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RAISING THE INFLATION TARGET: HOW MUCH EXTRA ROOM DOES IT REALLY GIVE?

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RAISING THE INFLATION TARGET: HOW MUCH EXTRA ROOM DOES IT REALLY GIVE?

Abstract

Less than intended. Therefore, in order to get, say, 2 pp. of extra room for monetary policy, the target needs to be raised to more than 4%. In this paper, we investigate the constraints on a policy aimed at achieving more monetary policy room by raising the inflation target. A theoretical analysis shows that the actual effective room gained when raising the target is always smaller than the intended room. The reason is a shift in the behavior of the private sector: Prices adjust more frequently, lowering the potency of monetary policy. We derive a simple formula for the effective gain expressed in terms of the potency of monetary policy. We then quantitatively investigate this channel across different models, based on a calibration using micro data. We find that, by raising the target to 4%, the monetary authority only gains between 0.51 and 1.60 percentage points (pp.) of policy room (not 2 pp. as intended). In order to achieve 2 pp. additional policy room, the target needs to be raised to approximately 5%. The quantitative models allow to derive the Bayesian distribution of the effective room under parameter uncertainty.

JEL Classification: E31, E52, E58

Keywords: Timidity trap, zero lower bound, liquidity traps, central bank design, Inflation targeting, Lucas proof, price stability

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Raising the Inflation Target: How Much Extra Room Does It Really Give?

Jean-Paul L'Huillier and Raphael Schoenle*

October 18, 2019

Abstract

Less than intended. Therefore, in order to get, say, 2 pp. of *effective* extra room for monetary policy, the target needs to be raised to *more* than 4%. In this paper, we investigate the constraints on a policy aimed at achieving more monetary policy room by raising the inflation target. A theoretical analysis shows that the actual effective room gained when raising the target is always smaller than the intended room. The reason is a shift in the behavior of the private sector: Prices adjust more frequently, lowering the potency of monetary policy. We derive a simple formula for the effective gain expressed in terms of the potency of monetary policy. We then quantitatively investigate this channel across different models, based on a calibration using micro data. We find that, by raising the target to 4%, the monetary authority only gains between 0.51 and 1.60 percentage points (pp.) of policy room (not 2 pp. as intended). In order to achieve 2 pp. additional policy room, the target needs to be raised to approximately 5%. The quantitative models allow to derive the Bayesian distribution of the effective room under parameter uncertainty.

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*Brandeis University; Brandeis University and Federal Reserve Bank of Cleveland. We thank Klaus Adam, Philippe Andrade, Guido Ascari, Paul Beaudry, Roberto Billi, Carlos Carvalho, Edouard Challe, Stephen Cecchetti, Jeff Fuhrer, Oleksiy Kryvtsov, Tomasso Monacelli, Robert Rich, John Roberts, Vincent Sterk and Lars Svensson and seminar participants at the Bank of England, the CEBRA Annual Meeting 2019, the Federal Reserve Bank of Boston and the Federal Reserve Bank of Atlanta for useful suggestions, and Emi Nakamura, Jon Steinsson, Patrick Sun and Daniel Villar for sharing data on the U.S. monthly frequency of price adjustment starting in the 1970s, and Jeff Fuhrer for sharing estimates of the Federal Reverse's inflation target. Schoenle thanks Harvard University for hospitality during the preparation of this draft. The views expressed here are solely those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Cleveland or the Federal Reserve System.

1 Introduction

The length of the recent liquidity traps in the U.S., Europe, and Japan have renewed attention to an old topic of macroeconomy policy: What can be done about the zero lower bound (ZLB) on nominal interest rates? There are at least two angles to this concern: one is growth-based, another purely monetary. The first is based on observing the sluggish recovery of developed economies following the global 2008 financial crisis, which has triggered a heated debate of whether these could have entered a so-called 'secular stagnation'. The second is grounded on recent evidence—based on lower-than-usual inflation and policy rates (Kiley and Roberts 2017)—suggesting that liquidity traps could be more frequent events in the future. As a result of both these concerns, academics have contemplated raising the inflation target as a valid strategy to create more monetary policy 'room' to counteract large negative demand shortfalls.[1]

The logic of the argument in favor of a higher target is the following. A higher inflation target should induce a higher steady-state inflation. This should increase the steady-state nominal interest rate. Therefore, starting from this steady state, there is more room away from the ZLB constraint in order to accommodate large negative shocks to aggregate demand, also referred to as more monetary policy room, or space.

Even though clearly relevant in the present macroeconomic environment of advanced economies, there are some reasons to be suspicious of this argument. Indeed, gains in policy room equal to the increase in the inflation target should arise only under the assumption that the behavior of the private sector does not adapt to the higher trend inflation. However, a raise of the inflation target constitutes a significant policy change. Thus, it is highly likely that the private sector will not behave in the same way as before the change. Under the assumption that the new target can be implemented successfully—and without major concerns of central bank credibility and related issues—our aim is to investigate how the most plausible reaction of the private sector will affect this strategy. In particular, we ask *which are the constraints* imposed on such a strategy by the private sector. Our goals are not solely theoretical; we make

[1]See, for instance, the discussions in Blanchard, Dell'Ariccia, and Mauro (2010), Mishkin (2018), Cechetti and Schoenholtz (2017), and Summers (2018). These authors differ with respect to their preferred solution. On secular stagnation, relevant references include Hansen (1939), Summers (2014), Eggertsson, Mehrotra, and Robbins (2019).

an effort to *quantify* these constraints in order to deliver a message that is potentially policy-relevant.

We consider a Lucas-proof version of this argument, by considering how general it is when one takes into consideration plausible reactions of the private sector to the increase in the inflation target. The first reaction that comes to mind is the possibility that firms will adjust prices more frequently with higher trend inflation. This channel is theoretically plausible, and was first considered in a classic paper by Ball, Mankiw, and Romer (1988).[2] Moreover, when looking at historical U.S. micro data on the frequency of price adjustment, we find a clear relationship between this frequency and trend inflation over the 1970–2015 period.[3]

We then set up a simple New Keynesian (NK) model in which the frequency of price adjustment (captured by the Calvo 1983 parameter) increases with trend inflation. The simplicity of the NK model it allows for an analytical characterization of the effect of increased price flexibility. We assume a functional form linking the Calvo parameter (fraction of firms with sticky prices) to trend inflation based on our empirical analysis. According to this relationship, when trend inflation is 2%, the quarterly Calvo parameter is 0.74; when 4%, the parameter falls to 0.70 and when 6%, it falls to 0.65. Price flexibility increases.

In our model, as usual, the monetary authority stabilizes output from nominal demand disturbances by moving the nominal interest rate, according to a baseline interest rate rule that systematically responds to inflation. For a given parameter of the reaction function, this reaction of the central bank is most effective when the degree of stickiness is high (i.e., the Calvo parameter is high.) The potency of monetary policy is crucially affected by the price flexibility channel: Because price flexibility increases with trend inflation, the higher is trend inflation, the lower is the Calvo parameter, and the lower the effectiveness of monetary policy in stabilizing output. For a given negative nominal demand shock, the nominal interest rate needs to fall more strongly to accommodate the shock. At the limit of perfect price flexibility (Calvo parameter tending to zero), nominal demand shocks have no effects, but this requires the nominal rate to move one-to-one with the nominal shock, i.e. very large amounts.

[2]See also Romer (1990).

[3]To this end, we use a recent dataset put together by Emi Nakamura and Jon Steinsson. This dataset recently become available through the work in Nakamura, Steinsson, Sun, and Villar (2018). It develops new micro price data from the Bureau of Labor Statistics (BLS), extended back to the 1970s.

The relevant question for the policy-maker in practice concerns the strength of these effects in a calibrated New-Keynesian model. Our key contribution is to quantify these effects based on a novel, empirically estimated relationship between frequency and trend inflation. We estimate this relation using micro data. We find a strong, positive relationship between the probability of price adjustment and trend inflation during the 1970-2015 period. The economic magnitude is large: Our preferred estimate of the elasticity is 0.98, which means that a 1% increase in the inflation target is associated with an increase in the annual monthly average frequency of price changes by 0.98%.

Our analysis based on the estimated relationship indicates that raising the target from 2% to 4%, as proposed by Blanchard, Dell'Ariccia, and Mauro (2010), generates an effective room of 0.51pp., not 2pp. Thus, only 25% of the intended room would be achieved. Furthermore, in order to achieve an *effective* room of 2pp, one would need to raise the target to 5.79%. Thus, the price flexibility channel seems quantitatively relevant in the discussion of raising the inflation target.

With the goal of a more serious quantification of our channel, we then move away from the simple NK model and consider two other state-of-the-art models: the Coibion, Gorodnichenko, and Wieland (2012) model (which includes a Phillips curve that explicitly depends on trend inflation), and a menu cost model a la Dotsey, King, and Wolman (1999) (in which the degree to which price stickiness varies with trend inflation is now disciplined by the model). We confirm that our mechanism is strong and quantitatively relevant.

