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Abstract

We combine an estimated monetary policy rule featuring time-varying trend inflation and stochastic coefficients with a medium scale New Keynesian framework calibrated on the U.S. economy. We find the impact of variations in trend inflation on the likelihood of equilibrium determinacy to be both modest and limited to the second half of the 1970s. In contrast, our counterfactual exercises suggest that the change in the Federal Reserve's policy response to inflation is likely to have been the main driver leading the U.S. economy to a unique equilibrium during the Great Moderation. We highlight the impact of wage indexation on policymakers' ability to induce economic stability, and provide fresh evidence on the relationship between trend inflation, wage indexation and determinacy in the post-WWII U.S. economic environment. Further simulations show that rising the Federal Reserve's inflation target to four percent would be consistent with equilibrium uniqueness conditional on a policy as the one estimated on the U.S. post-1982 sample period.

JEL classification: C22, E3, E43, E5.

Keywords: Monetary Policy, Trend Inflation, Great Moderation, Determinacy, Wage indexation.

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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 interpretations of the U.S. Great Moderation involves the change in the Federal Reserve's systematic monetary policy. According to this view, monetary policy became more aggressive at the end of the 1970s, when Paul Volcker was appointed Chairman of the Federal Reserve and implemented an aggressive monetary policy that successfully drove the U.S. economy on a low volatility-path (at least until the recent financial crises).[1] Clarida et al. (2000) estimate a variety of simple policy rules and find evidence consistent with this explanation. 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 does not hold when trend inflation occurs: the higher trend inflation is, the more aggressive the policy reaction to inflation to guarantee determinacy must be. Intriguingly, Coibion and Gorodnichenko (2011a) (CG henceforth) provide empirical support for the role of trend inflation in the Great Moderation. Using an estimated monetary policy rule and a microfounded small scale AS/AD model that features a fully-flexible labor market, they show that the U.S. economy switched to determinacy as a result both of the change in the Federal Reserve's response to macroeconomic variables, and of the decrease in trend inflation. They conclude that the reduction in trend inflation after the mid-1980s is a necessary condition to achieve equilibrium uniqueness in the U.S. economy.

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 eliminate inefficient fluctuations, policy makers should refrain from increasing 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, and would therefore give the Federal Reserve extra degrees of freedom when facing dramatic economic downturns. Following this reasoning, Blanchard et al. (2010) recently proposed to increase the inflation target pursued by the Federal Reserve to four percent. In light of the risks of falling into indeterminacy 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 effects of systematic monetary policy and trend inflation on the probability of determinacy in the U.S. economy. To achieve this goal, we combine the policy rule estimated by

[1] An alternative view emphasizes the change in volatility of the U.S. macroeconomic shocks. See for instance Primiceri (2005), Sims and Zha (2006), Canova, Gambetti, and Pappa (2008) and Justiniano and Primiceri (2008).

CG 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 et al. (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 with which to investigate the role played by monetary policy and trend inflation in the economy's attainment of the Great Moderation. The world as represented by these medium-scale frameworks is characterized by a number of nominal and real frictions, whose importance in magnifying or dampening the role of trend inflation and systematic monetary policy is investigated in this paper.

Our main finding gives robust support to changes in systematic monetary policy as the sufficient factor to explain the conquest of U.S. inflation. Diversely, trend inflation is shown to exert a modest influence on the likelihood of falling in the indeterminacy region. 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. In particular, our analysis demonstrates the pivotal role of the change in the Taylor parameter in the Fed interest rate rule. Consequently, the message popularized by Clarida et al. (2000) re-emerges as the key driver behind the U.S. economy's enjoyment of more than two decades of relatively stable macroeconomic conditions.

The degree of wage indexation we assume in the model is a critical determinant of our results. We investigate all the frictions typically included in medium scale models, and show that wage indexation substantially dampens the deterioration of the probability of determinacy caused by an increase in trend inflation. We conduct a battery of exercises under different calibrations of this parameter and find that CG's result holds true when low values of wage indexation (less than 0.25) are combined with high values of trend inflation (higher than six percent). To deepen our understanding of the relationship between these two objects, we then provide fresh estimates of the degree of wage indexation in the U.S. by estimating a time-varying reduced-form linear model of the relationship between wage and price inflation, which we use to 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 remarkably drops to zero when entering the Great Moderation sample.[2] Our estimated time-varying degree of wage indexation is found to be highly correlated with an alternative measure of wage indexation constructed by considering the number of workers covered by the cost-of-living-adjustment clause in their labor contracts, as in Ragan and Bratsberg (2000). We also document a positive correlation between wage indexation and the trend inflation process obtained by CG. The possible 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 occurring in the 1970s. Therefore, we conclude that empirically plausible measures of wage indexation support the interpretation first popularized by Clarida et al. (2000). Our empirical findings can also be interpreted as a call to understand the effects related to the misspecification of small scale models. In particular, we show that

[2] This result is in line with the recent findings proposed by Hofmann et al. (2010).

wage indexation and, more generally, labor market frictions are likely to be one of these relevant ingredients.

We close our analysis by assessing the extent to which an increase in trend inflation could lead to indeterminacy under an aggressive policy, as the one estimated in the U.S. Great Moderation sample. We find that the proposal formulated by Blanchard et al. (2010) to increase trend inflation to four percent would basically leave the likelihood of determinacy unaltered in a plausibly calibrated setting.

