Trend Inflation, Wage Indexation, and Determinacy in the U.S.*

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Abstract

We combine an estimated monetary policy rule for the U.S. economy featuring time-varying trend inflation and stochastic coefficients with a plausibly calibrated medium scale new-Keynesian framework embedding positive trend inflation. We find that the impact of the decline in trend inflation on the likelihood of being in a determinate state is modest and limited to the second part of the 1970s. In line with Clarida, Galí, and Gertler (2000), a change in the policy response to inflation is shown to be sufficient to drive the economy to a unique equilibrium regardless of the level of trend inflation. We identify wage indexation as the crucial element supporting our "Taylor parameter only" result about the the switch to determinacy.

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"Is it more difficult to anchor expectations at 4 percent than at 2 percent?"

Blanchard, Dell'Ariccia, and Mauro, 2010, p. 11.

1 Introduction

One of the most popular stories researchers tell to explain the U.S. Great Moderation regards the change in the Federal Reserve's systematic monetary policy. According to this story, monetary policy became more aggressive at the end of the 1970s when Paul Volcker became the Chairman of the Federal Reserve, which succesfully drove the U.S. economy on a low volatility-path (at least until the recent financial crises).[1] Clarida, Galí, and Gertler (2000) estimate a variety of simple policy rules and find evidence consistent with this interpretation of the Great Moderation. A list of contributions, including Lubik and Schorfheide (2004), Boivin and Giannoni (2006), and Benati and Surico (2009) consolidate this finding.

Some recent investigations (Hornstein and Wolman, 2005, Kiley, 2007 and Ascari and Ropele 2009)), however, highlight the role of trend inflation in shaping the determinacy region in a simple New Keynesian model. They show that the Taylor principle generally does not hold in presence of trend inflation: the higher is trend inflation, the more aggressive must be the policy reaction to inflation to guarantee determinacy. Intriguingly, Coibion and Gorodnichenko (2011a) (CG henceforth) provide empirical support to the role of trend inflation by showing that its decrease during the 1980s and 1990s was as important as the switch in policy to conquest U.S. inflation.

The role of trend inflation is clearly relevant from a policy standpoint. If low trend inflation is fundamental to pin down a unique equilibrium and get rid of inefficient fluctuations, policymakers should refrain from raising it. On the other hand, an increase in trend inflation would leave more room for conducting conventional monetary policy easings before hitting the zero-lower bound, therefore giving the Fed extra degrees of freedom when called

[1] The main alternative to this story emphasizes the change in volatility of the U.S. macroeconomic shocks. See, among others, Sims and Zha (2006), Canova, Gambetti, and Pappa (2008), and Justiniano and Primiceri (2008).

to face dramatic economic downturns. Following this reasoning, Blanchard, Dell'Ariccia, and Mauro (2010) have recently proposed to increase the inflation target pursued by the Federal Reserve to four percent. In light of the risks of falling into determinacy when raising trend inflation, however, the pros and cons of undertaking this policy move must be carefully assessed.

This paper contributes to this debate by conducting a variety of experiments designed to disentangle the role played by systematic monetary policy and trend inflation as for their impact on the probability of determinacy in a world resembling the U.S. economy. To achieve this goal, we combine the policy rule estimated by Coibion and Gorodnichenko (2011a) with a plausibly calibrated operational medium scale model à la Christiano, Eichenbaum, and Evans (2005). Medium scale frameworks like those popularized by Schmitt-Grohe and Uribe (2004), Christiano, Eichenbaum, and Evans (2005), and Smets and Wouters (2007) have been widely adopted by research centers and academic circles for some years now. Such frameworks provide a natural benchmark to investigate the role possibly played by monetary policy and trend inflation in leading the economy to the Great Moderation.

Our main finding gives robust support to changes in the systematic monetary policy as the sufficient factor to explain the conquest of U.S. Great Moderation. Differently, trend inflation is shown to exert just a modest influence on the likelihood of falling in the indeterminacy territory. This influence is confined to the last years of the 1970s, a phase in which trend inflation reached its historical peak in the post-WWII sample. Consequently, the "Taylor parameter only" story popularized by Clarida, Galí, and Gertler (2000) re-emerges as the key-driver that may have led the U.S. economy to enjoy more than two decades of relatively stable macroeconomic conditions.

Importantly, our result is shown to depend upon the degree of wage indexation we allow in the model. Wage indexation counteracts the negative effects of trend inflation on the width of the determinacy region. We find that CG's story holds true when low values of wage indexation are combined with high values of trend inflation. The empirical literature, however, has proposed a wide variety of values, ranging from the very high calibration in Christiano, Eichenbaum, and Evans (2005) to the low point estimates by Justiniano and Primiceri (2008). We then conduct a battery of exercises

under different calibrations of this parameter. Moreover, we provide fresh empirical evidence on wage indexation by running rolling-window estimations of a reduced-form linear model linking wage and price inflation, from which we back out the implied degree of wage indexation. We find that wage indexation is unstable over time, i.e., it is high and significant in the 1970s, but it dramatically drops to zero when entering the Great Moderation sample, an evidence in line with the one recently provided by Hofmann, Peersman, and Straub (2010). Our estimated time-varying degree of wage indexation is correlated with an alternative measure constructed by considering the number of workers covered by the cost-of-living-adjustment clause in their labor contracts as collected by Ragan and Bratsberg (2000). We document a positive correlation between wage indexation and the trend inflation process estimates obtained by CG. Therefore, the effects of high realizations of trend inflation on the determinacy region are likely to have been dampened by the relatively high degree of wage indexation occurred in the 1970s. Hence, empirically plausible measures of wage indexation supports the "Taylor parameter only" story popularized by Clarida et al. (2000). We close our analysis with an exercise with which we try to assess to what extent an increase in trend inflation could lead to indeterminacy. We find that, under plausible calibrations, the proposal formulated by Blanchard et al. (2010) would be consistent with equilibrium uniqueness under a policy conduct as the one estimated for the post-1982 U.S. monetary policy.

Our paper closely relates to Coibion and Gorodnichenko's (2011). They couple an estimated monetary policy rule featuring both time-varying policy coefficients and time-varying trend inflation with a microfounded small scale AS/AD model assuming absence of frictions on the labor market. They show that the U.S. economy switched to determinacy during the Volcker disinflation because of both the change in the Fed's response to macroeconomic variables and the decrease in trend inflation. Differently, we combine their estimated policy rule with a richer macroeconomic framework featuring a variety of nominal and real frictions. We find that, once wage indexation is accounted for, the role of trend inflation becomes modest. CG's empirical findings can therefore be interpreted as a call for relevant ingredients that are omitted in a small scale representation of the U.S. economic envi-

ronment. Our study shows that wage indexation and, more generally, labor market frictions are likely to be one of these relevant ingredients.

Our paper is structured as follows. The next section investigates the impact of the different real and nominal frictions featured in a medium-scale model on the determinacy region, given a simple Taylor rule. Section 3 is the main section of the paper, which provides the main results and our counterfactual exercises. Section 4 investigates the role of wage indexation. Section 5 scrutinizes the risks associated to augmenting trend inflation to four percent as suggested by Blanchard et al. (2010). Section 6 concludes.

2 Determinacy: the role of frictions

We use a workhorse medium-scale macroeconomic model (see, e.g., Schmitt-Grohé and Uribe, 2004, Christiano et al., 2005, Smets and Wouters, 2007) that extends the standard textbook, one-sector dynamic stochastic growth model by adding various real and nominal frictions. Real frictions are monopolistic competition in goods and labor markets, habit formation in preferences for consumption, variable capital utilization and adjustment costs in investment. Nominal frictions include Calvo-style nominal price and wage contracts, and backward-looking indexation in wages. In particular, as typically assumed in this literature, wage setters that cannot re-optimize automatically update their nominal wages conditional on past inflation. Section 4 analyzes in details the implication of this assumption for our results. Following CG, we do not assume price indexation. As for the remaining parameters, we calibrate our medium-scale model by exploiting Christiano et al.'s (2005) baseline calibration/estimates, which we report in Table 1.[2]

It is of interest to investigate the role played by each friction in shaping the determinacy region under alternative calibrations of trend inflation. In order to do that, we first log-linearize the model around a generic trend inflation level. As a reference framework, we use the baseline small-scale New Keynesian model featuring monopolistic competition and price staggering version, which is obtained by shutting down all the modeled real frictions and

[2] A complete description of the structural equations and of the parameter calibration used in this paper is contained in an Appendix available upon request.

wage staggering. We then investigate how the determinacy region changes by activating one friction at a time. We undertake this exercise to have a first assessment of the relative importance of the different frictions characterizing our medium-scale model.