How important it is however depends—not surprisingly—on model parameters. When we consider an empirically relevant joint distribution of the main model parameters, our channel remains always highly relevant quantitatively. We assess the empirical relevance by drawing 10000 joint draws from the joint parameter distribution estimated in the Smets-Wouters model. Then, we compute effective room in our main model for each draw, going from 2% to 4% steady state inflation. Our median estimate for effective room is 1.416pp., with a mean of 1.418pp. The 25th and 75th percentile of the distribution are 1.371pp. and 1.430pp. Clearly, for a wide set of empirically relevant model parameters, the policy maker is not able to achieve his intended room of 2pp.

The role of monetary policy is of independent theoretical and policy interest. We investigate variations of the monetary policy rule and find that the interest rate rule is crucial. A rule in which inflation deviations from target are strongly penalized by the monetary authority alleviates the concerns raised by the loss of monetary policy potency. On the other hand, if the rule puts a high weight on the output gap, for instance, then we find the opposite: monetary policy potency is a big concern.

Our paper relates to a growing literature on the optimal inflation target such as Billi (2011), Coibion, Gorodnichenko, and Wieland (2012), Blanco (2017), Adam and Weber (2017), or Andrade, Gali, Le Bihan, and Matheron (2017). Billi (2011) and Coibion, Gorodnichenko, and Wieland (2012) derive the optimal inflation target in NK models with a ZLB. Blanco (2017) studies the optimal inflation target comparing NK and menu cost models. His focus lies on the interaction of the inflation target with the macroeconomic dynamics during periods of a binding ZLB. The recent paper by Adam and Weber (2017) adds a new angle to the question, by considering heterogeneity among producers. By contrast to most of the literature, our work focuses on the effectiveness for monetary policy *away* from the ZLB if the policymaker raises the inflation target. Our main contribution lies in a quantitative analysis based on a novel, empirically estimated relationship between frequency and trend inflation.

The paper is organized as follows. Section 2 presents the empirical evidence given support to the conclusion that a higher target increases price flexibility. Section 3 presents the simple analytical model to transparently show the mechanisms at play in our analysis. Section 4 quantifies these mechanisms in several ways, with the goal of measuring the effective gains in monetary policy room achieved by raising the target. We then present a few conclusions in Section 5. The Appendix presents all tables and figures.

2 Empirical Evidence: Inflation Target and the Degree of Price Stickiness

The purpose of this section is to present new empirical evidence establishing a clear relation between the inflation target and the degree of price stickiness. Our analysis is fairly comprehensive by presenting five different and complementary exercises. Taken jointly, these constitute evidence of a strong, positive, and causal relationship between these two variables.

Specifically, we primarily establish the relationship using micro data on the frequency of price adjustment and inflation. We confirm the findings and establish causality of the relationship using a benchmark structural approach based on aggregate data. We then look deeper at inflation targets, by relying on four different measures produced by other researchers. Finally, we complement this by going back to Fernandez-Villaverde and Rubio-Ramirez (2007) and studying their high frequency estimates of the inflation target and the probability of price adjustment (the Calvo parameter).

2.1 Data Description

Our data set encompasses a variety of micro and aggregate data. We focus on U.S. data covering the 1970s, a period in U.S. history with significantly higher inflation.

First, we include a new micro-data set on U.S. consumer prices from the Bureau of Labor Statistics (BLS). These data have recently become available through the work of Nakamura, Steinsson, Sun, and Villar (2018) and extend back to 1978, including the peak of inflation at roughly 12% per year. Previous to the work of Nakamura, Steinsson, Sun, and Villar (2018), the BLS CPI Research Database contained data starting in 1988. The existence and availability of data going back to 1978 is a remarkable achievement through the digitization of old microfilm scanners that cannot be read with modern scanners. For more details of the process, please refer to their paper. Nakamura, Steinsson, Sun, and Villar (2018) have generously shared with us a series of the annual average of the frequency of price adjustment (Figure 14 in their paper). The series goes up to 2014.

Second, we also include several aggregate time series. We use two alternative measures of inflation: CPI inflation and the implicit GDP deflator. We also include the other series typically used in DSGE estimation: GDP, consumption, investment, employment (measured in hours), wage inflation, and the Fed Funds rate.

Third, to complement a simple measure of trend inflation we obtain from the inflation series mentioned above, we also include four other measures of trend inflation developed by other researchers. These are obtained using several approaches based either on VARs, structural estimation, or Kalman filtering. Specifically, we include the estimates that Cogley and Sbordone (2008) obtain from a two-step VAR procedure and present in their Figure 1. We use two model-based estimates: the inflation target series underlying Figure 4 in Ireland (2007), and the inflation target series underlying Figure 1 in Milani (2006). Finally, we borrow the inflation target estimate series underlying Figure 3 in Fuhrer and Olivei (2017). This is obtained using a rich state-space representation of the target. It includes variables as the Federal Reserve's Greenbook and Tealbook, along with survey and market inflation expectations, among others. All our trend inflation series go up to right before the Great Recession, including the the series kindly shared by Fuhrer and Olivei (2017).[4]

2.2 A First Pass: Evidence Based on Micro Data

The first exercise we present is very simple. However, we view this simplicity as a virtue, because it provides fairly telling and straightforward evidence of the link between trend inflation and the frequency of price adjustment. To this end, it exploits the regime change in monetary policy after the high inflation of the 1970s and the subsequent appointment of Paul Volcker at the Federal Reserve. We interpret this change of regime as the shift from a 'high' to a 'low' inflation target.[5] To this end, and following this distinction, we divide the aggregate inflation series and the frequency of price adjustment series into two plausible sub-samples: a high trend inflation sub-sample (1978-1984) and a low

[4]Another piece of work providing data-rich measures of the Federal Reserve's inflation goals is by Amstad, Potter, and Rich (2017). Unfortunately, we could not use it since it starts in 1994, and therefore it is too short to assess longer term changes in the target.

[5]Actually, early on, the Federal Reserve did not have an explicit inflation target, so we interpret these as "implicit" targets. A similar interpretation is the shift from a regime in which long-term inflation was not explicitly targeted and was allowed to move freely at high levels (anything between, say, 2% and 10%), to a regime in which inflation was pinned down by a low target (around 2%).

trend inflation sub-sample (1985-2014).[6]

We use the inflation series to measure the (implicit) target in each subsample by simply computing average inflation.[7] We then use the frequency of price adjustment and compute its average over each subsample. The question is whether we observe any sizeable change in the frequency of price adjustment over these subsamples, which were chosen according to average inflation. Also, we want to see whether this is consistent with a lower target being associated with a lower frequency of price adjustment (more sticky prices).

Figure 2 presents the results. The blue full line is inflation (left axis); the red dotted line is the frequency (right axis). An initial observation is that the frequency of price adjustment series shows large volatility, peaking at 17.31% in 1980, and with lowest observation in 2002 at 7.78%. These numbers imply a change in the duration of price spells of roughly 6 months to 13 months.

The flat horizontal lines show the average of each series over the subsamples. Clearly, both series are lower in the second subsample. The difference, for both, is economically significant: average inflation drops from 6.73% to 2.25%; the frequency of price adjustment drops from 13.32% to 10.08%. Thus, prices change on average roughly every 7 months and a half in the first sample, and every 10 months in the second subsample. Because average inflation can be seen as a measure of the target, this figure provides support to the view that a lower target is associated with a lower frequency of price adjustment. Moreover, under the assumption that the relation is linear—an assumption not crucial for our analysis but useful for illustrative purposes—the observed change implies an elasticity of frequency to target of 0.72.[8]

2.3 Structural Estimates

To further study whether there is evidence that the inflation target has an impact on the degree of price stickiness, we now turn to structural estimation. Structural estimation has the advantage of establishing causality of the relationship of interest, and showing that the conclusions of the previous subsection are the same when using a different data set (because for structural estimation we

[6]Later we will also exploit the full variation in our data set to look at the link between the target and the frequency of price adjustment.

[7]For brevity, we shall use the term "target" instead of "implicit target" throughout the paper.

[8]$0.72 = \frac{13.32-10.08}{6.73-2.25}$

will not use the micro data, but an array of aggregate time series.)

We estimate a benchmark DSGE model. Two key parameters in the estimation are the (implicit) target (determined, in the model, by the monetary authority), denoted by $\overline{\pi}$, and the probability of price adjustment in a time period or Calvo parameter, denoted by θ. Our empirical strategy consists in estimating these parameters (among all others in the model) over the full sample, and the same low-target subsample as above (post 1984).

In order to make our results transparent, we use the benchmark DSGE model developed by Smets and Wouters (2007) (henceforth SW). We proceed by Bayesian estimation. The appendix presents the details of the procedure, include the full model specification, prior selection, and construction of variables used for estimation.

Table 1 presents the estimated values of the target and the Calvo parameter. We estimate a lower inflation target in the post-1984 subsample compared to the full sample (3.33% versus 2.59%), and a higher Calvo parameter (0.61 versus 0.71). This is a large increase in the Calvo parameter, indicating stickier prices in the post-1984 subsample.[9]

This estimation allows to make the following identification argument. Under the assumption that the lower inflation target estimated in the post-1984 subsample was the result of a policy choice, then the sample split allows to identify the effect of this policy on the other deep parameters of the model, including the Calvo price parameter. All other changes are "controlled for" by the rich autocovariance of the shocks process of the SW model. In particular, this allows to control for a potentially lower volatility of shocks during the Great Moderation (Blanchard and Simon 2001), a lower cyclicality of productivity in the 1985-2015 period (Gali and van Rens 2019), and so on.