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 provides the factual and counterfactual simulations with which we isolate the impact of systematic monetary policy vs. trend inflation. Section 4 focuses on the theoretical role of wage indexation and its empirical relevance. Section 5 scrutinizes the risks associated with the raising of 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 is typically assumed in this literature, wage setters that cannot re-optimize automatically update their nominal wages conditionally on past inflation. Section 4 provides a detailed analysis of what this assumption implies 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.[3]

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 a baseline small-scale New Keynesian model that features monopolistic competition and price staggering; we obtain this model by shutting down all the modeled real frictions and 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 that characterize our medium-scale model.

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

The model is closed by means of 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 simply 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-equation 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, in that models embedding positive trend inflation require a stronger response of the policy rate to inflation to guarantee the determinacy of the equilibrium.

The solid line in Figure 1a) plots the minimum level of ϕ_π necessary to ensure a unique rational expectation equilibrium as a function of trend inflation in a simple New Keynesian model that exclusively features monopolistic competition and price staggering (without both real frictions and wage staggering). The determinacy region lies above the line (i.e., ϕ_π values larger than the minimum), while the indeterminacy region lies below the line (ϕ_π values 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) also visualizes the effects of adding one real friction at a time to those (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 to differing levels of trend inflation of the minimum response to inflation necessary to achieve determinacy. As a result, the line flattens with respect to the solid one. Thus, 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 has the smallest.

Figure 1b) displays the effects of introducing wage stickiness into 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 4% level of trend inflation, 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 sufficient to move the determinacy line quite a long way towards the one that features no wage stickiness. Full indexation in wages would completely offset the interaction between trend inflation and nominal wage stickiness. Consequently, the line would simply 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 assumes full indexation in wages as in Christiano et al. (2005). 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 levels of trend inflation exert 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. In contrast, a model without real frictions, such as that used in CG, 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, i.e., the curve is flatter, and indexation is even more effective in counteracting the effects of wage stickiness.

To summarize, Figures 1a)-1d) provide a synthesis of the relationship between trend inflation, wage rigidities, and determinacy. All else being equal, trend inflation shrinks the determinacy region. 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 weakens 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 a determinate rational expectations equilibrium. Before conducting these exercises, we follow Coibion and Gorodnichenko (2011 a,b) and estimate a policy rule that features time-varying i) coefficients and ii) trend inflation. We then exploit this estimated rule in our simulations.

3.1 Estimated policy rule and factual simulations

We replicate the estimates concerning the U.S. policy rule obtained by CG. Such rule features time-varying coefficients to account for the variations in the U.S. monetary policy since the early-1970s. The rule reads as follows:

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

where

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

Eq. (2) describes the policy rate r_t as responding to a time varying intercept c_t, to expected inflation over the subsequent 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) and 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. We stick to CG's sample choice, i.e., March 1969-December 2002, and replicate their results.[4] 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 the recovery of an estimate of time-varying trend inflation $\overline{\pi}_t$.[5] 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 Tinsley (2005), Ireland (2007), Cogley and Sbordone (2008), and Cogley et al. (2010).

We now feed in the estimated time-varying policy rule (2) and the time-varying trend inflation in our medium-scale model to compute the probability of the US economy's being in determinate state in each quarter of the sample.[6] The solid line in Figure 2 depicts the

[4] 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.

[5] 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.

[6] Said probabilities are computed as follows. We draw a realization from the estimated distributions of each policy coefficient and the time-varying inflation rate in each given period. Conditionally on these realizations, we check whether the economy features a unique rational expectations equilibrium. We repeat this exercise 10,000 times, and compute the time-dependent probability of determinacy as the ratio between the number of times we verified that the equilibrium is unique and the total number of draws.

outcome of our computations. Recall that the evolution of such probability over time depends on the time-dependence both of the monetary policy coefficients and 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 exclusively in the 1975-1980 sample. This result is similar to CG's, who condition their analysis on a smaller-scale model than ours.

Thus, one could be 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 merely on the basis of the solid line, because both trend inflation *and* monetary policy coefficients fluctuate in any given period. The 1975-1980 sample is a period of high trend inflation *and* weak monetary policy response to aggregate variables, while the Great Moderation period presents the opposite combination. The main aim of our research is to ascertain *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 thus engage in counterfactual exercises that feature different combinations of systematic policy (weak, strong) and of trend inflation (high, low) to shed light on this issue.

3.2 Counterfactual exercises

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 the estimated policy rule?*

Accordingly, we employ the estimated time-varying policy rule, and we consider two scenarios for trend inflation. The first features a fixed inflation target set at six percent (roughly the average inflation rate in the pre-Volcker period). The second features a fixed inflation target calibrated at three percent (roughly the average inflation rate during the Great Moderation). These scenarios are compared with the previously scrutinized case, where trend inflation changed in every quarter.

The outcomes for each scenario are presented in Figure 2. Recall that these cases share the same evolution in the policy coefficients. Therefore, differences between the probabilities must be driven by the three differing trend inflation processes. More precisely, the larger the impact exerted by trend inflation on the computed probabilities, the larger the difference should be between the three lines displayed in Figure 2. As a matter of fact, the evolution of the computed probabilities differs clearly exclusively in the pre-Volcker period. Moreover, our simulations show that a high level of trend inflation, i.e. 6%, would have exerted a virtually zero-impact during the Great Moderation. In other words, during this phase the probability of determinacy is *de facto* independent from trend inflation, as shown by the similarity between the estimated probabilities. Hence, diversely from CG, we find that the impact of trend inflation on the probability that the US economy has been in a determinate equilibrium is negligible in the post-Volcker period.