The model is closed by using a very simple Taylor rule, expressed in log-deviations from the steady state values:

$$r_t = \phi_\pi \pi_t, \tag{1}$$

where the policy rate r_t just responds to the deviation of inflation from the long-run inflation objective (i.e., trend inflation). Woodford (2003) shows that when such a rule is coupled with the simplest two-equations New Keynesian model with zero trend inflation, the "Taylor principle" arises, i.e., $\phi_\pi > 1$ is the simple and intuitive necessary condition for the existence of a unique rational expectations equilibrium. Some recent contributions (Hornstein and Wolman, 2005, Kiley, 2007, and Ascari and Ropele, 2009), however, demonstrate that the Taylor principle fails when positive trend inflation is considered. Models embedding positive trend inflation require a stronger response of the policy rate to inflation in order to guarantee the determinacy of the equilibrium.

The solid line in Figure 1a) plots the minimum level of ϕ_π necessary to ensure a rational expectation equilibrium as a function of trend inflation in a simple New Keynesian model featuring just monopolistic competition and price staggering (without both real frictions and wage staggering). The determinacy region lies above the line (i.e., values of ϕ_π larger than the minimum), while the indeterminacy region lies below the line (values of ϕ_π lower than the minimum). Clearly, the minimum level of ϕ_π required for a unique rational expectation equilibrium is equal to 1, when trend inflation is zero. However, it increases quite rapidly with trend inflation. For example, for values of trend inflation around 3%, ϕ_π should be larger than 5.

Figure 1a) visualizes the effects of adding one real friction at a time among the ones (i.e., variable capital utilization, investment adjustment costs and habit in consumption) present in our medium-scale New Keynesian model. All these frictions have the same qualitative effect: they reduce the sensitivity of the minimum response to inflation necessary to achieve determinacy to

different levels of trend inflation. As a result, the line flattens with respect to the solid one, and, for any level of trend inflation larger than 1, the minimum ϕ_π is lower whenever one of these frictions is present. From a quantitative point of view, the investment adjustment costs have the largest effect, while variable capital utilization the smallest.

Figure 1b) displays the effects of introducing wage stickiness in a standard simple New Keynesian model without real frictions. Wage stickiness qualitatively shrinks the determinacy region as trend inflation increases. This effect is quantitatively very powerful. Wage stickiness makes the determinacy region so sensitive to the trend inflation level that the monetary authority needs to dramatically increase the response to inflation to ensure a determinate equilibrium. For example, for a level of trend inflation of 4%, ϕ_π should be larger than 25. On the other hand, indexation is very effective in counteracting the effects of introducing wage stickiness. A 50% indexation clause is already sufficient to get the determinacy line quite a long way towards the one featuring no wage stickiness. Full indexation in wages would completely offset the interaction between trend inflation and nominal wage stickiness. Consequently, the line would just overlay to solid one.

Figure 1c) shows the difference between our operational medium-scale model and a simple New Keynesian model, as in CG. Our basic calibration assume full indexation in wages as in CEE. In Figure 1c) the effects of the three real frictions on the sensitivity of the minimum policy response to inflation is clearly evident. The line is very flat and moderate level of trend inflation has only very minor effects on the minimum ϕ_π necessary to induce a unique rational expectation equilibrium: the Taylor principle would still be a good rule-of-thumb in such a model. A model without real frictions, as in CG, instead, is much more sensitive to the level of trend inflation.

Finally, Figure 1d) shows the effects of wage stickiness and wage indexation in a model with frictions. Qualitatively, wage stickiness has the same effects as in a model without frictions: it increases the sensitivity of the determinacy region to trend inflation levels. However, in a model with frictions this effect is much milder: the curve is flatter and indexation is even more effective in counteracting the effects of wage stickiness.

To summarize, Figures 1a)-1d) provide us a lot of insights on the re-

lationship between trend inflation, wage rigidities, and determinacy. Trend inflation shrinks the determinacy region all else being equal. However, its impact turns out to be quite limited when the usual "bells and whistles" present in medium-scale models are considered. In this sense, investment adjustment costs exert a substantial effect on the determinacy frontier. Wage stickiness clearly "works against determinacy". Its effect appears to be quantitatively important in a small-scale version of the model, but it tends to vanish when more nominal and real frictions are embedded in the analysis. In contrast, wage indexation widens the determinacy region, and its impact appears to be substantial in both the small-scale and the medium-scale versions of the model.

3 Determinacy: the role of trend inflation vs. monetary policy

This section engages in a battery of exercises to assess the impact of trend inflation vs. monetary policy on the likelihood of being in a determinate state. Before conducting this exercises, we follow Coibion and Gorodnichenko (2011 a,b) and estimate a policy rule featuring time-varying i) coefficients and ii) trend inflation. We will then exploit this estimated rule in our simulations.

3.1 Estimated policy rule

We replicate the estimates concerning the U.S. policy rule obtained by CG. Such rule features time-varying coefficients to account for the variations of the U.S. monetary policy over the post-WWII sample. The rule reads as follows:

$$r_t = c_t + (1-\rho_{1,t}-\rho_{2,t})(\phi_{\pi,t}E_t\pi_{t+2} + \phi_{gy,t}E_t gy_t + \phi_{x,t}E_t x_t) + \rho_{1,t}r_{t-1} + \rho_{2,t}r_{t-2} + \varepsilon_t \tag{2}$$

where

$$c_t = (1-\rho_{1,t}-\rho_{2,t})[(1-\phi_{\pi,t})\overline{\pi}_t + \omega_t - \phi_{gy,t}\overline{gy} - \phi_{x,t}\overline{x}_t] \tag{3}$$

Eq. (2) describes the policy rate r_t as responding to a time varying intercept c_t, to expected inflation over the next two quarters $E_t\pi_{t+2}$, to expected output growth $E_t gy_t$ and expected output gap $E_t x_t$ in the current quarter. Following Coibion and Gorodnichenko (2011 a,b), we allow for two lags of the policy rate to achieve a better empirical fit of the observed policy rate dynamics. The policy shock ε_t is assumed to be a white-noise process. Regarding (3): $\overline{\pi}_t$ is the target rate of inflation, ω_t is the equilibrium real interest rate, $\overline{gy}$ is the target rate of growth of real GDP, and $\overline{x}_t$ is the target level of the output gap. As in Boivin (2006), Coibion and Gorodnichenko (2011 a,b) policy parameters are assumed to follow random walk processes. Greenbook forecasts of current and future macroeconomic variables prepared by staff members of the Federal Reserve are employed in the estimation. By sticking to CG's sample choice, i.e., March 1969-December 2002, we are able to replicate their results (Coibion and Gorodnichenko, 2011 a,b).[3] We find compelling evidence in favor of changes in the policy coefficients. In particular, after 1982 the policy rule features an increase in the response to inflation and output growth, and also in the overall degree of interest rate smoothing. Eq. (3) allows to recover an estimate of time-varying trend inflation $\overline{\pi}_t$.[4] The estimated trend inflation process displays substantial variations over time. In particular, it starts from a value close to three percent in 1969, then it gradually increases until the end of the 1970s, where it reaches values close to eight percent. Then, a substantial drop occurs during the Volcker disinflation, and a continuous decline towards two percent follows. Compelling evidence in favor of changes in trend inflation is also found by Kozicki and

[3] The evolution of the coefficients and processes in equations (2) and (3) is estimated via the Kalman smoother. Two breaks in the volatility of shocks to the parameters are modeled, one in 1979 and the other one in 1982. A detailed description of the data employed in this analysis may be found in CG. The measure of time-varying trend inflation is extracted from the time varying constant - see eq. (3) - conditional on some additional assumptions on the equilibrium real interest rate and the Federal Reserve's targets for real GDP growth and the output gap. Such targets are approximated by computing the trend measures of the observables via the Hodrick-Prescott filter (smoothing weight: 1,600), which we then feed into (3) along with the estimated time-varying parameters, to extract the trend inflation measure.

[4] As in CG, the equilibrium real interest rate, the target growth rate of real GDP, and the target output gap are approximated by using the Hodrick-Prescott filter. These series are then used in eq. (3), along with estimates of time-varying parameters, to extract the measure of trend inflation.