We finish by noting that our estimation is consistent with the estimation in SW for the pre-1979 versus post-1984 samples. They also find a higher target and lower value of both Calvo parameters (prices and wages) in the pre-1979 sample (see Table 5, p. 603).

[9]Interestingly, we also estimate a lower Calvo parameter for wage stickiness in the post-1984 subsample.

2.4 A Deeper Look at the Inflation Target and Micro Data

In order to exploit all the time-variation in the micro data, we next regress the frequency of price adjustment on measures of the inflation target and show that we find an economic and statistically significant relation between the two variables. This is the next exercise we consider.

As explained above in the data section, we have constructed a data set that includes 4 different measures of the target produced by other researchers. Figure 3 plots these series. It shows mainly that the 4 series for the inflation target share key dynamics. They are highly correlated with one another with a cross-correlation coefficient of 0.70-0.90, with the exception of the series of Fuhrer and Olivei (2017) which shows a positive but more moderate cross-correlation with the other series of 0.17-0.43. Aside from these commonality, a few noticeable differences emerge from different measures of the target. For instance, it is clear that the two most volatile measures are the model-based ones (by Ireland 2007 and Milani 2006, shown in green and light blue respectively). The two reduced form measures (by Cogley and Sbordone 2008 and Fuhrer and Olivei 2017, shown in blue and black respectively) show less volatility. According to these measures, the target or inflation goal raised to between 5 to 7% in the 1970s. The Cogley and Sbordone 2008 measure is the less volatile and slightly anticipates the Volcker disinflation, whereas the Fuhrer and Olivei 2017 turns around precisely in 1979.

As a further look at these data, Figure 4 shows a scatter plot of the annual frequency of price changes against the pooled, annual averages for the estimated inflation target series. The figure shows a remarkable positive relationship between the frequency of price changes and the different measures of the inflation target.

We estimate the following specification:

$$f_t = \beta_0 + \beta_1 \overline{\pi}_t + \epsilon_t \tag{1}$$

where f_t is the annual average monthly frequency of price changes in percentages, and $\overline{\pi}_t$ the annualized inflation target, also in percentages. We estimate this specification separately for each of the four inflation target series. Table

2 summarizes the results. We find that the frequency of price changes is statistically highly significantly, positively associated with the target. In all four specifications, the coefficient on the target is significant at the 1% level. The magnitudes of this elasticity are economically large, and range from 0.98 in specification (II) to 2.26 in specification (IV). Among the purely model-based estimates, the median estimate is 1.04, which means that a 1% increase in the inflation target is associated with an increase in the annual monthly average frequency of price changes by 1.04%. The average monthly frequency in the data is at 10.69%—prices change approximately every 9 to 10 months.

One may be concerned that all these regressions are capturing is the drop in the frequency after the Volcker disinflation. This is not at all the case. Our results are robust to omitting the 1970s (by estimating the above specification only for the post-1984 period.) Table 3 shows the results. Now, both the mean and the median estimated coefficients on the target are between 1.03 and 1.10 for the model-based estimates (Specifications II and III). Including the VAR-based specification (IV) raises the mean estimated coefficient to 1.32 and the median to 1.13. In all four specifications, the coefficient on the target is again significant at the 1% level. This gives us confidence that the arguably somewhat special period of the 1970s does not much affect our main relationship: When the inflation target is higher, the frequency of price adjustment is higher.

A few papers in the recent literature, such as Nakamura and Steinsson (2008), Gagnon (2009) or Alvarez, Beraja, Gonzalez-Rozada, and Neumeyer (2018), have considered a related relationship: the relationship between the frequency of price adjustment and inflation. They all find a positive relationship between the frequency of price adjustment and inflation. While this finding is supportive and complementary to our empirical results, we view it as quite distinct. The main reason lies in the distinction of one of the objects we analyze: the inflation target rather than the inflation rate. These two objects embody a big conceptual difference. For example, this difference leads us to have no negative inflation targets in our data while the inflation rate can be negative.

Furthermore, our interest lies in quantitatively answering a specific policy question for the U.S.. This interest means that related elasticity estimates, for example from Argentina or Mexico, are quantitatively less relevant for our focus. For example, the frequency of price changes starts off at a much high level in

Argentina with around 22% compared to the US with around 10%.[10] While these economic environments are clearly different, this necessarily also means in practical terms that even if absolute changes in the frequency are similar as we go from 2% to 4% inflation, the implied elasticity will be much lower. We nonetheless replicate some of the regression results in Alvarez, Beraja, Gonzalez-Rozada, and Neumeyer (2018) which show that the frequency of price changes increases from 0.25 to 0.27 as one goes from 2% to 4% inflation. We show in our empirical part that our findings are somewhat diminshed but remain quantitatively robust when we use the implied elasticity.

Finally, a reason why our results continue to be generally robust is the following: Even small implied changes in the frequency of price changes can have large effects on the slope of the Phillips Curve, κ, in our models. The reason mainly lies the hyperbolic shape of the function that maps the frequency parameter into κ. Moreover, time aggregation from monthly to quarterly frequency also plays a role, complemented by the large shock we are considering. The combination of these three factors generates a substantial kick in the context of our mechanism. We note that in the context of menu cost models, there is no explicit solution for the slope of the Phillips curve for large shocks. However, because the time-aggregation and size-of-the-shock channel are there, we find a sizable effect in the context of these models as well.

2.5 Complementary Regressions

An alternative way of checking the validity of our main assumption is, instead of producing our own estimates of a SW model over different subsamples as shown above, to instead go back to a previous paper by Fernandez-Villaverde and Rubio-Ramirez (2007) (henceforth FVRR) that estimated a time-varying parameter DSGE similar to SW. By doing this, they obtained time series of estimates for several parameters of interest. We use their series of estimates for the (time-varying) frequency of price adjustment, and for the (time-varying) inflation target. We regress the former on the latter in order to see if there are significantly associated statistically.

This exercise complements our previous estimation of a SW model in two ways. First, it allows for a richer time-variation between the frequency of price

[10] Idiosyncratic shocks are likely also more prevalent in Argentina than in the U.S..

adjustment and the target (while at the same time allowing for rational expectations on the part of agents about these changes.) Second, it confirms our previous aggregate-data claims using data produced by other researchers.[11]

For convenience, we reproduce Figure 2.20 from Fernandez-Villaverde and Rubio-Ramirez (2007) (Figure 5), which plots, from 1956 to 2000, their estimate of quarterly (non-annualized) target and the duration of price spells. The Figure shows that the target increases steadily from the beginning of the sample to roughly 1979, reaching a less more than 2% (quarterly). Then, the target steadily declines to roughly 0.5%. The duration of price spells is negatively correlated, decreasing and then increasing. To check this correlation more precisely, we consider the specification

$$f_t^{FVRR} = \beta_0 + \beta_1 \overline{\pi}_t^{FVRR} + \epsilon_t$$

where the superscript $FVRR$ indicates these are measures from Fernandez-Villaverde and Rubio-Ramirez (2007): f_t^{FVRR} is the quarterly frequency of price adjustment, and $\overline{\pi}_t^{FVRR}$ is the target (converted, for convenience, to annual).

Table 4 presents the results. The first column presents the baseline regression over the whole sample considered by FVRR. The estimated elasticity β_1 is significant at the 1% level, and positive. The second and third column consider the robustness over the post-1970 and post-1984 subsamples. In both cases the estimated elasticity is also significant at the 1% level and positive. Thus, the conclusion from looking at the data by FVRR is that a higher inflation target robustly implies more flexible prices.

The next section will develop a simple analytical framework to study the effect of increased price flexibility on the effective room away from the ZLB, as a function of the inflation target.

[11]We could also have estimated a time varying DSGE, but we decided to stick to the 2-subsamples exercise presented above because it allows for the identification argument based on pre- and post-Volcker Federal Reserve policy.

3 Analytics Based on a Simple New Keynesian Model

Our setup follows similar steps to those found in Gali (2015), ch. 3. Due to the widespread familiarity with this model, we do not write down all standard first-principle programs, but instead present directly the log-linearized equations.

The model has an output gap shock (which, in this model, can be thought as resulting from preference or TFP shocks) and a nominal interest rate shock. The consumption Euler equation (with log utility) is

$$c_t = E[c_{t+1}] - (i_t - E[\pi_{t+1}]) + \zeta_t$$

where c_t is the log-deviation of consumption from steady state at time t, i_t is the deviation of the nominal interest rate from the its steady-state value $\bar{i}$, π_{t+1} is the log-deviation of inflation at $t+1$ from trend inflation $\overline{\pi}$, $E[\cdot]$ is the expectation operator, and ζ_t is an i.i.d. preference shock. This shock generates deviations of desired consumption away from productivity. Thus, we name it a 'demand' shock. (In this analytical section, we restrict attention to i.i.d. shocks for simplicity. It is easy to generalize our results to AR(1) shocks.)