To summarize, *trend inflation matters only conditionally on a weak monetary policy rule.* In this case, high (6%) and low (3%) trend inflation 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 an aggressive monetary 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 differing (high and low) trend inflation levels *given the estimated time-varying policy rule.* To isolate the effect of policy *per se*, we now conduct a specular exercise where we analyze the effect of differing 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 each of these estimated policy rules in turn. As for trend inflation, we consider the estimated time-varying process $\overline{\pi}_t$ as described by eq. (3).

Figure 3 depicts our computed probabilities. Recall that, diversely from Figure 2 above, the two scenarios in Figure 3 share the same evolution of time-varying trend inflation (from high levels in the 1970s to low levels in the 1990s) and different policy parameters (pre-Volcker vs. post-Volcker). Therefore, differences between 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 with the pre-1979 policy has an average value above 0.30, while the more aggressive post-1982 policy rule yields an average value above 0.70. Both probabilities turn out to be very stable over time. In other words, for a given constant policy rule, we do not observe any changes in the probability of determinacy, 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 which corroborates that in Clarida et al. (2000).

3.2.3 The role of policy coefficients

The previous Section demonstrates the prominent role of the policy switch in inducing determinacy in an environment that admits time-varying trend inflation. It is of interest to distinguish the role that the 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 et al. (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:

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

To answer this question, we examine how the probabilities of determinacy are affected by counterfactually fixing all the monetary policy coefficients according to the pre-'79 estimates, and then switching a *single* 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 in accordance with eq. (3). Figure 4 displays our results. Recall that the two lines in each panel differ merely by a single coefficient in the policy rule: the further apart the two lines are, 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 proves to be the only one that substantially influences the probability of determinacy. Perturbations in the remaining policy coefficients imply much milder changes in such probability. 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 et al.'s (2000) result is simply restored in an operational medium-scale macroeconomic model that features 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. 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 nominal and real friction in the model at work and verified that there is a single key ingredient behind our results: wage indexation. Wage indexation insures households against the negative welfare effects generated by an increase in the price level, in that it allows them to keep up with their desired level of real expenditures independently of the level of trend inflation. In particular, the higher wage indexation is, the less important trend inflation is in affecting the size of the determinacy region of the policy rule. It is accordingly somewhat natural to investigate different scenarios characterized by alternative degrees of indexation.

Figure 5 displays the probability of determinacy (conditional on fixed policies and time-varying trend inflation) for differing degrees of wage indexation. Evidently, the degree of wage indexation is critical to our result.[7] Our baseline calibration (i.e., full wage indexation, as in Christiano et al., 2005) clearly points toward systematic monetary policy as the only driver of the probability of determinacy. Our results hold true for a variety of calibrations of the indexation parameter. On reduction of 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 exclusively affect the period 1977-1983, in which the low frequency component of inflation recorded its highest values in the investigated sample. The probability of the US economy's being in a state of determinacy remains above 0.5 irrespective of the trend inflation values consistent with historical realizations. A drastically different result is obtained when we calibrate the degree of wage indexation to 0.25 (see panel b)). In this case, high trend inflation dramatically reduces the probability of determinacy, even conditional on 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 with 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 determinacy than does the weaker pre-1979 policy.[8]

To summarize, when high wage indexation prevails, the effect played by 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. When wage indexation is low, trend inflation gains power and substantially affects the determinacy

[7] 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.

[8] 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 CG. When price/wage indexation is full, the effects of trend inflation on the dynamics of the model are merely muted.

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 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

We now turn to the empirical assessment of the 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, one that possibly changes over time as a result of variations in economic conditions. Therefore, coherently with our exercises so far, we will 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. We obtain the first measure by relating wage inflation to price inflation via a dynamic model as in Hofmann et al. (2010). In particular, we estimate the following equation with U.S. data, 1948:I-2010:III:

$$\pi_t^w = c + \sum_{j=1}^{J} \gamma_j^w \pi_{t-j}^w + \sum_{k=1}^{K} \gamma_k^\pi \pi_{t-k} + \varepsilon_t^w, \qquad (4)$$

where π_t^w is wage inflation, and π_t stands for price inflation.[9] Lags in eq. (4) capture wage inflation persistence in a reduced form fashion. As in Hofmann et al. (2010), the degree of wage indexation is computed as follows:

$$WI = \frac{\sum_{k=1}^{K} \gamma_k^\pi}{1 - \sum_{j=1}^{J} \gamma_j^w}. \qquad (5)$$

Equation (4) is estimated with rolling techniques, which allow us to track the time-evolution of the reduced-form coefficients γ_k^π and γ_j^w. We can then recover a time-varying measure of the degree of wage indexation, which we term WI_t.[10] We then feed our medium-scale model with our estimated WI_t (mean realizations), and re-conduct our formerly presented exercises.

[9] Inflation rates are 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.

[10] We set $J = 3$ to eliminate 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. For 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 for 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.

Our second measure relies on figures coming from micro data. Such data regard individuals covered by the cost-of-living-adjustment (henceforth COLA) clause in their labor contracts.[11] 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 workers were covered by major collective bargaining contracts. Subsequently, 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 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).[12] We will return to this correlation later.

