no longer holds exactly, implying a trade off between price inflation stabilization and output gap stabilization. In the rest of this section, we show that wage inertia is not sufficient to deliver a meaningful policy trade-off, nor is it a source of (price) inflation persistence.

6.1 The EHL Model Revisited

Consider the baseline model of Section 2 but now with staggered price and wage setting à la Calvo, as in EHL.

Given our assumptions, *wage inflation* is described by the difference equation:

$$
\begin{aligned}
\pi^w &= \beta E\pi^w(+1) - \lambda_w(w - mrs - \mu^w) \\
&= \beta E\pi^w(+1) - \lambda_w(w - \alpha m - (1-\alpha+\phi)n - \xi - \mu^w) \\
&= \beta E\pi^w(+1) - \lambda_w(w - w_2) + \lambda_w(1-\alpha+\phi)(n - n_2)
\end{aligned}
$$

where w_2 and n_2 are, respectively the natural levels of the real wage and employment (i.e., the ones that would obtain under flexible prices and wages).

μ^w is a constant desired wage markup, and λ_w is a coefficient which is a function of structural parameters, including the Calvo parameter indexing the probability that any individual wage is reset in a given period (see EHL for details).

Price inflation, now denoted by π^p, is given by:

$$\begin{aligned}\pi^p &= \beta E\pi^p(+1) + \lambda_p(mc + \mu^p) \\ &= \beta E\pi^p(+1) + \lambda_p(w - \alpha m + \alpha n - \log(1-\alpha) + \mu^p) \\ &= \beta E\pi^p(+1) + \lambda_p(w - w_2) + \lambda_p\alpha(n - n_2)\end{aligned}$$

Note that neither wage nor price inflation depends only on the employment gap. In both cases, inflation depends on the employment gap and the distance of the wage from the natural wage. Thus, the divine coincidence does not apply, either with respect to price inflation, or with respect to wage inflation.

Define however the composite inflation rate $\pi \equiv (\lambda_w\pi^p + \lambda_p\pi^w)/(\lambda_w + \lambda_p)$. It follows from the definition that:

$$\pi = \beta E\pi(+1) + \kappa(n - n_2) \tag{21}$$

where $\kappa \equiv (\lambda_w\lambda_p(1+\phi))/(\lambda_w + \lambda_p)$.

Given that, in the EHL model, the distance between first and second best employment is given by

$$n_1 - n_2 = \frac{\mu}{1+\phi} \equiv \delta$$

where $\mu \equiv \mu^p + \mu^w$, we can rewrite (21) as:

$$\pi = \beta E\pi(+1) + \kappa(n - n_1 + \delta)$$

Hence the divine coincidence emerges again, though in a different guise: Stabilizing the distance of employment from first best is equivalent to stabilizing a weighted average of wage and price inflation.

What are the policy implications of this weaker form of the divine coincidence? As shown by EHL the utility-based loss function needed to evaluate alternative policies is a weighted average of the squares of the employment gap, price inflation and wage inflation. In this context strict price inflation targeting is generally suboptimal, and often involves welfare losses that are several times larger than other, better designed policies. Interestingly, while strict employment gap stabilization (and hence stabilization of the composite inflation index) is exactly optimal only for a specific parameter configuration, EHL conclude that it is nearly optimal for a large range of parameter values (see also Woodford (2003), Chapter 6). Hence, and for all practical purposes, a meaningful policy tradeoff is also missing in the EHL model.