The Phillips curve is

$$\pi_t = \beta E[\pi_{t+1}] + \kappa(c_t - a_t)$$

where β is the discount factor, $\kappa \in [0, \infty)$ is the slope of the Phillips curve, where a_t is an i.i.d. shock to log TFP (normalized to zero in steady state.) Note that κ depends on the Calvo parameter θ because

$$\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta} \cdot \frac{1 + (\varphi + \alpha)}{1 - \alpha + \alpha\varepsilon}$$

where $1 - \alpha$ is the elasticity of output to the labor input, φ denotes the Frisch elasticity, and ε is the elasticity of substitution between goods. At each period t, a fraction $1 - \theta$ of firms is allowed to adjust prices. Following Ascari (2004) and others (Christiano et al. 2005; Smets and Wouters 2007), we use the fact that firms perfectly index sticky prices to either past inflation or trend inflation in order to get an expression of the Phillips curve similar to the baseline case of zero trend inflation. Below, in the quantitative section 4.2, this assumption is relaxed.

The nominal interest rate rule is:

$$i_t = \phi \pi_t + \nu_t$$

where $\phi > 1$ is the systematic reaction of policy to inflation, and ν_t is an i.i.d. monetary shock. This rule is constrained by the zero bound:

$$i_t \geq -\bar{i}$$

Following standard steps, the first equation can be written as the following IS relation:

$$x_t = E[x_{t+1}] - (i_t - E[\pi_{t+1}]) + \eta_t$$

where x_t is the output gap at time t:

$$x_t \equiv c_t - a_t$$

and η_t is now an output-gap shock (function of ζ_t and a_t.) Also, the Phillips curve in terms of the output gap is

$$\pi_t = \beta E[\pi_{t+1}] + \kappa x_t$$

In steady state, the Fischer equation holds:

$$\bar{i} = \bar{r} + \bar{\pi} \tag{2}$$

where $\bar{r}$ is the steady-state real interest rate, and $\bar{\pi}$ is steady-state inflation, equal in this model by the inflation target of the monetary authority. Thus, increasing the inflation target $\bar{\pi}$ amounts to increasing $\bar{i}$.

Lemma 1 *For a sequence of η_t, ν_t such that $i_t \geq 0$, the (unique) solution of* *the model is given by*

$$
\begin{aligned}
x_t &= \frac{1}{1+\phi\kappa}\eta_t - \frac{1}{1+\phi\kappa}\nu_t \\
\pi_t &= \frac{\kappa}{1+\phi\kappa}\eta_t - \frac{\kappa}{1+\phi\kappa}\nu_t \\
i_t &= \frac{\phi\kappa}{1+\phi\kappa}\eta_t + \frac{1}{1+\phi\kappa}\nu_t
\end{aligned}
$$

and

$$x_{t+\tau} = \pi_{t+\tau} = i_{t+\tau} = 0, \quad \forall \tau \geq 1$$

This proposition fully characterizes the solution away from the zero lower bound. The proof is standard via the method of undetermined coefficients.

The key departure from the canonical NK approach is the assumption that prices are more flexible for a higher inflation target.

Assumption 1 *The Calvo parameter θ is a decreasing function of the inflation target $\overline{\pi}$:*

$$\frac{\partial \theta}{\partial \overline{\pi}} < 0$$

We justify this assumption mainly on an empirical basis, given the evidence presented earlier. We also emphasize how easy it is to implement this assumption on the NK model—the economics of the NK model are unaffected; the same approach goes through with a θ parameter that is different depending on policy parameters, as $\overline{\pi}$ or ϕ.[12] Moreover, conceptually there is no a priori reason why the Calvo parameter should not take different values depending on the environment; other models clearly indicating that this frequency should indeed vary with the target[13].

For convenience, we define the parameter $\mathfrak{f} \in [0,1]$, which is an increasing indicator of the degree of price flexibility. If $\mathfrak{f} = 0$, prices are completely sticky or rigid, if $\mathfrak{f} = 1$, prices are completely flexible. (In the NK model, of course, $\mathfrak{f} = 1 - \theta$, but we find that having an increasing indicator of flexibility facilitates expressing the results below.) Given assumption 1 then,

$$\frac{\partial \mathfrak{f}}{\partial \overline{\pi}} > 0$$

[12]Notice that we maintain (consistent with our notation) that the monetary authority chooses policy parameters once and for all, and that this is anticipated by agents.

[13]Below, in our quantitative analysis, we look at the predictions of a menu cost model.

and using the fact that the slope of the Phillips curve κ is an increasin function of $\mathfrak{f}$, it is straightforward to establish that κ is an increasing function of the target $\overline{\pi}$:

$$\frac{\partial \kappa}{\partial \overline{\pi}} > 0$$

Thus, the higher the target, the steeper the Phillips curve, and the more inflation moves with both shocks η and ν. On the contrary, if the target is low, the Phillips curve flattens, with muted responses of inflation to the shocks.

Of special interest for our purposes is the coefficient of reaction of the interest rate to demand shocks η_t, which we will write as a function of κ:

$$g(\kappa) = \frac{\phi\kappa}{1+\phi\kappa}$$

Because $g(\kappa) > 0$, a positive demand shock induces an increase in the rate, and vice-versa.

Notice two points about this function. First, g is an increasing function of κ, and thus an increasing function of $\overline{\pi}$. The higher the target, the *more* the interest rate reacts to a given shock η_t.

Second, the function g is convex in κ, which suggests that, when the Phillips curve is fairly flat (small κ), a small change in κ can induce big differences in how much the rate reacts to demand shocks. What we ultimately want is the curvature of g in the Calvo parameter θ, but the quantitative results below indeed suggest that this convexity over κ is at play.

It is interesting to consider what happens when prices become very flexible ($\mathfrak{f} \longrightarrow 1$). Since

$$\lim_{\mathfrak{f}\to 1} \kappa(\mathfrak{f}) = \infty$$

then, when prices becomes very flexible we have that demand shocks have no effect on the output gap:

$$\lim_{\mathfrak{f}\to 1} \frac{1}{1+\phi\kappa} = 0$$

and the coefficient of nominal rates tends to 1 (from below):

$$\lim_{\mathfrak{f}\to 1} g(\kappa) = 1$$

The first result is expected: in a flexible prices economy, demand shocks should have no effect. What is interesting is the second result. For this to be true, the nominal interest rate has to move one-to-one with demand shocks, that is, it has to move *a lot*. To give a sense of the magnitudes, a large negative demand shock resembling a financial crisis would be, perhaps, of -10%.[14] So, facing such a shock, the nominal rate would need to fall by 10 pp. If the steady-state real rate r is 2% (and the nominal rate 4%), not even raising the inflation target by 5 percentage points (from $\overline{\pi} = 2\%$ to 7%) can ensure not hitting the ZLB during a financial crisis.

All of these ideas hinge on the crucial role of monetary policy, and how much bite it has on the economy, which we call the *potency* of monetary policy. When potency is high, an unexpected monetary shock moves the output gap by a lot. This make this precise, the following definition is useful.

Definition 1 *Consider the effect of a one-time shock $\nu > 0$ to the nominal interest rate i_t. The maximum effect possible on the output gap is $-\nu$. Thus, the potency of monetary policy $\mathfrak{P} \in [0, 1]$ is given by*

$$\mathfrak{P} = -\frac{x_t}{\nu}$$

Following on the reasoning above, when the potency is high, it is relatively easy for the systematic arm of monetary policy to stabilize the output gap. The main question we are after in this paper is: how are the potency $\mathfrak{P}$ and the monetary policy room related?

A few straightforward facts about the potency $\mathfrak{P}$ are worth noticing. First, $\mathfrak{P}$ is decreasing in trend inflation $\overline{\pi}$. Thus, monetary shocks have less of an effect on the output gap. This is an implication of money 'becoming neutral' for more flexible prices, and it is trivial to prove by using the solution of the model above.[15] By similar logic, output gap shocks have less of an effect on the output gap.

Besides these two points, a less obvious and critical question for us concerns the impact of output gap shocks *on the nominal rate*. This is characterized as

[14]This is a rough estimate used purely for illustration. The idea is that a year after the 08 financial crisis, the output gap in the U.S. was, say -5%. If, for purposes of this illustration, about half of the shock was absorbed by automatic stabilizers, then the size of shock was about -10 pp. The quantitative section below takes a more careful quantitative approach at determining the plausible size of this shock.

[15]Focusing on the stable solution above avoids the subtlety that more generally, the nominal interest rate is not determined.

follows.

Proposition 1 (Effects of Flexibility) *Consider the effect of a one-time shock $\eta > 0$ to the output gap x_t. Then, the response of i_t is increasing in $\overline{\pi}$. At the limit when $\mathfrak{f} \longrightarrow 1$:*

$$x_t = 0; \quad \pi_t = \frac{1}{\phi}\eta; \quad i_t = \eta$$

$$\mathfrak{P} = 0$$

The proof immediately follows from the solution above.