Figure 6 shows our estimates of the degree of wage indexation coming from macro data using (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, i.e., in the 1977-1983 sample period. Recall that Figure 5 demonstrates that high trend inflation in that period would have mattered only if wage indexation had been low. However, this is not the case in our estimates, according to which the case of panel d) is more plausible than that of panel a) in Figure 5. This is clearly demonstrated in Figure 7, where we perform the same exercises as in Figure 5 (fix policy and time-varying trend inflation) and allow for a time varying indexation as obtained both from our macroeconomic estimates[13] (panel a)) and from the COLA coverage (panel b)). Trend inflation has only marginal effects in the 1977-1983 sample, but, conditional on a strong policy response to inflation, the likelihood of determinacy remains well above 0.5 in both cases. In contrast, a weak policy response would very likely result in an indeterminate equilibrium regardless of the level of trend inflation.

[11] 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.

[12] The COLA indicator is a measure of explicit indexation regarding unionized workers, who constitute a minority 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 in the entire U.S. economy.

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

Finally, Figure 8 displays what can be considered as our final estimates, which we constructed by letting policy parameters, trend inflation and the degree of wage indexation vary over time. Again, our aim is to compute the probability of the US economy's being in a determinate state. We do so by alternatively considering the two measures of wage indexation presented above. Despite the differences between said measures, the two estimates of our probability are very similar, a finding that stresses the robustness of our results under empirically relevant degrees of wage indexation. Again, the only historical period in which our analysis identify a high likelihood of indeterminacy is the second half of the 1970s, a period characterized by skyrocketing trend inflation and weak systematic monetary policy.

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 significantly 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 occurrence of and the change in wage indexation over time and its interaction with (possibly, its dependence) trend inflation and the policy regime in place.

5 On the risks of raising trend inflation

Blanchard et al. (2010) have recently proposed to increase trend inflation to four percent. Faced with negative shocks that depress the real side of the economy, the Federal Reserve typically reacts by lowering the cost of money to boost the economy and thus bring real GDP growth back to its target. Clearly, a trend inflation of four percent would give policy makers more room for manoeuvre than a target set to two percent, because the latter implies a much higher probability 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 rising trend inflation in a small-scale world is very risky, because the likelihood of falling into a multiple-equilibria situation is high even conditionally on an aggressive monetary policy conduct. Our paper shows that a medium-scale model may lead to different conclusions on the basis of frictions in the labor markets, and specifically of wage indexation to past inflation. It is therefore of interest to understand what risks lie in the raising of trend inflation to four percent in a medium-scale world like ours. We answer this question by simulating the probability of determinacy as a function of differing 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, assuming the post-82 policy. 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 an approximate 30% decrease in the probability of determinacy, driving said probability to around 50%. This prediction, however, proves to be extremely sensitive to variations in the degree 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 increases with the degree of wage indexation, whose marginal returns decrease 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, under a four-percent trend inflation rate, it would be very likely for the economy to feature a unique rational expectation equilibrium even 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 conducting our exercises we allow for an increase in trend inflation while holding wage indexation fixed. This working hypothesis appears to be counterfactual. The degree of wage indexation is, more plausibly, a reduced-form coefficient that correlates positively with the average level of price inflation. Fresh evidence along these lines is provided by Hofmann et al. (2010) and by ourselves in the present paper. As we show, such evidence squares with the COLA coverage presented and discussed in section 4.1. To provide further evidence of 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 of less than 0.01.[14] While not assigning any causal interpretation to this finding, we interpret it as corroborating the fact that, historically, increases in trend inflation rate go hand in hand with increases in wage indexation. This evidence is consistent with Holland (1995), who runs a variety of Granger-causality type regressions and finds that increases in inflation precede increases in wage indexation. These results cast doubts on the assumption that wage indexation is a 'structural parameter' in the sense of Lucas (1976). This finding mirrors that in Benati (2008) on the degree of price indexation, which is also found to be sensitive to changes in policy conducts in a variety of industrialized countries.

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 because of the positive impact exerted by price indexation on the width of the determinacy territory, a well known result in the literature (see Ascari and Ropele 2009 and CG). Logically, one would expect price

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

indexation to increase following an increase in average inflation in the economy, a prediction that is 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 even 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 that features time-varying trend inflation and stochastic coefficients with the medium scale model popularized by Christiano et al. (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 the US economy's being in a determinate state. We show that even with positive trend inflation, the Taylor principle is sufficient to guarantee a determinate equilibrium. In other words, trend inflation does not seem to play a relevant role in determining the probability determinacy. Our results differ from those proposed by CG, 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 et al.'s (2010) proposal to raise the inflation target to four percent to avoid a liquidity-trap during economic downturns is likely not to increase economic instability. From a normative perspective, however, more research is needed to understand whether such a choice would actually be optimal from a welfare standpoint. An interesting investigation along this dimension has recently been proposed by Coibon et al. (2010).

We find wage indexation to be the key element in the gap between our results and CG's. A high degree of wage indexation dampens the role played by trend inflation and, consequently, reinforces that played by 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 monetary policy aggressiveness towards inflation stabilization. Indeed, both the fresh empirical evidence on macrodata provided in this paper, and the correlation between the measure of COLA coverage in Ragan and Bratsberg (2000) and the trend inflation estimate in CG support this pattern. As a consequence, our results suggest that high inflation has been historically coupled with a high degree of wage indexation that dampened the impact of trend inflation on the determinacy region. 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 with the aim of quantifying the different role played by wage indexation in differing countries.