Equation (21) shows that a particular weighted average of wage and price inflation displays no intrinsic persistence: it depends exclusively on current and expected future output gaps, with past inflation (wage, price, or a weighted average of the two) being irrelevant for the determination of current inflation. How does this result carry over to price inflation, the variable whose persistence (or lack thereof) has been the focus of much recent attention? One way of looking at it is to consider the worse case for our argument, the case where there is only nominal wage staggering. In this case, wage inflation exhibits no intrinsic inflation persistence:

$$\pi^w = \beta E \pi^w(+1) + \lambda_w(1-\alpha+\phi)(n-n_2) \tag{22}$$

To derive price inflation, note that:

$$\begin{aligned} \pi^p &= \pi^w - (w - w(-1)) \\ &= \pi_w + \frac{1-\alpha}{\alpha}\,\Delta v \end{aligned}$$

So price inflation is given by:

$$\pi^p = \beta E \pi^p(+1) + \lambda_w(1-\alpha+\phi)(n-n_2) + \frac{1-\alpha}{\alpha}(\Delta v - \beta E \Delta v(+1)) \tag{23}$$

Solving forward, price inflation depends only on current and expected future employment gaps and change in the real price of the non produced input. It still does not directly depend on past inflation.

We conclude from this comparison with the EHL model that the effects of real rigidities are fundamentally different from those of nominal rigidities. Real rigidities remove the divine coincidence and generate inflation inertia. Nominal wage rigidities, at least in the form formalized by Calvo and EHL, do not.

7 Conclusions

The standard new Keynesian framework is often criticized for its lack of intrinsic inflation inertia, and by the implied absence of a trade-off between inflation and output gap stabilization. In the present paper we have argued that the introduction of real wage rigidities is a natural way to overcome those shortcomings. We have proposed a tractable modification of the new Keynesian framework that incorporates these real wage rigidities and show how their presence affects the dynamics of inflation and generates policy trade-offs.

Our model implies a simple representation of inflation as a function of lagged and expected inflation, the unemployment rate and the change in the price of non-produced inputs. When we estimate that relationship using annual postwar US data, we find that it fits the data pretty well. The latter result may not be very surprising given that the resulting empirical equation is not too different from some of the ad-hoc specifications that other authors have used in the older Phillips curve literature. A key difference lies in the relevance (confirmed empirically) of a forward-looking component in the determination of inflation, a feature emphasized by the more recent literature. In a sense our framework helps bridge the gap between the old and new Phillips curve literatures in a way that is consistent with the micro evidence on price setting.

There are several avenues that we plan to pursue, building on the framework developed in the present paper. First, we plan to estimate a model of joint wage and price inflation dynamics that combines both nominal and real rigidities in wage setting. Secondly, we plan to conduct a quantitative analysis of the optimal monetary policy response to a change in the price of oil or other raw materials, and the implications for that optimal response of alternative assumptions on the degree of real wage rigidities and well as the persistence of the shock.

More generally, we hope our paper contributes to raise macroeconomists' awareness of the likely interactions between aggregate shocks and the size of distortions, and of the potential perils of ignoring that interaction.

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Appendix: Alternative Representations of Inflation Dynamics in the presence of Real Wage Rigidities

Throughout this appendix we assume the marginal cost and wage setting schedules:

$$mc + \mu^p = w - mpn + \mu^p$$

$$w = \gamma w(-1) + (1-\gamma) mrs$$

as well as the inflation equation implied by Calvo staggered price setting:

$$\pi = \beta E \pi(+1) + \lambda(mc + \mu^p) \tag{24}$$

Representation #1: in terms of the gap between actual and second best employment.

Combining the wage schedule with (1) and (3)

$$w = \gamma w(-1) + (1-\gamma)(\alpha m + (1-\alpha+\phi)n + \xi)$$

which can be combined with the marginal cost schedule to yield

$$mc + \mu^p = \gamma(mc(-1) + \mu^p) + (1-\gamma)(\xi - \log(1-\alpha)) + (1-\gamma)(1+\phi)n - \gamma\alpha(\Delta m - \Delta n)$$

Setting $mc = mc(-1) = -\mu^p$ (flexible price assumption):

$$0 = (1-\gamma)(\xi - \log(1-\alpha)) + (1-\gamma)(1+\phi)n_2 - \gamma\alpha(\Delta m - \Delta n_2)$$

which can be subtracted from the equation immediately above to yield:

$$mc + \mu^p = \gamma(mc(-1) + \mu^p) + (1-\gamma)(1+\phi)(n - n_2) + \gamma\alpha(\Delta n - \Delta n_2)$$