So, it turns out that the nominal rate moves *by more* the higher trend inflation. This observation allows to go back to our original question regarding the link between the inflation target and policy room. We analyze this by considering the following thought experiment. Consider 2 economies: $\{\overline{\pi}_1, \kappa_1, \bar{i}_1\}$, $\{\overline{\pi}_2, \kappa_2, \bar{i}_2\}$ with $\overline{\pi}_2 > \overline{\pi}_1$. Thus, $\mathfrak{f}(\overline{\pi}_2) > \mathfrak{f}(\overline{\pi}_1) \Longleftrightarrow \kappa_2 > \kappa_1$.

Now, consider a shock η that lowers the economy 1 interest rate by $-(\bar{i}_1 - \epsilon)$ from steady state (the ZLB is just attained—but not binding—for $\epsilon \longrightarrow 0$):

$$\eta^\epsilon = -(\bar{i}_1 - \epsilon)\frac{1 + \phi\kappa_1}{\phi\kappa_1}$$

Suppose now that η^ϵ hits economy 2. The question at hand is: By how much does i_2 move?

To answer this, consider the following definition of the *intended* increase in policy room:

$$\mathfrak{R} \equiv \Delta\overline{\pi} = \overline{\pi}_2 - \overline{\pi}_1$$

Definition 2 *The **effective increase** in policy room is given by*

$$\mathfrak{R}^{eff}(\eta^0) = \Delta\overline{\pi} + (i_2(\eta^0) - i_1(\eta^0))$$

where $i_1(\eta^0)$ and $i_2(\eta^0)$ are the responses to the shock η^0 in economies 1 and 2 respectively.

The idea here is that this intended increased takes into consideration the change in the response of policy rate. The key insight is that the change in potency $\mathfrak{P}$ affects the room available for policy, formally expressed as follows.

Theorem 1 (Formula for Policy Room) *Consider the shock $\eta^0 < 0$. Then,* *1. The effective increase in policy room is given by*

$$\mathfrak{R}^{eff}(\eta^0) = \Delta\overline{\pi} + \Delta\mathfrak{P} \cdot |\eta^0|$$

2. The effective increase is strictly smaller than the intended increase:

$$\mathfrak{R}^{eff}(\eta^0) < \mathfrak{R}$$

Proof (Sketch.) The first part follows from simple algebra using the closed-form solution. To prove the second part, notice

$$\kappa_2 > \kappa_1 \iff i_2(\eta^0) < i_1(\eta^0) \iff \Delta\mathfrak{P} < 0$$

and so

$$\mathfrak{R}^{eff}(\eta^0) = \Delta\overline{\pi} + \Delta\mathfrak{P} \cdot |\eta^0| < \mathfrak{R} = \Delta\overline{\pi}$$

■

By the formula above, the effective room then is equal to the intended room, plus the change in monetary policy potency times the shock. Since potency is reduced after an increase in the target, the effective room is lower than the intended room. Also, the formula above is revealing from a quantitative point of view. The gap between the effective and the intended room depends on the potency reduction *and* the size of the shock. The latter is likely to be large, and therefore, unless the change in potency is negligeable, the gap should be sizeable.

To complement Theorem 1, it is actually possible to show the following stronger result regarding the effects of price flexibility when raising the target.

Proposition 2 (Room Neutrality) *Consider economy $\{\overline{\pi}_1, \kappa_1, \bar{i}_1\}$. For any moderate change in the target $\Delta\overline{\pi}$, there exists a slope of the Phillips curve κ_2 such that the change is room-neutral:*

$$\mathfrak{R}^{eff}(\eta^0) = 0$$

Proof Using the expressions above, we want κ_2 such that

$$0 = \overline{\pi}_2 - \overline{\pi}_1 + (g(\kappa_2) - g(\kappa_1))\eta^0$$

Equivalently,

$$g(\kappa_2) = \frac{\overline{\pi}_2 - \overline{\pi}_1}{|\eta^0|} + g(\kappa_1)$$

Since $g(x)$ is strictly increasing, $g(0) = 0$, and $\lim_{x \to \infty} g(x) = 1$, for $\overline{\pi}_2$ close to $\overline{\pi}_1$, one can compute a unique κ_2 such that $\mathfrak{R}^{eff}(\eta^0) = 0$.

■

This result can be extended to trace out the degree of flexibility needed, as a function of all admissible targets, that delivers room-neutrality. In that case, the inflation target becomes irrelevant for the question asked in this paper. Indeed, any given raise in the target can be neutralized by a suitable increase in price flexibility, leaving the room available for monetary policy unchanged. An interesting question is whether this is at all possible quantitatively. In the quantitative section we explore this. We compute this degree of flexibility for an increase in the target of 2pp, and explore the parameter region for empirically admissible values to check whether this (quite strong) theoretical result is at all relevant.[16]

Another question raised by these results is whether the monetary authority could engineer a way to increase trend inflation and try to minimize the adverse effect of potency loss. It turns out that there is a way—that even has practical content—described in the following corollary.

Corollary 1 (Avoiding the Loss of Potency) *The loss in potency of monetary policy is given by:*

$$\Delta\mathfrak{P} = -\frac{\phi(\kappa_2 - \kappa_1)}{(1 + \phi\kappa_1)(1 + \phi\kappa_2)} < 0$$

Thus, the potency loss vanishes when the effect of the systematic response of monetary policy to inflation ϕ is very strong.

(The proof is immediate.) In other words, in order to minimize the potency loss, the monetary authority should raise the inflation target, but keep inflation very close to this target. The intuition for this result is that this dampens the effect of the loss of potency. Even is there is such loss, if the interest rate is

[16] For a larger increase in the target ($\overline{\pi}_2$ far away from $\overline{\pi}_1$) prices will keep on getting flexible, but the potency loss is not strong enough to keep the effective room at zero. However, as shown above, it will still be lower than intended.

very aggressive on inflation, the effective extra room will tend to approach the intended extra room.

We close this analytical section by being explicit about a point that has been lurking in the background of the above discussion. What happens when the monetary authority behaves optimally instead of following a simple rule as the one postulated above? In the model considered, this corresponds to looking at the monetary policy under commitment that minimizes welfare losses arising from inflation and output gap volatility. Under output gap shocks solely, this can be shown to amount to setting the nominal interest rate such that the real rate is equal to the natural rate.[17] In this case, the effective extra room is equal to the intended extra room, because how inflation behaves does not change the nominal rate set by the authority. This is a result of theoretical appeal but perhaps of limited practical interest, since in realistic settings central banks do use inflation as a guide for policy, and thus the effects of price flexibility are likely to be present. Moreover, empirically, realistic interest rate rules as the one considered in the next section fit the data better.[18]

[17]How to obtain this rule is well known, see for example Svensson (2010). For a recent treatment, we refer, for example, to the textbook by Gali (2015) for more details.

[18]Moreover, this optimal nominal rate is the same rate discussed above in the context of fully flexible prices. Thus, it is unrealistically volatile.

4 Quantitative Importance

We now show our quantitative results by studying three models conventionally used in policy analysis. First, we consider a standard New-Keynesian model; second, we consider a conventional medium-scale New-Keynesian DSGE model; and third, we consider a medium-scale DSGE model that features endogenous price adjustment in the form of menu costs. All our models are calibrated using standard values.

In the first two models, we postulate, for the Calvo parameter of price adjustment, the empirically estimated relation presented earlier. In the case of the menu cost model, we assume constant real menu costs across inflation targets, and let the model discipline the increased price flexibility.

4.1 Using the Standard New-Keynesian Model

We first quantitatively consider the textbook model in Gali (2015). We follow his calibration exactly, complementing it with the empirically estimated relation between the Calvo parameter and the inflation target. We find a large and substantial gap between the intended extra policy room and effective one as we increase the target.

4.1.1 Model Setup

We consider two versions of this New-Keynesian model. Both versions are identical to the model described in the previous section, with one slight difference. The first version features the exact specification of the monetary policy rule in Gali (2015), that is:

$$i_t = \phi_\pi \pi_t + \phi_c x_t + \nu_t \tag{3}$$

where ϕ_π is the weight the policy-maker places on inflation[19] and ϕ_c the weight he places on the output gap, and ν_t is a monetary policy shock. We name this version "std. NK". The second version, which we name "simple NK", features no systematic response to output, $\phi_c = 0$ in the monetary policy rule, that is

$$i_t = \phi_\pi \pi_t + \nu_t \tag{4}$$

[19] An intentional and minor abuse of notation is to denote this coefficient ϕ_π instead of simply ϕ as in Section 3.

Our choice of parametrization includes a value of β equal to 0.99, a value of ϕ equal to 1.5, and a value of ϕ_c equal to 0.5/4. The value of κ is determined both by the Calvo parameter θ and a number of other parameters that we take from Gali.[20] For the Calvo parameter, we postulate the function (1) estimated above for the monthly frequency of price adjustment. We have four different estimates of this relationship (Table 2). We choose to be conservative and choose the estimate with the *lowest* elasticity of the frequency of price adjustment and the inflation target (Specification II based on Ireland 2007). This implies the following equation for the Calvo parameter at quarterly frequency:

$$\theta = (1 - (0.0742 + 0.98\overline{\pi}))^3$$

This function implies a range of values for κ depending on $\overline{\pi}$. For $\overline{\pi} = 2\%$, this gives $\kappa = 0.18$; for For $\overline{\pi} = 4\%$, $\kappa = 0.27$.