Tinsley (2005), Ireland (2007), Cogley and Sbordone (2008), and Cogley, Primiceri, and Sargent (2010).

We now turn to our counterfactual simulations.

3.2 Counterfactual exercises

Following CG, we consider the estimated time-varying policy rule in (2) and the time-varying trend inflation consistent with the estimated policy rule from (3). We then feed these estimates in our medium-scale model to compute the probability of determinacy per each quarter of the sample.[5] The solid line in Figure 2 depicts the outcome of our computations. Recall that the evolution of such probability over time depends on both the time-dependence of the monetary policy coefficients and that of trend inflation. This Figure clearly shows that, according to the estimates of the policy reaction function and of trend inflation, a medium-scale macroeconomic model would predict a low probability of determinacy in the 1975-1980 sample only. This result is similar to CG's, who condition their analysis on a smaller-scale model than ours.

Thus, one is tempted to conclude that trend inflation matters when it is high (1975-1980) and does not matter when it is low (Great Moderation). However, this conclusion cannot be granted by just looking at the solid line because both trend inflation *and* monetary policy coefficients are changing in any period. The sample 1975-1980 is a period of high trend inflation and weak response of monetary policy to aggregate variables, while the Great Moderation period presents the opposite combination. Our main research question, however, is how much of the probability of determinacy can be attributed to the systematic component of monetary policy and how much to the level of trend inflation. We engage in counterfactual exercises studying different combinations of systematic policy (weak, strong) and trend inflation (high, low) to shed light on this issue.

[5] Such probabilities are computed as follows. We draw a single realization from the estimated distributions of each single policy coefficient per each given period. Conditional on that, per each given period we check if the economy features a unique rational expectations equilibrium. We repeat this exercise 10,000 times, and compute the time-dependent probability of being in a determinate state as the ratio between the number of times we verified the equilibrium is unique and the total number of draws.

3.2.1 The role of trend inflation

The first counterfactual exercise aims at assessing the relevance of changes in trend inflation *alone* in generating indeterminacy of the rational expectation equilibrium. More precisely, we address the following question:

> *What is the impact of trend inflation on the probability of determinacy conditional on a given policy conduct?*

We consider two scenarios. The first one features a fixed inflation target set at six percent (roughly the average inflation rate in the pre-Volcker period). The second one features a fixed inflation target calibrated at three percent (roughly the average inflation rate during the Great Moderation). These scenarios are constrasted with the already scrutinized case allowing for trend inflation to change every quarter.

The outcomes related to these three scenarios are presented in Figure 2. Recall that these scenarios share the same evolution of the policy coefficients. Therefore, differences among the probabilities, if present, must be driven by the three different trend inflation processes. Hence, the larger is the impact exerted by trend inflation on the computed probabilities, the larger should be the difference among the three lines displayed in Figure 2. As a matter of fact, the evolution of the computed probabilities is clearly different only in the pre-Volcker period. Trend inflation. Differently, according to our simulations a high trend inflation would have exerted a virtually zero-impact during the Great Moderation. In other words, during this phase the probability of being in a state of determinacy is *de facto* independent from trend inflation, as shown by the similarity among the estimated probabilities. Hence, differently with respect to CG, we find that the impact of trend inflation on the probability of being in a determinate state is negligible in the post-Volcker period.

To summarize, *trend inflation matters only conditional to a weak monetary policy rule.* In this case, high (6%) and low (3%) would deliver a substantial difference in the estimated probability of determinacy. However, when the monetary policy rule features a strong reaction to inflation and output growth, as in the Great Moderation sample, trend inflation has no

effects on the probability of determinacy. Figure 2 thus suggests that policy may neutralize the effects of trend inflation, that is, policy plays a dominant role with respect to trend inflation. The next sections corroborate this result.

3.2.2 The role of policy

To ascertain the effects of trend inflation alone, the previous analysis investigated the effects of different (high and low) trend inflation levels *for a given time-varying policy rule.* To isolate the effect of policy *per se*, we now conduct a specular exercise with which we analyze the effect of different policies *given the estimated time-varying trend inflation.* We thus ask the following question:

> *What is the impact of the policy rule on the probability of determinacy conditional on the estimated time-varying trend inflation?*

We then set up the following exercise. We move from our rule with time-varying coefficients to rules featuring fixed policy coefficients $x_t = x, x_t = \left[\phi_{\pi,t}, \phi_{gy,t}, \phi_{x,t}, \rho_{1,t}, \rho_{2,t}\right]'$. We calibrate such rules with the pre 1979 vs. post 1982 point estimates obtained by CG (see their Table 1, under "Mixed Taylor rule"). We then couple our medium-scale macroeconomic model with both estimated policy rules in turn, assuming the estimated time-varying trend inflation process $\overline{\pi}_t$ from (3).

Figure 3 depicts our computed probabilities. Recall that, differently with respect to Figure 2 above, the two scenarios in Figure 3 share the same evolution of trend inflation (from high levels in the 70's to low levels in the 90's) and different policy parameters (pre-Volcker vs. post-Volcker). Therefore, differences among the probabilities, if present, must be driven by the two different policies. Intriguingly, the two scenarios tell quite heterogeneous stories. The probability of determinacy associated to the pre-1979 policy has an average value above 0.30, while the more aggressive post-1982 policy rule yields a value above 0.70 on average. Both probabilities turn out to be very stable over time. That is, for a given constant policy rule, we do not observe any changes in the probability of being in a determinate state, despite dramatic changes in trend inflation. The effect of trend inflation is

thus marginally visible in (and confined to) the period 1977-1983. Overall, however, the impact of the time-varying inflation process is marginal.

Our findings reveal the following. Had the Fed maintained a constantly weak monetary policy in the pre-1979 sample, and had it switched to a constantly aggressive monetary policy in the post-1979 phase, we would have registered a switch from a state of indeterminacy to a state of uniqueness for whatever value of trend inflation (in the range of its historical realizations). Hence, our results offer solid support to the role played by systematic monetary policy in anchoring inflation expectations, a result corroborating those put forward by Clarida, Galí, and Gertler (2000).

3.2.3 Scrutinizing the role of policy coefficients

The previous Section demonstrates the prominent role of the switch in policy in inducing determinacy in an environment that admits time-varying trend inflation. It is of interest to distinguish the role that the different coefficients in the monetary policy rule play in delivering our results. In particular, given the debate in the literature, we are actually mostly interested in the Taylor coefficient, i.e., the response of policy to inflation. Clarida, Galí, and Gertler (2000) point to the weak monetary policy response to inflation as the main driver of the Great Inflation period.

We thus run counterfactual experiments to assess the role of the different coefficients in the Fed's monetary policy rules (2). The precise question in this Section is:

> *What is the impact of each policy rule's coefficient in isolation on the probability of determinacy all else being equal?*

To answer this question, we look at how the probabilities of determinacy are affected by counterfactually fixing all the monetary policy coefficients according to the pre-79 estimates, and then switching *just* one policy rule coefficient at a time to its post-82 estimate. As in our previous exercises, we model trend inflation as a time-varying process according to eq. (3). Figure 4 displays the results. Recall that the two lines in each panel differ only for a single coefficient in the policy rule: the more the two lines are far apart, the more the coefficient matters.

Figure 4 (top-left panel) clearly shows that a shift in ϕ_π is sufficient to determine the switch from a low probability of determinacy in the Great Inflation period to a high probability of determinacy in the Great Moderation period. Interestingly enough, the Taylor parameter turns out to be the only one substantially influencing the probability of being in a determinate state. On the other hand, perturbations of the remaining policy coefficients imply much milder changes of such probabilities. In other words, an increase in the Fed's response to inflation alone is sufficient to insure determinacy regardless of trend inflation (at least when a calibration consistent with its historical levels is employed). Clarida, Galí, and Gertler's (2000) result is simply restored in an operational medium-scale macroeconomic model featuring time-varying trend inflation.

4 The role of wage indexation

The medium-scale model includes a number of features that are not present in the baseline New Keynesian framework employed by CG in their analysis. One may then wonder which friction, or set of frictions, is responsible for the discrepancy between CG's results and ours. We extensively scrutinized the role of each extra nominal and real friction in the model at work, and verified that there is a single key-ingredient for our results: wage indexation to past inflation.