Finally, we combine the previous difference equation for real marginal cost with the Calvo equation (24) to obtain:

$$\pi = \beta E \pi(+1) + \frac{\lambda}{1-\gamma L}[(1-\gamma)(1+\phi)(n - n_2) + \gamma\alpha(\Delta n - \Delta n_2)]$$

or, equivalently,

$$\pi = \frac{\gamma}{1+\gamma\beta}\pi(-1)+\frac{\beta}{1+\beta\gamma}E\pi(+1)+\frac{\lambda}{1+\beta\gamma}[(1-\gamma)(1+\phi)(n-n_2)+\gamma\alpha(\Delta n-\Delta n_2)]+\zeta$$

where $\zeta \equiv \frac{\beta\gamma}{1+\gamma\beta}(\pi - E(\pi| - 1))$.

Representation #2: in terms of the gap between actual and first best employment, and underlying exogenous shocks.

Combining the wage schedule with (1) and (3)

$$w = \gamma w(-1) + (1-\gamma)(\alpha m + (1-\alpha+\phi)n + \xi)$$

which can be combined with the marginal cost schedule to yield

$$mc+\mu^p = \gamma(mc(-1)+\mu^p)+(1-\gamma)(\xi-\log(1-\alpha))+(1-\gamma)(1+\phi)n-\gamma\alpha(\Delta m-\Delta n)$$

Using the expression for first best employment, we can rewrite the previous difference equation in terms of the welfare relevant employment gap and the underlying shocks:

$$mc+\mu^p = \gamma(mc(-1)+\mu^p)+(1-\gamma)(1+\phi)(n-n_1+\delta)+\gamma\alpha(\Delta n-\Delta n_1)-\gamma\alpha[\Delta m+(1+\phi)^{-1}\Delta\xi]$$

Combined with (24) we obtain:

$$\pi = \beta E\pi(+1)+\frac{\lambda}{1-\gamma L}\{(1-\gamma)(1+\phi)(n-n_1+\delta)+\gamma\alpha(\Delta n-\Delta n_1)-\gamma\alpha[\Delta m+(1+\phi)^{-1}\Delta\xi]\}$$

or, equivalently,

$$\begin{aligned}\pi \quad = \quad & \frac{\gamma}{1+\gamma\beta}\pi(-1) + \frac{\beta}{1+\beta\gamma}E\pi(+1) \\ & +\frac{\lambda}{1+\beta\gamma}[(1-\gamma)(1+\phi)(n-n_1+\delta) + \gamma\alpha(\Delta n - \Delta n_1) - \gamma\alpha(\Delta m + (1+\phi)^{-1}\Delta\xi)] + \zeta\end{aligned}$$

Basic point: when $\gamma > 0$ a tradeoff between inflation and employment gap stabilization emerges in response to both types of shocks.

Representation #3: in terms of the gap between actual and first best employment, and the real price of nonproduced input.

Combining the wage schedule with (1) and (3)

$$w = \gamma w(-1) + (1-\gamma)(\alpha(m-n) + (1+\phi)n + \xi)$$

Using the fact that $m - n = (w - v) + \log(\alpha/1-\alpha)$, as implied by cost minimization:

$$w = \gamma w(-1) + (1-\gamma)(\alpha(w-v) + \alpha \log(\alpha/1-\alpha) + (1+\phi)n + \xi)$$

Rearranging terms:

$$w = \Gamma\ w(-1) + (1-\Gamma)(1-\alpha)^{-1}\ (\alpha \log(\alpha/1-\alpha) - \alpha v + +(1+\phi)n + \xi) \quad (25)$$

where $\Gamma \equiv \frac{\gamma}{1-\alpha(1-\gamma)} \in [0,1]$ is a monotonic transformation of the index of real wage rigidities γ.