4.1.2 Model Results

We now present the most important result of the paper, in the context of the textbook New-Keynesian model: Effective policy room is substantially smaller than intended room.

To arrive at this result, we consider the same thought exercise described in Section 3. That is, we consider a large, negative shock $\zeta_t < 0$ that makes the nominal interest rate drop to zero upon impact. We fix the size of this shock, and we ask, for different values of $\overline{\pi}$, by how much the interest rate can fall (away from steady state) before hitting the ZLB. The difference between how much more or how much less room there is for higher levels of $\overline{\pi}$ is called "effective extra room". For instance, if the monetary authority raises $\overline{\pi}$ to 4%, we find an effective extra room of 0.511 percentage points (pp.) in the case of the simple NK model. This means, even thought the *intended* extra room was 2% (because the steady-state interest rate is raised by 2% according to (2)), the *effective* extra room is only 0.511 pp. when one takes into account the effect of increased price flexibility and the implied loss of monetary policy potency—which pushes the nominal rate to fall by more than before raising the target. About a quarter of the intended gains are obtained.

[20]The Frisch elasticity of labor supply is set to 0.2; the capital share to 0.25; the goods market markup is 12.5% (see p. 67.)

The results are shown in Figure 6. The 45 degree line represents the intended extra room by moving from a 2% to a higher inflation target $\overline{\pi}$. For instance, raising the target from 2% by 2 pp. (to 4%), delivers an intended extra room of 2%. The red curve represent the effective extra room according to the simple New-Keynesian model; the blue curve represents the effective extra room according to the standard New-Keynesian model. (The red and blue curves look straight, but they are not. This is visible when one considers targets above 16%.) Both of these curves are below the 45 degree line because of the loss of potency of monetary policy due to the price flexibility effect—as formally shown by Theorem 1 for the simple NK model. The blue curve is, however, above the red curve because of an effect going in the opposite direction: More price flexibility implies less of a fall of the output gap, and therefore, if $\phi_c > 0$, monetary accommodation is less necessary. Thus, the effective extra room is higher (1.064 pp. for the standard NK model, thus only about half of the intended space is achieved). Furthermore, in order to achieve an *effective* extra room of 2 pp., one would need to raise the target to 5.790%, the simple NK model delivering a significantly higher number. Thus, according to the models considered so far, the price flexibility channel is highly relevant in the discussion of raising the inflation target. Morever, the large difference between the figures obtained for the simple and standard NK models underlines the importance of the interest rule in determining the effective extra room obtained.

4.2 Using a Medium-Scale New-Keynesian DSGE Model

One of the key questions for policy-makers and the general reader may be if our results hold in realistic and commonly used, medium-scale DSGE models. In this subsection and the next, we show that yes, they do.

First, we consider a medium-scale DSGE model à la Coibion et al. (2012) and Andrade, Gali, Le Bihan, and Matheron (2017). Our model shares the common features of these and other modern New-Keynesian DSGE models. The main deviation from the barebone New-Keynesian model lies in incorporating trend inflation under imperfect indexation in the first place, in the line of related papers such as Ascari and Ropele (2009). We outline the relevant features of the model setup in the following and then discuss our quantitative exercise of increasing trend inflation.

4.2.1 Consumers

The infinitely-lived, representative consumer maximizes their expected discounted stream of utility from consumption and labor:

$$\max E_t \left[\sum_{j=0}^{\infty} \beta^j \left\{ \log \left(C_{t+j} - h C_{t+j-1} \right) - \frac{\varphi}{1+\varphi} \int_0^1 N_{i,t+j}^{\frac{1+\varphi}{\varphi}} di \right\} \right] \tag{5}$$

where final goods consumption is denoted by C_t, labor supplied to sector i at time $t+j$ by $N_{i,t+j}$, the Frisch elasticity of labor supply by φ, internal habit by h, and the rate of time preference by β.

The consumer solves (5) subject to the following period budget constraint:

$$P_t C_t + S_t \leq \int_0^1 N_{it} W_{it} \; di + e^{\zeta_{t-1}} R_{t-1} S_{t-1} - P_t T_t + P_t D_t$$

where P_t denotes the aggregate price level, S_t the holdings of one-period bonds, W_{it} the nominal wage rate in sector i, R_t the gross nominal rate of return, T_t lump-sum taxes and D_t dividends paid to the consumer by firms. The risk-premium shock ζ_{t-1} follows the auto-regressive process

$$\zeta_t = \rho_\zeta \zeta_{t-1} + \epsilon_t^\zeta$$

where ϵ_t^ζ is i.i.d. with $E[\epsilon_t^\zeta] = 0$ and $var[\epsilon_t^\zeta] = \sigma_\zeta^2$. It can be shown that this shock is equivalent to a discount factor or preference shock—as written in Section 3, but here we follow CGW and write it as a risk-premium shock.

4.2.2 Firms and Price-Setting

A perfectly competitive sector produces the final consumption good. The final goods producer combines the continuum of intermediate goods using the following Dixit-Stiglitz production function:

$$Y_t = \left(Y_{it}^{(\varepsilon-1)/\varepsilon} di \right)^{\varepsilon/(\varepsilon-1)}$$

where Y_t denotes the amount of the final good produced each period, Y_{it} the amount of intermediate good i used from sector i and ε the elasticity of substitution between any two intermediate goods. The aggregator implies the following raggregate price level and demand for sector i intermediate good demand:

$$P_t = \left[\int_0^1 P_{it}^{1-\varepsilon} \right]^{1/(1-\varepsilon)}$$

and

$$Y_{it} = Y_t (P_{it}/P_t)^{-\varepsilon}$$

Monopolistically competitive firms produce each intermediate i using a production technology that is linear in labor, given by

$$Y_{it} = A_t N_{it}$$

where A_t denotes productivity. (In our simulations, we will actually not use technology shocks and thus A_t grows a at constant rate $A_t/A_{t-1} - 1 = \mu$.)

In terms of price setting, we assume that intermediate goods' prices will adjust exogenously following Calvo (1983) (unlike in the next subsection where we outline a model with endogenous price adjustment.) Each period, a firm will be able to adjust prices with probability $1-\theta$. If firms do not get to re-optimize, they will automatically re-scale their prices by the steady state rate of inflation, $\overline{\pi}$, with a degree of indexation $\omega \in [0, 1)$. Thus, $\omega = 1$ denotes full indexation, $\omega = 0$ no indexation.

Firms that get to adjust prices maximize the following expression for choosing the new price P_{it}^*:

$$E_t \left[\sum_{j=0}^{\infty} (\beta\theta)^j Q_{t,t+j} \left(Y_{t+j} P_{it}^* \overline{\pi}^{\omega j} - W_{i,t+j} N_{i,t+j} \right) \right]$$

where $Q_{t,t+s}$ denotes the stochastic discount factor. These assumptions about price setting imply that the aggregate price level evolves as

$$P_t^{1-\varepsilon} = (1-\theta) \left(P_{it}^*\right)^{1-\varepsilon} + \theta \left(P_{t-1} \overline{\pi}^{\omega}\right)^{1-\varepsilon}$$

4.2.3 Monetary Policy and Market Clearing

We assume that monetary policy follows an interest rate rule that also features interest-rate smoothing:

$$I_t = I_{t-1}^{\rho_1} I_{t-2}^{\rho_2} (\pi_t^{\phi_\pi} Y_t^{\phi_y} (Y_t/Y_{t-1})^{\phi_{\Delta y}})^{1-\rho_1-\rho_2}$$

where I_t is the gross nominal interest rate, ρ_1 and ρ_2 denote the interest rate smoothing parameters with respect to the first and second lags of the nominal rate, ϕ_π, ϕ_y, and $\phi_{\Delta y}$ parametrize the systematic response of the policymaker to inflation, output and output growth.

Goods market clearing requires

$$Y_t = C_t + G_t$$

where we allow for government consumption of the final consumption good, evolving with a persistence parameter ρ_g as follows:

$$G_t = \bar{G}^{1-\rho_g} G_{t-1}^{\rho_g} e^{\epsilon_t^g}$$

Government spending will be constant in our simulations ($\epsilon_t^g = 0$).

4.2.4 Quantitative Exercise

We now repeat the same experiment as in the previous subsection. That is, at a steady-state rate of 2% inflation, we consider a demand shock that drives the nominal interest to the ZLB upon impact. We then fix the size of the shock and increase the inflation target. Again, we ask how much effective room we gain as we increase the target in this quantitative medium-scale model. Table 5 summarizes the parameters we use to calibrate the model.

Our main result continues to hold in this realistic model calibration. The green line in Figure 6 summarizes our findings, relative to the benchmark of intended, one-to-one increases in policy room which are indicated by the dashed 45-degree line. Clearly, the green line is quantitatively substantially below the 45-degree line. For example, when moving from a 2% to a 4% inflation target, we see that effective room only increases to 1.537 pp. One would expect an increase by 2 pp. The policy-maker is only able to achieve 76.5% of his or her intended policy room gains.