Wage indexation is important in this environment it enables households to face the increase in the price level due to trend inflation and keep up with their desired level of real expenditures. In particular, the higher is wage indexation, the less important is trend inflation in affecting the width of the determinacy territory. As a matter of fact, the empirical evidence concerning the degree of wage indexation has not converged to a puntual indication yet. In conducting estimations based on indirect inference of the model we focus on in this paper, Christiano, Eichenbaum, and Evans (2005) calibrate it to one. Smets and Wouters (2007) estimate a similar model with Bayesian techniques and find a posterior mode of 0.58 for such a parameter. Rabanal and Rubio-Ramírez (2005) obtain a posterior mean equal to 0.25 conditional on a smaller scale model estimated with Bayesian techniques.

Justiniano and Primiceri (2008) estimate a value very close to zero with a flexible medium scale framework allowing for time-varying volatilities of the macroeconomic shocks. It is, then, somewhat natural to study different scenarios characterized by alternative degrees of indexation.

Figure 5 displays the probability of being in a determinate state (conditional on fixed policies and time-varying trend inflation) for different degrees of wage indexation. Evidently, the degree of wage indexation is key for our result.[6] Our baseline calibration, which is the one in Christiano, Eichenbaum, and Evans (2005), clearly points toward systematic monetary policy as the only driver of the probability of determinacy. Our results holds true for a variety of calibrations of the indexation parameter. When reducing wage indexation to 0.58 (panel d) in Figure 5), the "Taylor parameter only" story is still supported by our simulations. The impact of trend inflation is minor and just limited to the period 1977-1983, in which the low frequency component of inflation recorded its highest values in the investigated sample. The probability of being in a determinate state remains above 0.5 no matter the value of trend inflation (among those consistent with historical realizations). A drastically different result is obtained when calibrating the degree of wage indexation to 0.25 (see panel b)). In that case, high trend inflation dramatically reduces the probability of being in a determinate state, even conditional to the post-82 policy rule. This last finding is *a fortiori* supported by the analysis undertaken with zero wage indexation. Interestingly, trend inflation does not seem to affect the probability of determinacy associated to a weak systematic policy conduct. Even more surprisingly, for very low values of wage indexation, the aggressive post 1982 policy induces a lower probability of being in a determinate state than the weaker pre 1979 policy.[7]

To summarize, in presence of high wage indexation, the effect played by

[6] Note that this would also be true for price indexation, as already noted by CG. However, to compare our results with CG, we stick to their baseline assumption of no indexation in prices. Since CG assume a competitive labor market and flexible wages, they obviously do not analyze the role wage indexation.

[7] The fact that indexation counteracts the effects of trend inflation on the model dynamics and determinacy of the rational expectation equilibrium has been already investigated by Ascari (2004), Ascari and Ropele (2009) and Coibion and Gorodnichenko (2011a). In presence of *full* indexation on prices/wages, the effects of trend inflation on the dynamics of the model are just muted.

trend inflation is small. Consequently, changes in systematic policy are sufficient to engineer a switch to a unique rational expectations equilibrium in a medium scale macroeconomic model. In presence of a low level of indexation, trend inflation gains power and importantly affects the determinacy region, a finding already stressed by CG. Our results suggest that the interaction between monetary policy and wage indexation is crucial for a correct understanding of the evolution of the U.S. macroeconomic dynamics. We provide novel evidence on wage indexation in the next section.

4.1 Empirical relevance of the role of wage indexation

This section aims at assessing the empirical relevance of the effects of wage indexation described above. To do so, we feed our macroeconomic model with an estimate of the degree of wage indexation in the United States. Wage indexation in this model is likely to be a reduced-form coefficient possibly changing over time due to variations in economic conditions. Therefore, coherently with our exercises so far, we should consider time-dependent measures of wage indexation. We will then re-compute the probability of determinacy (as in our previous sections) conditional on these evolving estimated degrees of wage indexation, rather than sticking to a calibrated fixed-value.

We consider two measures of wage indexation. This first measure is an estimate obtained by relating wage inflation to price inflation via a dynamic model as in Hofmann, Peersman, and Straub (2010). In particular, we estimate the following dynamic equation with U.S. data, 1948:I-2010III:

$$\pi_t^w = c + \sum\nolimits_{j=1}^{J} \gamma_j^w \pi_{t-j}^w + \sum\nolimits_{k=1}^{K} \gamma_k^\pi \pi_{t-k} + \varepsilon_t^w, \tag{4}$$

where π_t^w is wage inflation, and π_t stands for price inflation.[8] Lags in eq. (4) capture the wage inflation persistence in a reduced form fashion. Then, as Hofmann, Peersman, and Straub (2010), the degree of wage indexation is computed as follows:

$$WI = \frac{\sum\nolimits_{k=1}^{K} \gamma_k^\pi}{1 - \sum\nolimits_{j=1}^{J} \gamma_j^w}. \tag{5}$$

[8]Inflation rates computed by considering the quarterly growth rate of nominal wages (hourly compensation in the non-farm business sector) and the GDP price deflator, respectively. The source of the data is the Federal Reserve Bank of St. Louis' website.

Equation (4) is estimated with rolling techniques, which allow to track the time-evolution of the reduced-form coefficients γ_k^π and γ_j^w. Therefore, it enables us to estimate a time-varying degree of wage indexation, which we term WI_t.[9] We then feed our medium-scale model with our estimated WI_t (mean realizations), and re-conduct our formerly presented exercises.

Our second measure relies on figures coming from micro data. Such data regard individuals covered by the cost-of-living-adjustment (COLA, henceforth) clause in their labor contracts.[10] Ragan and Bratsberg (2000) collect COLA coverage based on 22 years of U.S. data and regarding 32 private-sector industries. They also provide an aggregate measure of COLA coverage (see their Figure 1, p. 306). COLA coverage peaked in 1976, a year in which 61% of the workers were covered by major collective bargaining contracts. Then, the overall COLA rate fell to 22% at the end of 1995, when COLA statistics were last collected. Ragan and Bratsberg (2000) use these data to estimate a model of the determinants of COLA coverage. In line with a variety of previous studies (see reference therein), they find that the major determinant of COLA coverage is inflation uncertainty (measured as the standard deviation of inflation expectations in the *Livingstone Survey*). Given the very high correlation between the level of inflation and its standard deviation in the U.S. data (see, e.g., Ball (1992)), this robust evidence is very relevant for our analysis. It suggests that the degree of wage indexation (as

[9] We set $J = 3$ to get rid of the serial correlation as detected by the Breusch-Godfrey LM test at a 5% confidence level. A search for the significant lagged price inflation regressors led us to set $K = 1$. The width of our windows is fixed to 64 quarters. The computation of the time-varying confidence interval is undertaken via boostrapping techniques. Per each window, we proceed as follows. First, we estimate eq. (4) with OLS. Second, we fix the parameter values of the regressors of eq. (4) to their OLS estimates, and we generate pseudo-data for wage inflation by sampling with replacement a number of realizations from the vector of residuals estimated at the first round. Third, we employ these pseudo-data to estimate eq. (4) with OLS, we compute the wage index (4), and we store it. Steps two and three are repeated 500 times per each window. We then pick the 5th and 95th percentiles along with the mean of the window-specific empirical distribution, and we move to the next window.

[10] The COLA indicator is computed as the ratio between the number of unionized workers with contracts featuring a cost-of-living adjustment clause over the total number of unionized workers (both conditional on contractual agreements involving over 1,000 workers). Therefore, it is a measure of *prevalence* of wage indexation more than a *degree* of wage indexation. However, as stressed by Holland (1988), a higher prevalence of indexation implies a higher average degree of indexation.

measured by COLA coverage) should be treated as time-varying, because it is high when inflation is volatile (and high), while it is low when inflation is stable (and low), an empirical finding in line with the results provided by Holland (1986).[11] We will return on this correlation later.

Figure 6 shows our estimates of the degree of wage indexation coming from macro data from (5) and the dynamics of COLA coverage from micro data. The two measures of the degree of wage indexation are statistically different, because the COLA coverage lies outside the confidence bands of our estimates of WI_t for a number of periods in the sample (see panel a) in Figure 6). Both measures assume the highest values when our measure of trend inflation peaks, that is in the sample period 1977-1983. Recall that Figure 5 demonstrates that high trend inflation in that period would have mattered only if wage indexation were low. However, this is not the case in our estimates, so that we are more likely to fall in the case of panel d), rather than panel a), in Figure 5. This is clearly demonstrated in Figure 7, that performs the same exercises as in Figure 5 (fix policy and time-varying trend inflation) allowing for a time varying indexation as resulted from our macroeconomic estimates[12] (panel a)) and from the COLA coverage (panel b)). Trend inflation has only marginal effects in the sample 1977-1983, but, conditional on a strong policy response to inflation, the likelihood of determinacy remains well above 0.5 in both cases. On the contrary, a weak policy response would very likely result in an indeterminate equilibrium regardless of the level of trend inflation.