Our current understanding of the wage indexation mechanism at a macroeconomic level is limited. Some interesting research on the interaction between monetary policy and labor market frictions has recently been proposed by a variety of authors (e.g., Krause and Lubik, 2007, Gertler and Trigari, 2009 , Blanchard and Galí, 2010). In light of our results, we believe that future investigations should aim to endogenize the wage indexation mechanism and to understand its determinants.

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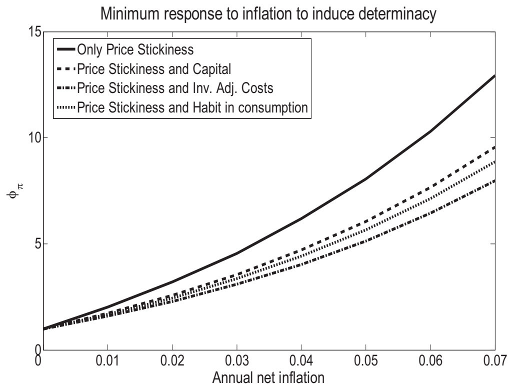
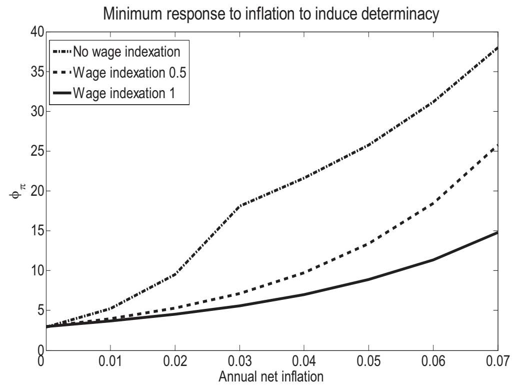
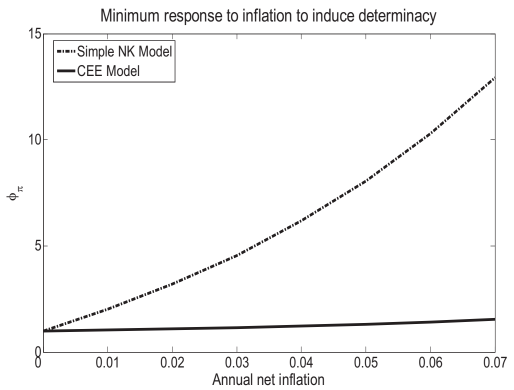
7 Figures



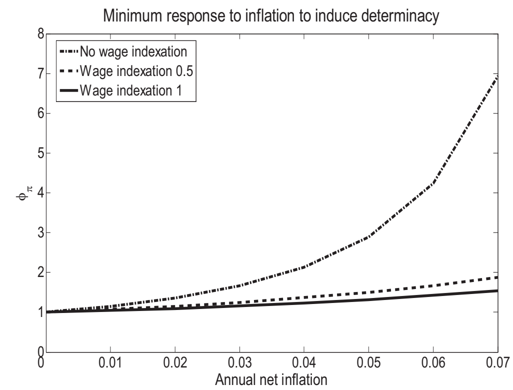
a) Real frictions and determinacy in a simple New Keynesian model.



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.

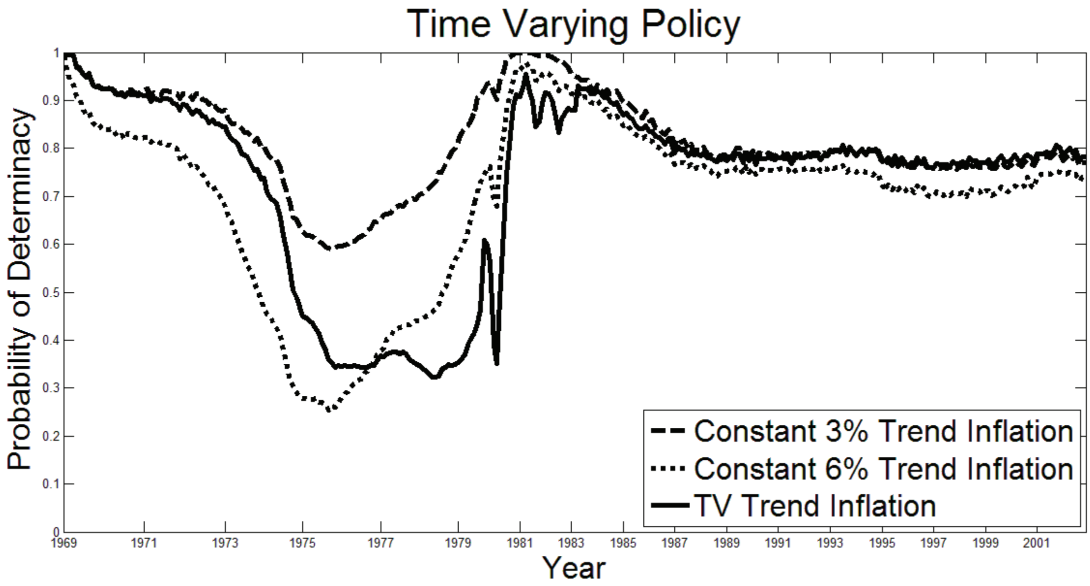


Figure 2. Probability of Determinacy with an Estimated Time-Varying Response Function by the Federal Reserve. The figure depicts the probability of determinacy implied by the distribution of time-varying parameters estimated as described in the text (see Section 3.1). The dashed (dotted) blue line assumes 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).