4.2.5 Parameter Uncertainty: Bayesian Assessment of the Effective Extra Room

The final exercise we perform with the medium-scale DSGE is the following. We consider the joint distribution of several key parameters that may affect the effective room in this quantitative model. Specifically, we consider the joint distribution of the following parameters: the Frisch elasticity of labor supply φ, the discount factor β, the habit parameter h, the steady-state growth rate μ, the interest rate smoothing coefficients ρ_1 and ρ_2, and all systematic response-parameters in the Taylor rule (ϕ_π, ϕ_y, and $\phi_{\Delta y}$). To approximate the joint distribution, we generate 10,000 joint draws from the Bayesian estimate of their joint distribution in the Smets-Wouters model. Then, we compute effective room for each draw when going from 2% to 4% steady state inflation.

Figure 8 illustrates the resulting, empirical distribution of the effective room policy room. Our median estimate is 1.416 pp., the mean is 1.418 pp. The 25th and 75th percentile of the distribution are 1.371 pp. and 1.430 pp. Clearly, for a wide set of empirically relevant model parameters, the policy maker is not able to achieve his intended room of 2 pp. In effect, his median room is only 70.8% of the intended room. Thus, we conclude that our results are robust to parameter uncertainty.

4.3 Using a Medium-Scale Menu Cost Model

While it does not bring with it analytical tractability and portability to conventionally used policy models, explicitly modeling endogenous price adjustment, for example through menu cost models, may affect the importance of the price flexibility channel in important ways. We show that modeling price setting endogenously leads to roughly the same quantitative conclusions.

To implement endogenous price setting, we follow the menu cost approach in Dotsey, King, and Wolman (1999). In this approach, firms compare the costs and benefits of price adjustment when deciding whether to change prices or not, and take into account past prices, the distribution of "vintages" of prices and a random cost of adjustment. Our quantitative exercise calibrates the menu cost for a given rate of the inflation target to match an empirically relevant average price duration, and then varies the inflation target while holding menu costs constant.

We use exactly the same model as in the previous subsection, with only minimal modifications and the main modification imposed on the price-setting mechanism. We outline all changes below.

4.3.1 Firms and Price-Setting

Now, firms adjust their prices endogenously. The adjustment decision of firms depends on weighing the value of adjusting its price, the value of not adjusting price, and the random, period realization of adjustment costs. Adjustment costs k_t are randomly drawn each period, independently across firms and over time, and represent a fraction of labor costs. We denote their c.d.f. by $\mathcal{G}$.

Following Dotsey et al. (1999), we denote by J the maximum number of periods, after which all firms adjust. That means the maximum duration of a price spell can be J periods. At the beginning of each period t, denote by ζ_{jt} the fraction of firms with price spells equal to j periods. Among these firms (i.e. those that have not changed its price for j periods) we write by θ_{jt} the (now endogenous) fraction that change it at t.

We now describe the firm's problem. To decide whether to adjust or not, a firm considers the value of adjusting and not adjusting. Denote by π_{jt} period profits of a firm at period t given it has set price P^*_{t-j} optimally j periods ago. Denote by V_{0t} the value at time t of an adjusting firm, gross of the adjustment cost, that chooses an optimal reset price P^*_t. Denote by V_{jt} the value of a firm at time t that last adjusted its price $j = 0, 1, ..., J-1$ periods ago. The value of an adjusting firms is the following:

$$V_{0t} = \max_{P_t} \left(\pi_{0,t} + E_t \left[\beta Q_{t,t+1} \left[(1-\theta_{1,t+1}) V_{1,t+1} + \theta_{1,t+1} V_{0,t+1} - \Xi_{1,t+1} \right] \right] \right)$$

where

$$\Xi_{jt} = \int_0^{\mathcal{G}^{-1}(\theta_{jt})} k \; d\mathcal{G}(k)$$

is the expected adjustment cost of firms with price spells of j periods. The value of a firm at time t with prior optimally chosen price P^*_{t-j} is the following:

$$V_{jt} = \left(\pi_{j,t} + E_t\left[\beta Q_{t,t+1}\left[(1-\theta_{j+1,t+1})V_{j+1,t+1} + \theta_{j+1,t+1}V_{0,t+1} - \Xi_{j+1,t+1}\right]\right]\right)$$

Because $\theta_{Jt} = 1$, the value of firms with price spell of $J-1$ periods is given as follows:

$$V_{J-1,t} = \left(\pi_{J-1,t} + E_t\left[\beta Q_{t,t+1}\left[V_{0,t+1} - \Xi_{J,t+1}\right]\right]\right)$$

Firms of each vintage decide to adjust price if the gain in value from doing so is at least as big as the cost of adjustment. That is, if

$$V_{0t} - V_{jt} = k_t W_t$$

Given the distribution of fixed costs, this implies that the fraction of firms θ_{jt} that adjust to the new optimal price P^*_t given that they have not adjusted for j periods is equal to

$$\theta_{jt} = \mathcal{G}(V_{0t} - V_{jt}/W_t)$$

Notice that the adjustment technology uses labor, which impacts the aggregate resource constraint compared to the previous variant of the New Keynesian model. The resource constraint now equals

$$Y_t = C_t + G_t + \sum_{j=1}^{J} \zeta_{jt}\Xi_{jt}$$

The aggregate price level is now pinned down by the vintage structure of prices. That is,

$$P_t = \left(\sum_{j=0}^{J-1} \zeta_{jt}\left(P^*_{t-j}\right)^{1-\varepsilon}\right)^{1/(1-\varepsilon)}$$

This completes the presentation of the new elements introduced in this model.

4.3.2 Quantitative Exercise

We calibrate the average size of menu costs, weighted by the steady-state shares of firms of different vintages to yield a 2-quarter average price duration at a steady-state inflation rate of 3.5%. This calibration and modeling setup follows the implementation in Coibion et al. (2012). It implies a menu cost of approximately 7% of steady-state output.

With this calibration at hand, we now repeat exactly the same experiment as in the previous subsections. That is, at a steady-state rate of 2% inflation, we consider a demand shock that drives the nominal interest to the ZLB upon impact. We then fix the size of the shock and increase the inflation target. However, as we increase the inflation target, the frequency of price adjustment now endogenously increases. Again, we ask how much effective room we gain as we move to higher targets.

Our main result continues to hold in this model calibration that includes endogenous price adjustment. Figure 7 shows our main finding. Increasing the inflation target from 2% to 4% only increases policy room by 1.600%, not by the full 2%. The policy-maker, similar in magnitude as before, only achieves 79.5% of the intended policy room.

5 Conclusion

In theory, a higher inflation target could be completely undone by the actions of the private sector. While we have not found that in the quantitative part of the paper, all of our quantitative results suggest that it is indeed relevant to consider this channel. This conclusion is given strong support by a range of empirical exercises, and by considering different models.

There are two ways of interpreting our results.

A conservative interpretation is that this channel provides a further reason not to attempt raising the inflation target in order to achieve higher inflation, because the monetary authority needs to *also* fight against the loss of potency in order to gain extra room for monetary policy. This may not justify the extra welfare costs of higher inflation.

Another interpretation, potentially of a more radical nature, is that—on the contrary—this channel provides a justification to raise the inflation target by *more* than intended or initially discussed (to say to 5% instead of 4%), in order to ensure getting enough room for monetary policy. Which of these two interpretations ought to be adopted seems to depend on the exact macroeconomic context, and on the relative importance of minimizing the impact and length of liquidity traps in the future.

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A Tables and Figures

Table 1: Inflation Target and Calvo Parameter Estimates, Full and Post-1984 Sample

	Full Sample	> 1984
Target $\overline{\pi}$	3.33	2.59
Calvo θ	0.61	0.71

The table shows structural parameter estimates of the inflation target $\overline{\pi}$ and the Calvo parameter of price adjustment θ in the Smets and Wouters (2007) model over subsamples, U.S. data.

Table 2: Frequency of Price Changes and Inflation Target

	(I)	(II)	(III)	(IV)
Target $\overline{\pi}_t$	1.61***	0.98***	1.04***	2.26***
	(0.24)	(0.08)	(0.11)	(0.41)
constant	4.61***	7.42***	7.26***	5.25***
	(0.86)	(0.37)	(0.40)	(0.91)
N	28	27	28	26
R^2	68%	83%	78%	66%
Data means:				
Target $\overline{\pi}_t$	3.42	4.04	3.90	2.85
Freq f_t	10.69	10.75	10.69	10.8

The table shows estimates of the following specification: $f_t = \beta_0 + \beta_1 \overline{\pi}_t + \epsilon_t$, where f_t is the annual average monthly frequency of price changes in %, and π_t^* the annual inflation target, also in %. We estimate this specification separately for our three inflation target series: Specification (I) is based on the estimates by Fuhrer and Olivei (2017); Specification (II) is based on Ireland (2007); Specification (III) is based on Milani (2006); and Specification (IV) in based on Cogley and Sbordone (2008). We use robust Newey-West standard errors. The rows "data means" show, respectively: the means of the independent variable (inflation target), and of the dependent variable (frequency of price changes).
*** denotes significant at the 1% level.