Finally, Figure 8 displays what can be thought to be our final estimates, which are constructed by letting both policy parameters and trend inflation and the degree of wage indexation vary over time. Again, our aim is to compute the probability of being in a determinate state. We do so by considering alternatively the two measures of wage indexation presented above.

[11] The COLA indicator is a measure of explicit indexation regarding unionized workers, which cover a minor share in the U.S. labor market (typically less than 25%). However, as shown by Holland (1988), the responsiveness of non-unionized workers' nominal wages to price level shocks is very similar to that of unionized workers' due to implicit indexation. Therefore, one can take COLA as a proxy for explicit and implicit wage indexation of the entire U.S. economy.

[12] When insignificant, the value of WI_t was set to zero in our simulations.

Despite the differences in such measures, the two estimates of our probability are very similar, a finding stressing the robustness of our results under empirically relevant degrees of wage indexation. Again, the only historical period in which our factual analysis puts in evidence a high likelihood of indeterminacy is the second half of the 1970s, a period characterized by very high trend inflation and a systematic monetary policy weaker that the one in place in the post-1982 period.

Our empirical findings lead us to conclude the following. The effect that the high trend inflation rate of the 1970s could potentially have played was in fact substantially dampened by a high degree of wage indexation. Such indexation dramatically dropped in the 1980s and 1990s, but trend inflation fell as well. Overall, the impact of trend inflation in a plausibly calibrated medium scale model is likely to be mild at best. However, our analysis calls for further empirical work to investigate the presence and variation of wage indexation over time and its interaction (possibly, dependence) with trend inflation and the policy regime in place.

5 On the risks of raising trend inflation

Blanchard et al. (2010) have recently proposed to raise trend inflation to four percent. Their idea is the following. In face of negative shocks depressing the real side of the economy, the Federal Reserve typically reacts by lowering the cost of money to boost the economy and bring real GDP growth back to its target. Clearly, a trend inflation of four percent would give policymakers more room to manouver than a target set to two percent, because the latter implies a much higher probabilty of hitting the zero-lower bound. The recent financial crisis is already a textbook example of this kind of scenario.

Of course, one must weight all pros and cons related to a proposal like Blanchard et al.'s. CG's paper importantly makes us understand that raising trend inflation in a small-scale world is very risky, in that the likelihood of falling into a multiple-equilibria situation is high even conditional on an aggressive monetary policy conduct. Our paper shows that a medium-scale model may lead to different conclusions due to frictions in the labor markets, in particular wage indexation to past inflation. Therefore, one may very

well wonder which are the risks of raising trend inflation to four percent in a medium-scale world like ours. We answer this question by simulating the probability of being in a determinate state as a function of different values of trend inflation. In line with our previous exercises, we conduct this experiment under four alternative degrees of wage indexation to assess its impact on our results.

Figure 9 displays our probabilities. In a world in which wage indexation is absent, it would be fairly risky to increase the inflation target to four percent. According to our simulations, this would imply a decrease in the probability of determinacy of about 30%, driving such probability to a level around 50%. This prediction, however, turns out to be extremely sensitive to the employment of different degrees of wage indexation. A moderate amount of wage indexation, i.e. 25%, is enough to substantially increase the probability of anchoring inflation expectations even under a four-percent trend inflation. This probability monotonically increase with the degree of wage indexation, whose marginal returns are decreasing along this dimension. Interestingly, CG's policy implication is re-established for higher values of trend inflation, e.g., a wage indexation of about 50% would not be enough to keep the probability of determinacy over 1/2 in correspondence to an eight-percent inflation target. However, we reiterate that, in correspondence of a four-percent trend inflation rate, it would be very likely for the economy to feature a unique RE-equilibrium ever under moderate amounts of indexation.

It is worth stressing that the probabilities displayed in Figure 9 are, if anything, conservative estimates of the true probabilities of determinacy. Two elements are clearly working against determinacy. First, in conducing our exercises we are increasing trend inflation while holding wage indexation fixed. This assumption appears to be counterfactual. The degree of wage indexation is, more plausibly, a reduced-form coefficients positively correlated with the average level of price inflation. Fresh evidence along this line is provided by Hofmann, Peersman, and Straub (2010) and ourselves in this paper. Such evidence squares with the COLA coverage presented and discussed in section 4.2. To provide further evidence on this correlation, we regress the COLA indicator on its own past values and on the trend inflation estimates provided by CG. We find a significant and positive correlation between trend inflation

and wage indexation. The coefficient on contemporaneous trend inflation reads 0.29, with a p-value associated to the t-statistic lower than 0.01.[13] While not assigning any causal interpretation to this finding, we interpret it as corroborating that fact that, historically, increases in trend inflation rate go hand in hand with increases in wage indexation.[14] Second, the results in Figure 9 (and those presented in this paper in general) are obtained under the assumption of zero price indexation. If we admitted a positive degree of price indexation, the probabilities displayed in Figure 9 would increase due to the positive impact exerted by price indexation on the width of the determinacy territory, a well known result in the literature (Hornstein and Wolman, 2005, Kiley, 2007, and Ascari and Ropele 2009). Logically, one would expect price indexation to increase following an increase in average inflation in the economy, a prediction corroborated by Benati (2008). Therefore, we conclude that the simulated probabilities presented in Figure 9 should be interpreted as "lower bounds", i.e., the true probabilities in this medium-scale world are likely to be higher than those depicted there.

As recalled at the beginning of this paper, Blanchard et al. (2010) ask if it is more difficult to anchor expectations at 4 percent than at 2 percent. In light of our simulations, our answer is negative.

6 Conclusions

We combine an estimated monetary policy rule featuring time-varying trend inflation and stochastic coefficients with the medium scale model popularized by Christiano, Eichenbaum, and Evans (2005), which we calibrate with their estimates. We conduct a variety of counterfactual experiments to isolate the influence of trend inflation on the likelihood of being in a determinate state. We show that even with positive trend inflation, the Taylor principle is sufficient to guarantee a determinate equilibrium in a world described by a

[13] Model estimated via OLS. A White heteroskedasticity-consistent covariance matrix was employed to ensure robustness. Yearly observations of trend inflation were obtained by computing within-year averages of the trend inflation estimates by CG. Standard diagnostic confirmed the absence of serial correlation of the error term. Further details on this estimation are available upon request.

[14] Holland (1995) runs a variety of Granger-causality type of regressions and finds that increases in inflation precede increses in wage indexation.

medium scale model as (or close to) the one adopted by most central banks nowadays. In other words, trend inflation does not seem to play a relevant role in determining the probability of being in an indeterminate region. Our results differ from those proposed by Coibion and Gorodnichenko (2011a), who indicate the reduction in trend inflation as a necessary ingredient for the switch to a more moderate macroeconomic environment. From a policy standpoint, our results demonstrate that Blanchard, Dell'Ariccia, and Mauro's (2010) proposal to raise the inflation target to four percent to avoid hitting the zero-lower bound during economic downturns is not likely to drive the U.S. economy "back to the 1970s". From a normative perspective, however, more research is needed in order to understand if such a choice would actually be optimal from a welfare standpoint. An interesting investigation along this dimension has recently been proposed by Coibion, Gorodnichenko, and Wieland (2010).

We find wage indexation to be the key element opening the gap between our results and CG's. A high degree of wage indexation dampens the role played by trend inflation and, consequently, reinforces the one assigned to systematic monetary policy. The literature on wage indexation (e.g., Ragan and Bratsberg, 2000, and the references therein) shows a positive correlation between the degree of wage indexation and inflation uncertainty. This suggests a negative correlation between the degree of wage indexation and the monetary policy aggressiveness towards inflation stabilization. Indeed, both our novel empirical evidence on macrodata and the measures of COLA coverage shows this pattern. As a consequence, our results suggest that high inflation has been historically coupled with a high degree of wage indexation that undid the effects of high trend inflation on the possibility of an indeterminate rational expectation equilibrium. Given that differences in unionization have been pretty dramatic across industrialized countries for the last decades, it would be of interest to conduct a cross-country empirical investigation aiming at quantifying the different role played by wage indexation in different countries.