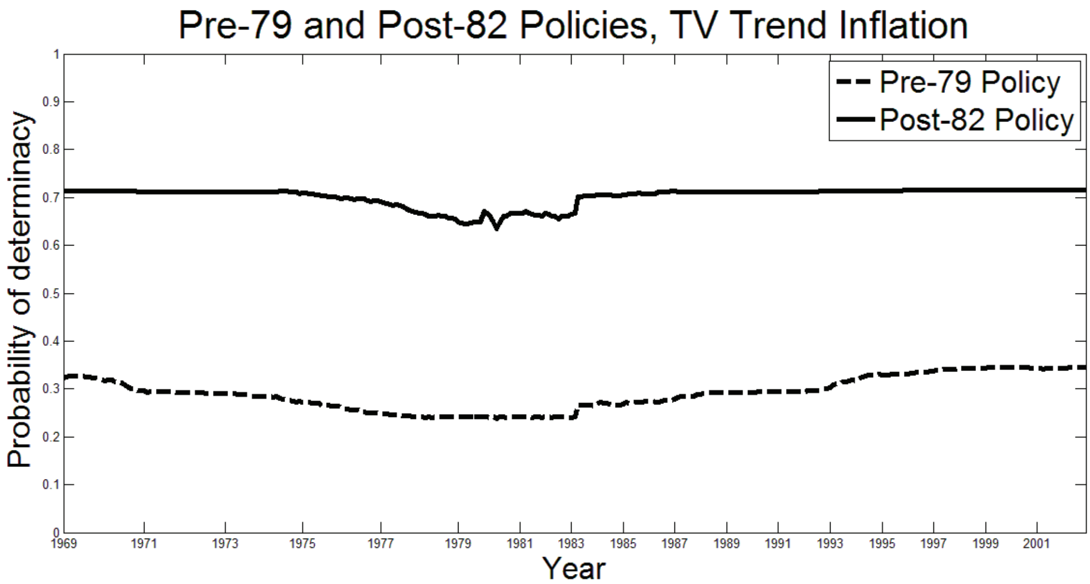


Figure 3. Probability of Determinacy with Estimated Fixed Policy Responses by the Federal Reserve. The figure depicts the probability of determinacy implied by the estimated fixed coefficient-policy rules as in Coibion-Gorodnichenko (2010), Table 1, mixed Taylor Rule. The volatility of the computed probability 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.

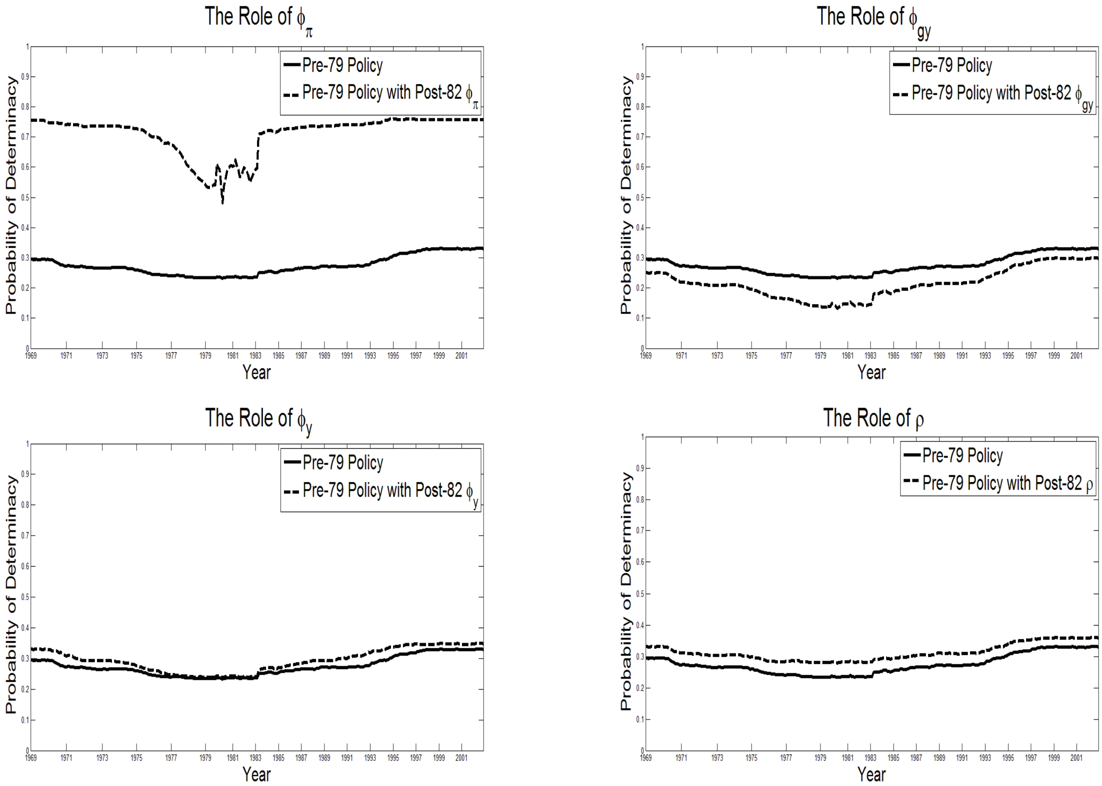
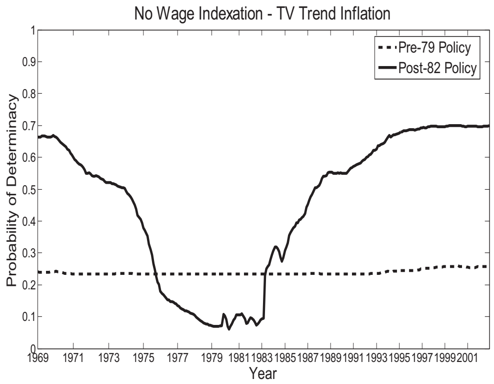
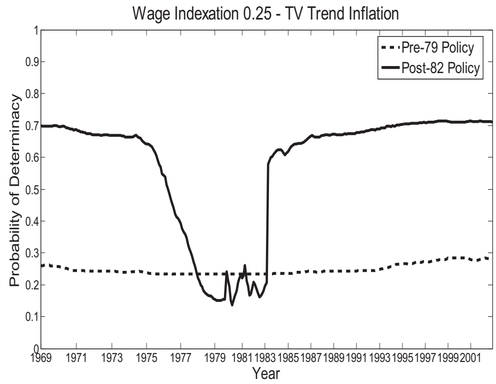