Notice also that

$$\begin{aligned} mc + \mu^p &= w - \alpha(m-n) - \log(1-\alpha) + \mu^p \\ &= w - \alpha(w-v) - \alpha \log \alpha - (1-\alpha)\log(1-\alpha) + \mu^p \\ &= (1-\alpha)\ w + \alpha\ v - \alpha \log \alpha - (1-\alpha)\log(1-\alpha) + \mu^p \quad (26) \end{aligned}$$

which is a version of the factor price frontier (allowing for variable markups). Thus we see that an increase in the real price of the endowment input (independently of the source, in principle any shock may do), will create both downward pressure on real wages and upward pressure on marginal costs and, hence, inflation.

Combining (25) and (26) we obtain (after some algebra):

$$mc + \mu^p = \Gamma\ (mc(-1) + \mu^p) + (1-\Gamma)(1+\phi)\ (n - n_1 + \delta) + \Gamma\alpha\ \Delta v \quad (27)$$

We can now rewrite inflation as

$$\pi = \beta\ E\pi(+1) + \frac{\lambda}{1-\Gamma L}\ [(1-\Gamma)(1+\phi)\ (n - n_1 + \delta) + \Gamma\alpha\ \Delta v]$$

or, equivalently,

$$\begin{aligned}
\pi &= \frac{\Gamma}{1+\beta\Gamma}\ \pi(-1) + \frac{\beta}{1+\beta\Gamma} E\pi(+1) + \frac{\lambda(1-\Gamma)(1+\phi)}{1+\beta\Gamma}(n-n_1+\delta) + \frac{\lambda\Gamma\alpha}{1+\beta\Gamma}\ \Delta v + \zeta \\
&= \frac{\gamma}{1-\alpha+\gamma(\alpha+\beta)}\ \pi(-1) + \frac{(1-\alpha(1-\gamma))\beta}{1-\alpha+\gamma(\alpha+\beta)}\ E\pi(+1) \\
&\quad + \frac{(1-\alpha)(1-\gamma)(1+\phi)}{1-\alpha+\gamma(\alpha+\beta)}(n-n_1+\delta) + \frac{\gamma\lambda\alpha}{1-\alpha+\gamma(\alpha+\beta)}\ \Delta v + \zeta
\end{aligned}$$

Representation #4: in terms of the unemployment rate and the real price of the non-produced input.

First we derive a simple relationship between marginal cost, the unemployment rate (defined as above), and the employment gap:

$$\begin{aligned}
mc + \mu^p &= w - (y-n) - \log(1-\alpha) + \mu^p \\
&= (y + \phi n_s + \xi) - (y-n) - \log(1-\alpha) + \mu^p \\
&= \phi\ (u - u_n) + (1+\phi)(n - n_1 + \delta)
\end{aligned}$$

We use the previous expression to substitute for $(n - n_1 + \delta)$ in the expression for real marginal cost in (27):

$$mc + \mu^p = \Gamma\ (mc(-1) + \mu^p) + (1-\Gamma)\ [mc + \mu^p - \phi\ u] + \Gamma\alpha\ \Delta v$$

After rearranging terms we obtain the difference equation:

$$mc = mc(-1) - \frac{(1-\gamma)(1-\alpha)\phi}{\gamma}\ u + \alpha\ \Delta v$$

which is well defined only if $\gamma > 0$ (notice that a γ approaches 0 so does u).

Combining the previous equation with (24), we obtain:

$$\pi = \frac{1}{1+\beta}\ \pi(-1) + \frac{\beta}{1+\beta} E\pi(+1) - \frac{\lambda(1-\alpha)(1-\gamma)\phi}{\gamma(1+\beta)}\ u + \frac{\alpha\lambda}{1+\beta}\ \Delta v + \zeta$$