Given our limited understanding of the wage indexation mechanism at a macroeconomic level, our results suggest that future research should aim to endogenize the wage indexation mechanism and to understand its determi-

nants. While important work has been done studying the interaction between monetary policy and the labor market (e.g., Krause and Lubik, 2007, Gertler and Trigari, 2009 , Blanchard and Galí, 2010), this paper provides a precise direction in this field of research.

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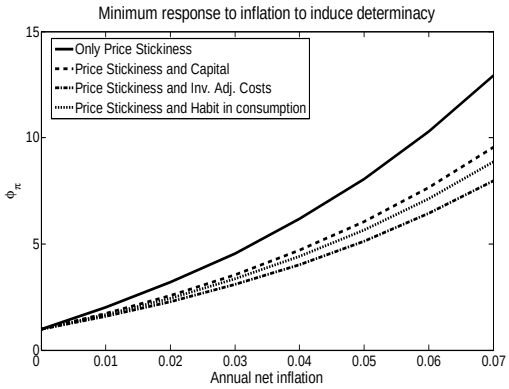
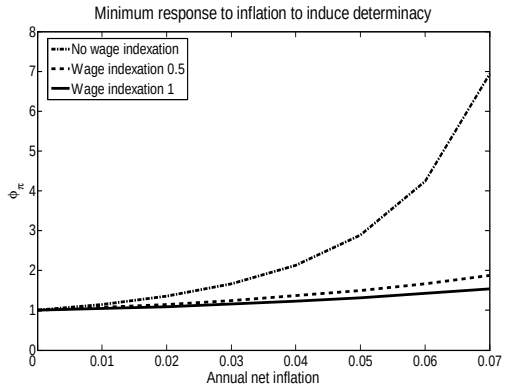
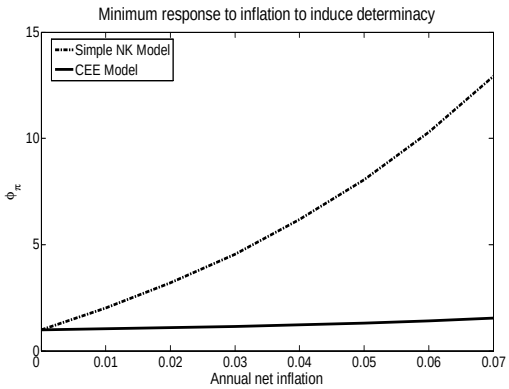


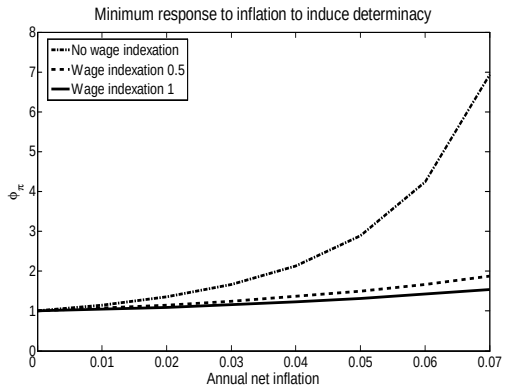
a) Real frictions and determinacy in a simple New Keynesian model.



b) Wage stickiness and determinacy in a simple New Keynesian model.



c) Determinacy in a simple vs. in a medium-scale New Keynesian model.



d) Wage indexation and determinacy in a medium-scale New Keynesian model.

Figure 1. Minimum Response to Inflation to Induce Determinacy in a New Keynesian Model with Positive Trend Inflation Rates.

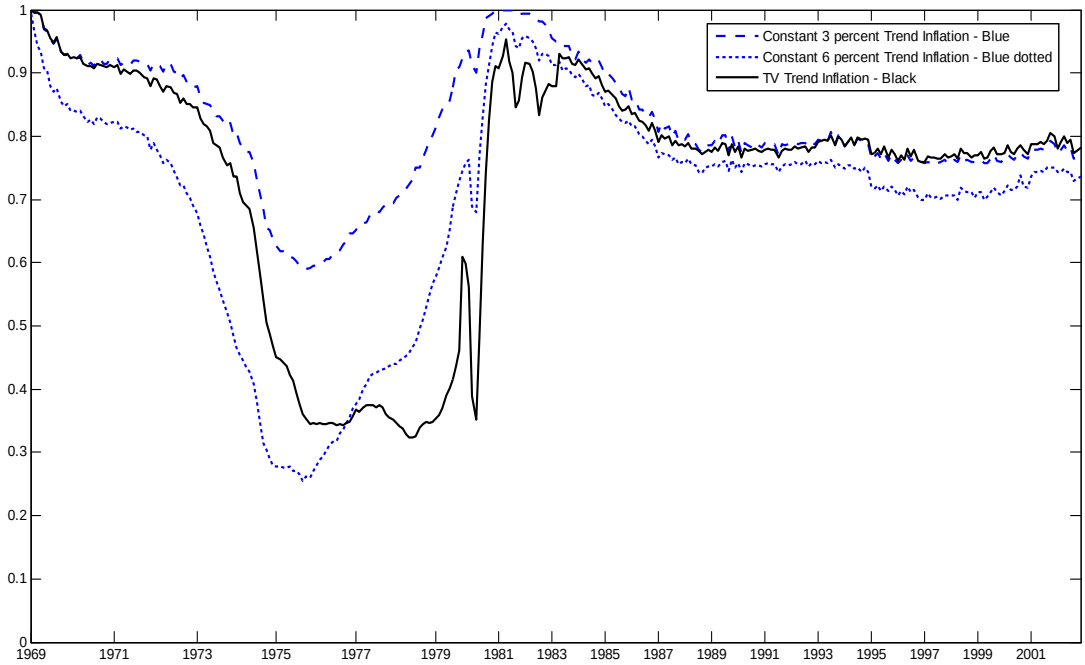


Figure 2. Probability of Determinacy using an Estimated Time-Varying Response Function by the Federal Reserve. The figure depicts the probability of determinacy implied by the distribution of time-varying parameters estimated as described in the text (see Section 3.1). The dashed (dotted) blue line assumes a constant rate of trend inflation of 3 percent (6 percent). The solid black line accounts for the time-varying measure of trend inflation computed as described in the text (Section 3.1).

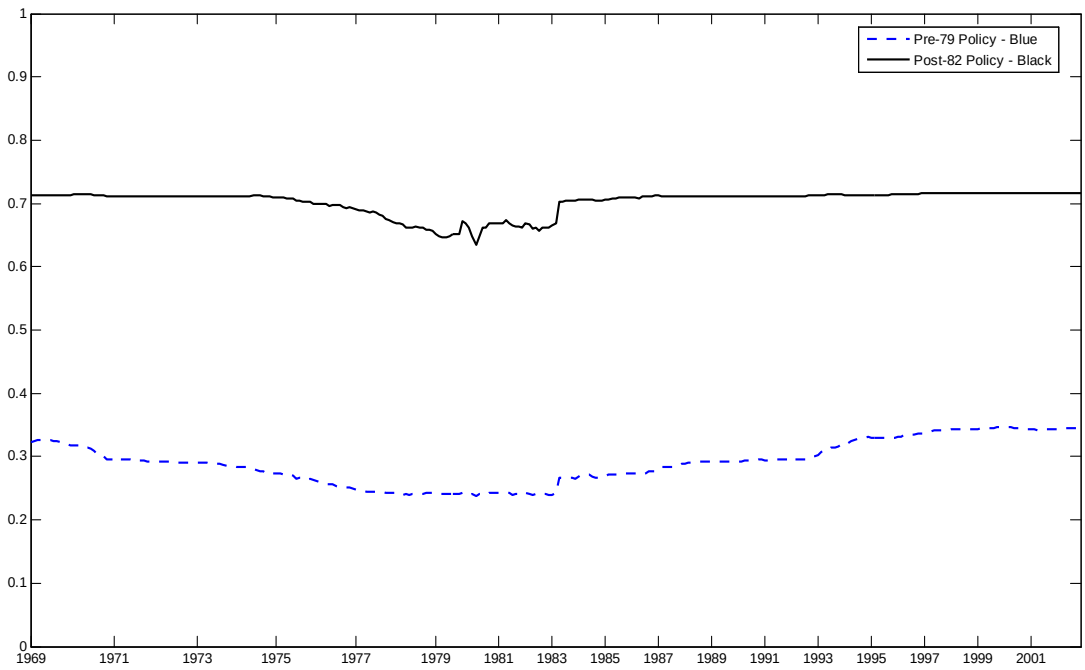


Figure 3. Probability of Determinacy using Estimated Fixed Policy Responses by the Federal Reserve. The figure depicts the probability of determinacy implied by the estimated fixed coefficient-policy rules as in Coibion-Gorodnichenko (2010), Table 1, mixed Taylor Rule. The volatility of the computed probability is driven by the time-varying trend inflation computed as described in the text (see Section 3.1). The dashed blue line considers a weak monetary policy. The solid black line takes an aggressive monetary policy into account.