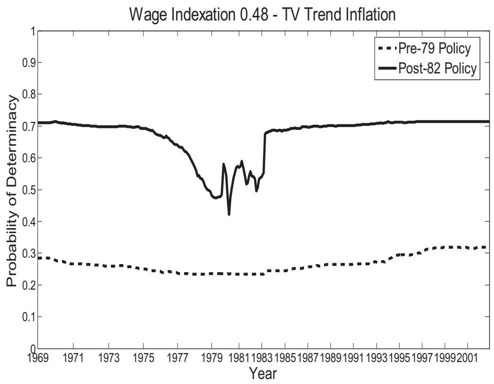
Figure 4. Probability of Determinacy: The role of policy coefficients. Time varying trend inflation employed in our simulations.



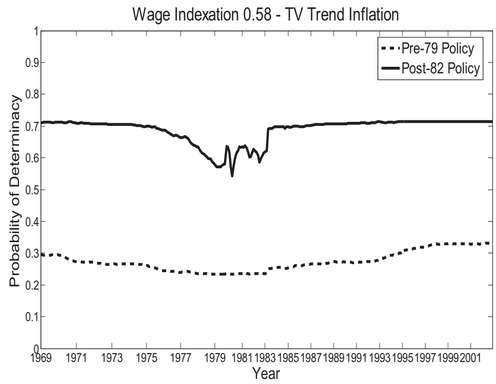
a) No Wage Indexation.



b) Wage indexation equal to 0.25.

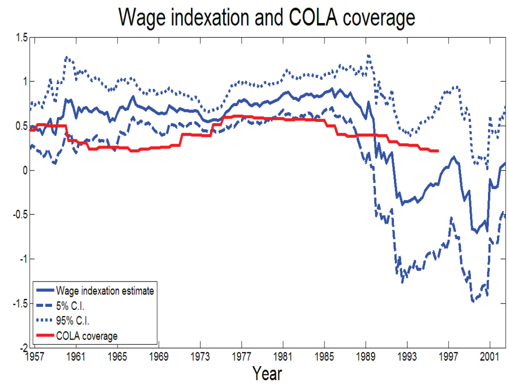


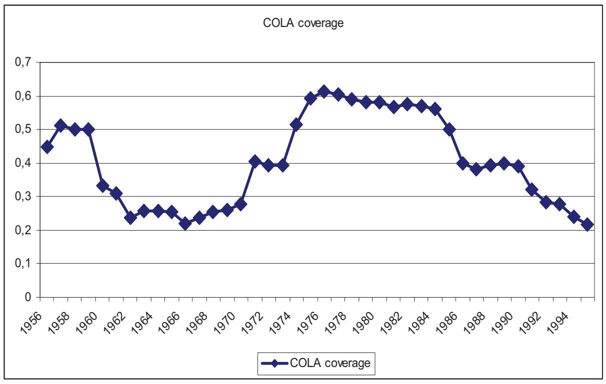
c) Wage Indexation equal to 0.48.



d) Wage Indexation equal to 0.58.

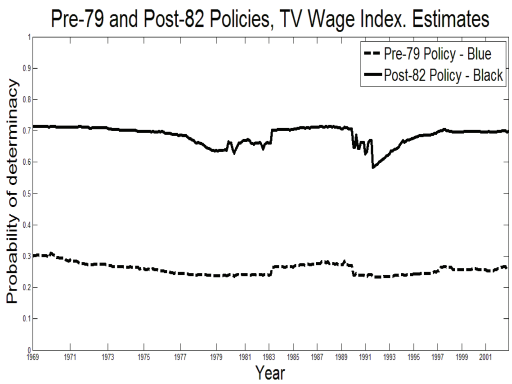
Figure 5. Probability of Determinacy with Estimated Fixed Policy Responses by the Federal Reserve. Various Degrees of Indexation.