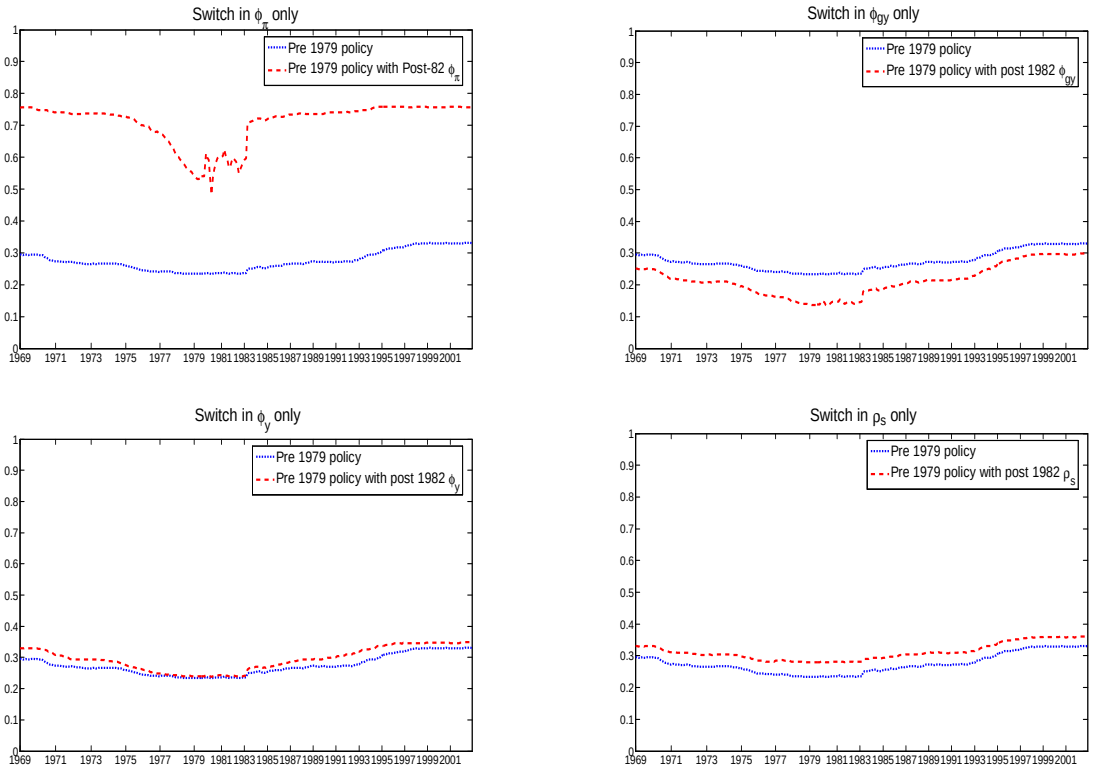
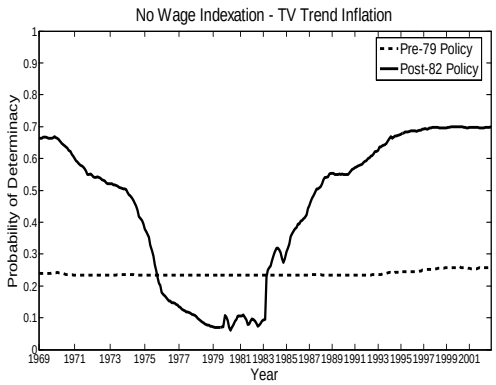
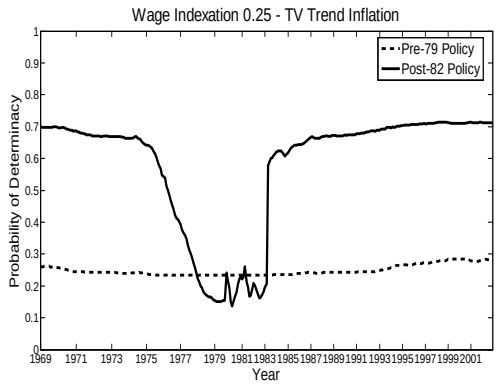


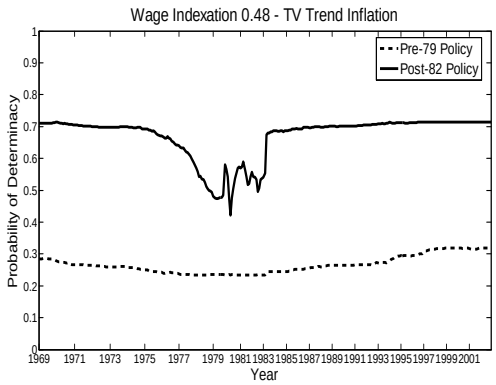
Figure 4. Probability of Determinacy: The role of policy coefficients. Time varying trend inflation employed in our simulations.



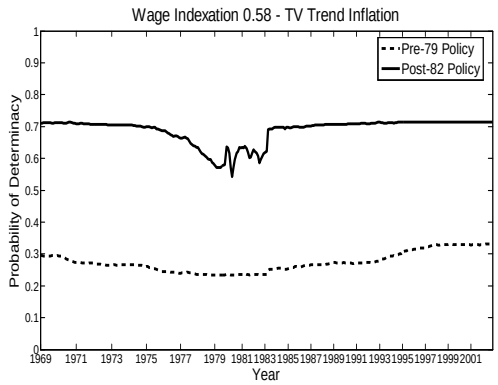
a) No Wage Indexation.



b) Wage indexation equal to 0.25.

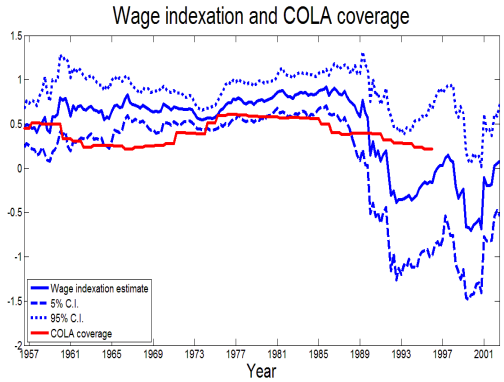


c) Wage Indexation equal to 0.48.

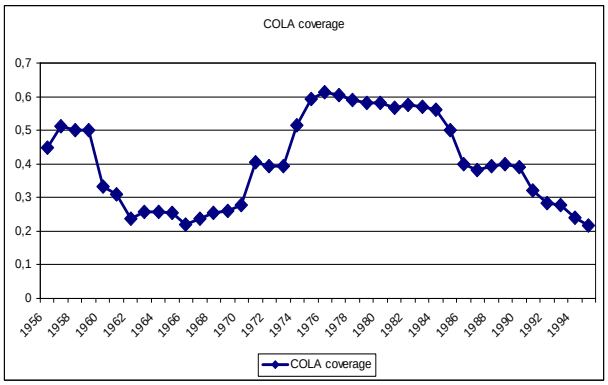


d) Wage Indexation equal to 0.58.

Figure 5. Probability of Determinacy using Estimated Fixed Policy Responses by the Federal Reserve. Various Degrees of Indexation.

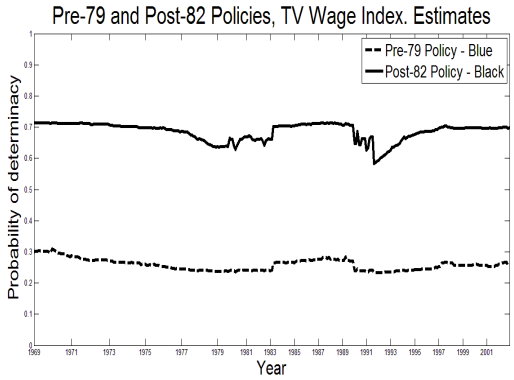


a) Different measures of Wage Indexation.

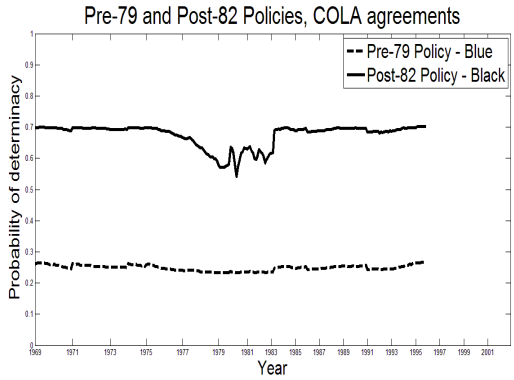


b) COLA indicator.

Figure 6. Estimated Degrees of Wage Indexation.



a) Role of Wage Indexation, our own estimates.



b) Role of Wage Indexation, COLA indicator.

Figure 7: Probability of Determinacy using Estimated Fixed Policy Responses by the Federal Reserve for estimated degree of indexation.

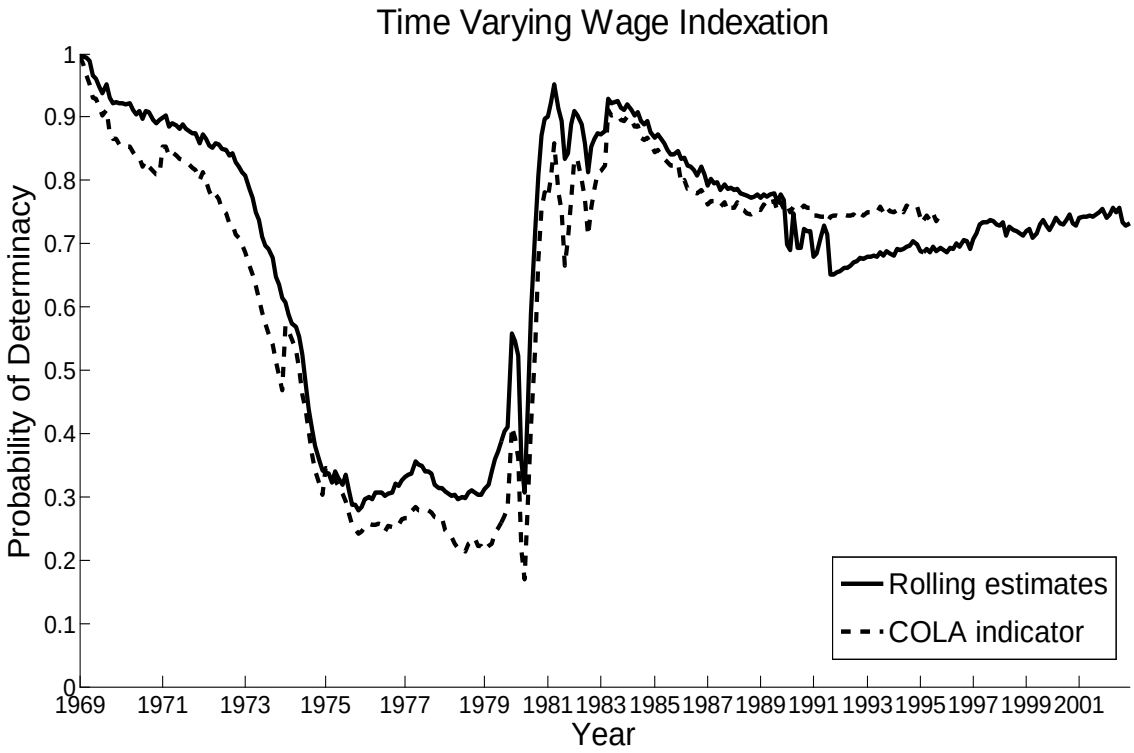


Figure 8. Probability of Determinacy using an Estimated Time-Varying Response Function by the Federal Reserve, time varying trend inflation and time varying degree of indexation.

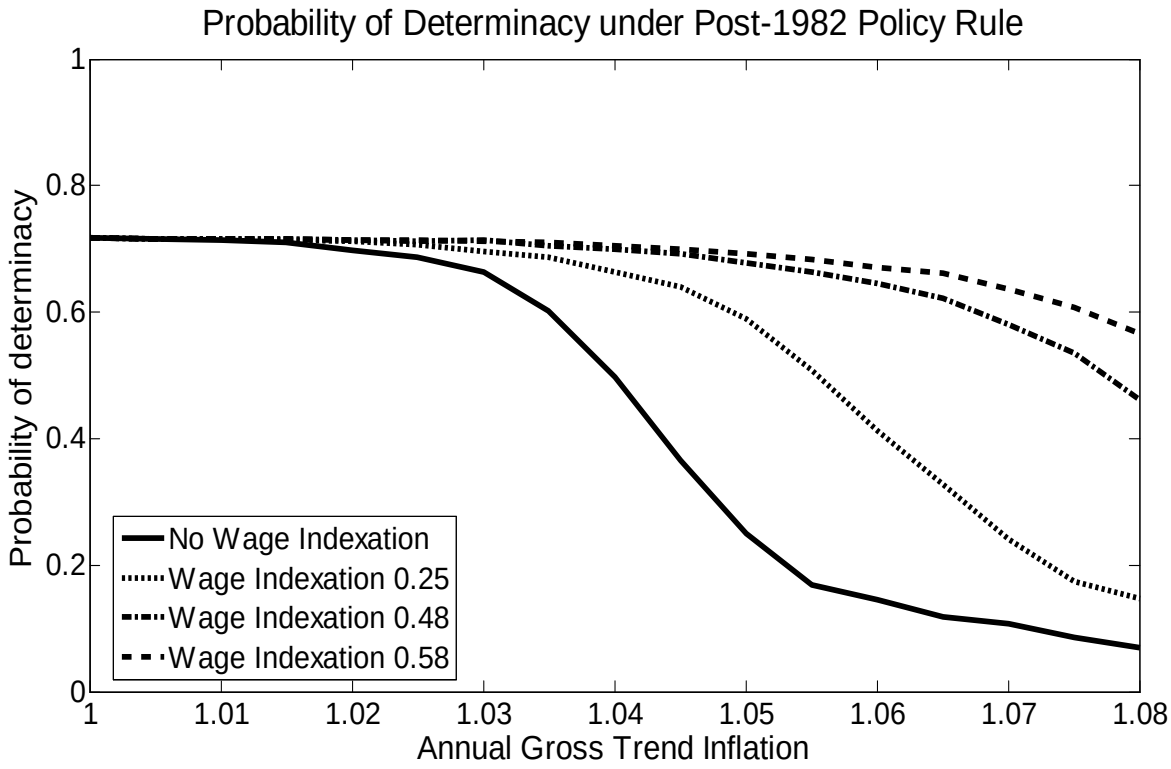


Figure 9. Probability of Determinacy: Role of Trend Inflation and Wage Indexation.

7 Tables

Table 1. Calibration		
β	$1.03^{-0.25}$	Time discount rate
θ	0.36	Share of capital
ψ	0.5827	Fixed cost (guarantee zero profits in steady state)
δ	0.025	Depreciation of capital
υ	1	Fraction of wage bill subject to CIA constraint
η	6	Elasticity of substitution of different varieties of goods
$\tilde{\eta}$	21	Elasticity of substitution of labour services
α	0.6	Probability of not setting a new price each period
$\tilde{\alpha}$	0.64	Probability of not setting a new wage each period
b	0.65	Degree of habit persistence
ϕ_0	1.1196	Preference parameter
ϕ_1	0.5393	Preference parameter
σ_m	10.62	Intertemporal elasticity of money
κ	2.48	Investment adjustment cost parameter
$\tilde{\chi}$	1	Wage indexation
χ	0	Price indexation
γ_1	0.0324	Capital utilization cost function parameter
γ_2	0.000324	Capital utilization cost function parameter
z	1	Steady state value of technology shock
λ_z	0.979	Serial correlation of technology shock (in log-levels)
η_z	0.0072	Standard deviation of technology shock
λ_g	0.96	Serial correlation of demand shock (in log-levels)
η_g	0.02	Standard deviation of demand shock
σ	0.18	Parameter scaling all exogenous shocks