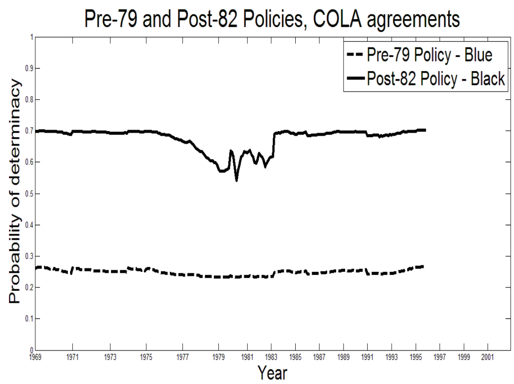


b) COLA indicator.

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 with Estimated Fixed Policy Responses by the Federal Reserve for estimated degree of indexation.**

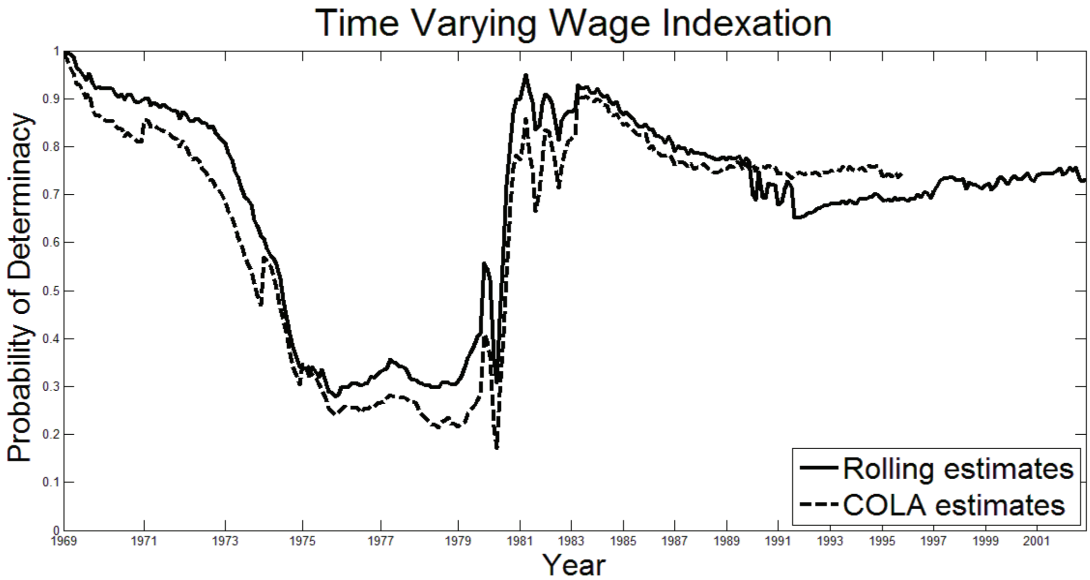


Figure 8. Probability of Determinacy with an Estimated Time-Varying Response Function by the Federal Reserve, time varying trend inflation and time varying degree of indexation.

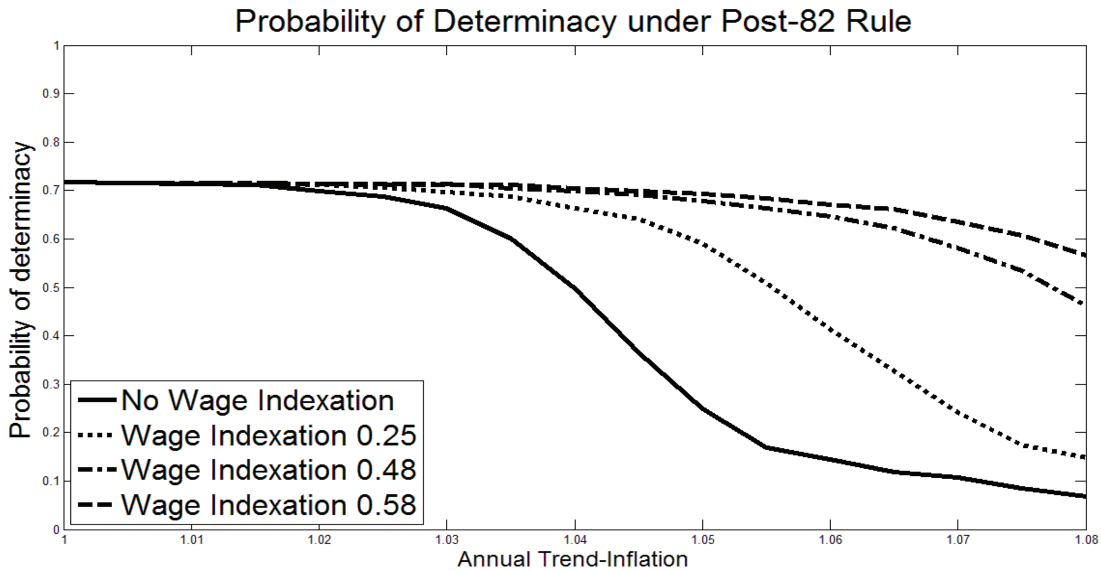


Figure 9. Probability of Determinacy: Role of Trend Inflation and Wage Indexation.

8 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