Table 3: Frequency of Price Changes and Inflation Target, Post 1984

	(I)	(II)	(III)	(IV)
Target $\overline{\pi}_t$	1.16***	1.10***	1.04***	1.99**
	(0.27)	(0.31)	(0.27)	(0.75)
constant	6.06***	7.26***	7.42***	5.86***
	(0.92)	(0.76)	(0.74)	(1.51)
N	21	20	21	19
R^2	47%	41%	42%	37%
Data means:				
Target $\overline{\pi}_t$	3.31	2.36	2.38	2.04
freq f_t	9.88	9.88	9.88	9.91

The table shows estimates of the following specification: $f_t = \beta_0 + \beta_1 \overline{\pi}_t + \epsilon_t$, where f_t is the annual average monthly frequency of price changes in %, and π^*_t the annual inflation target, also in %. We use robust Newey-West standard errors. We estimate this specification separately for our three inflation target series: Specification (I) is based on the estimates by Fuhrer and Olivei (2017); Specification (II) is based on Ireland (2007); Specification (III) is based on Milani (2006); and Specification (IV) in based on Cogley and Sbordone (2008). The rows "data means" show, respectively: the means of the independent variable (inflation target), and of the dependent variable (frequency of price changes).
*** denotes significant at the 1% level.

Table 4: Frequency of Price Changes and Inflation Target, based on Fernandez-Villaverde et al. (2007)

	(I) 1956-2000	(II) > 1978	(III) > 1984
Target $\overline{\pi}^{FVRR}$	2.95***	3.34***	8.57***
	(0.73)	(0.38)	(1.12)
constant	17.38***	11.99***	7.41***
	(0.97)	(0.51)	(0.79)
N	180	88	64
R^2	6%	31%	30%

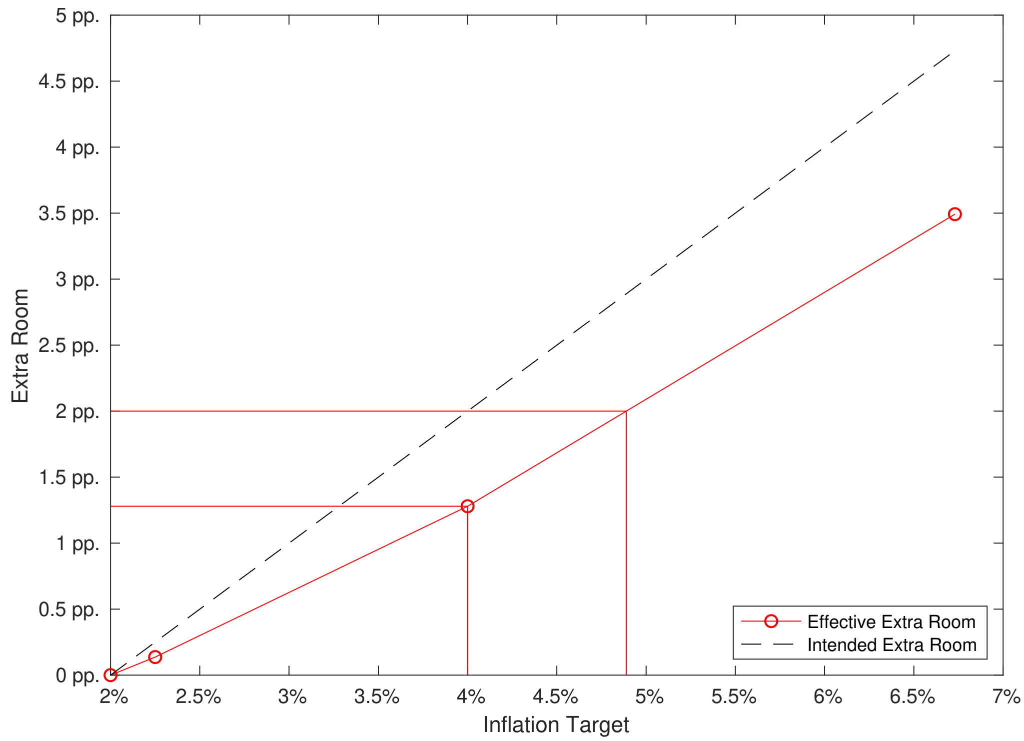
The table shows estimates of the following specification: $f_t^{FVRR} = \beta_0 + \beta_1 \overline{\pi}_t^{FVRR} + \epsilon_t$, where f_t^{FVRR} is the quarterly frequency quarterly average of price changes estimated by Fernandez-Villaverde and Rubio-Ramirez (2007) in %, and π_t^{FVRR} the annual inflation target estimated by Fernandez-Villaverde and Rubio-Ramirez (2007), also in %. We use robust Newey-West standard errors. We estimate this specification separately for different subsamples. *** denotes significant at the 1% level.

Table 5: Model Parameters

Parameters of Utility Function		**Steady-State Values**	
φ: Frisch Labor Elasticity	1.00	μ: Growth Rate of RGDP/cap	1.5% p.a.
β: Discount factor	0.998	$\overline{c_y}$: Consumption Share of GDP	0.80
h: Internal habit	0.7	$\overline{g_y}$: Government Share of GDP	0.20
Pricing Parameters		**Shock Persistence**	
ϵ: Elasticity of substitution	7	ρ_g: Government Spending Shocks	0.97
		ρ_ξ: Risk Premium Shocks	0.947
Taylor Rule Parameters		**Shock Volatility**	
ϕ_π: Long run response to inflation	2.50	σ_g: Government Spending Shocks	0.0052
ϕ_y: Long run response to output growth	1.50	σ_ξ: Risk Premium Shocks	0.0024
$\phi_{\Delta y}$: Long run response to output gap	0.11		
ρ_1: Interest smoothing	1.05		
ρ_2: Interest smoothing	-0.13		

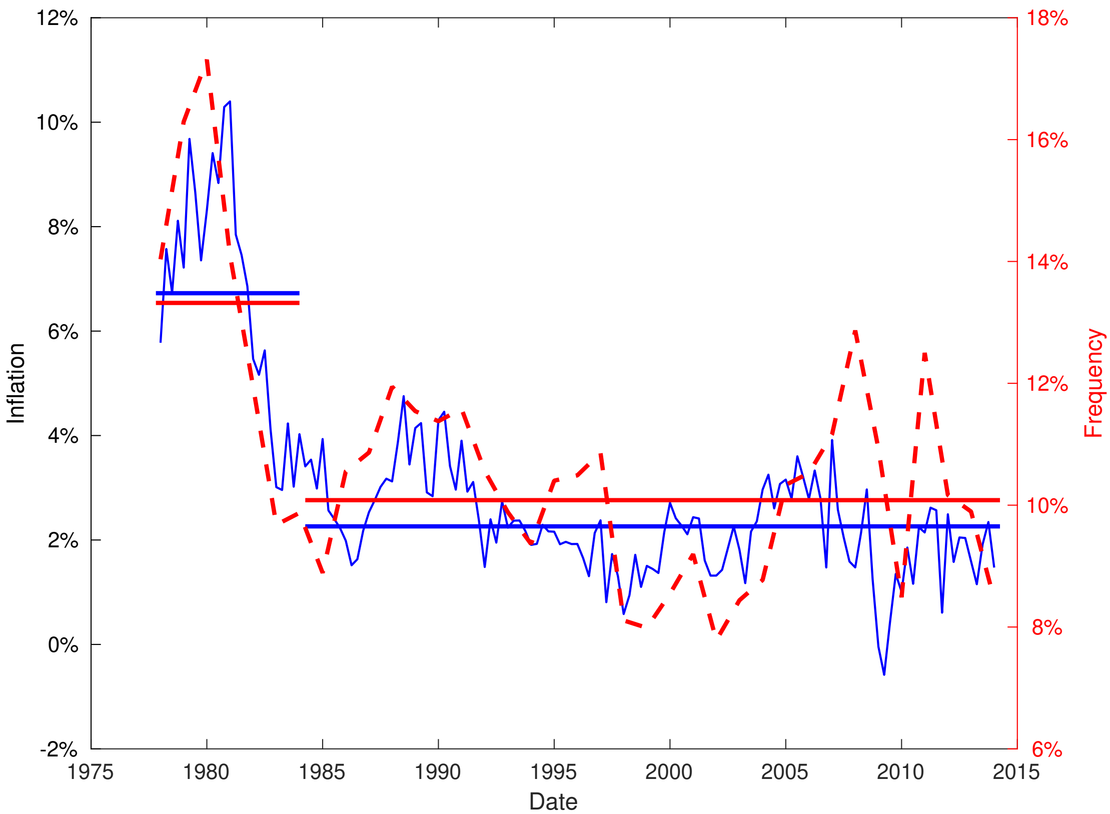
The table summarizes the parameter choices in our medium-scale model. They are identical to the relevant parameters in Coibion et al. (2012), with the exception of the Calvo parameter for which we assume the functional form $\theta = (1-(0.0726+1.04\overline{\pi}))^3$, where $\overline{\pi}$ denotes the steady-state inflation target.

Figure 1: Intended Gains in Policy Room When Raising the Target, and Effective Gains



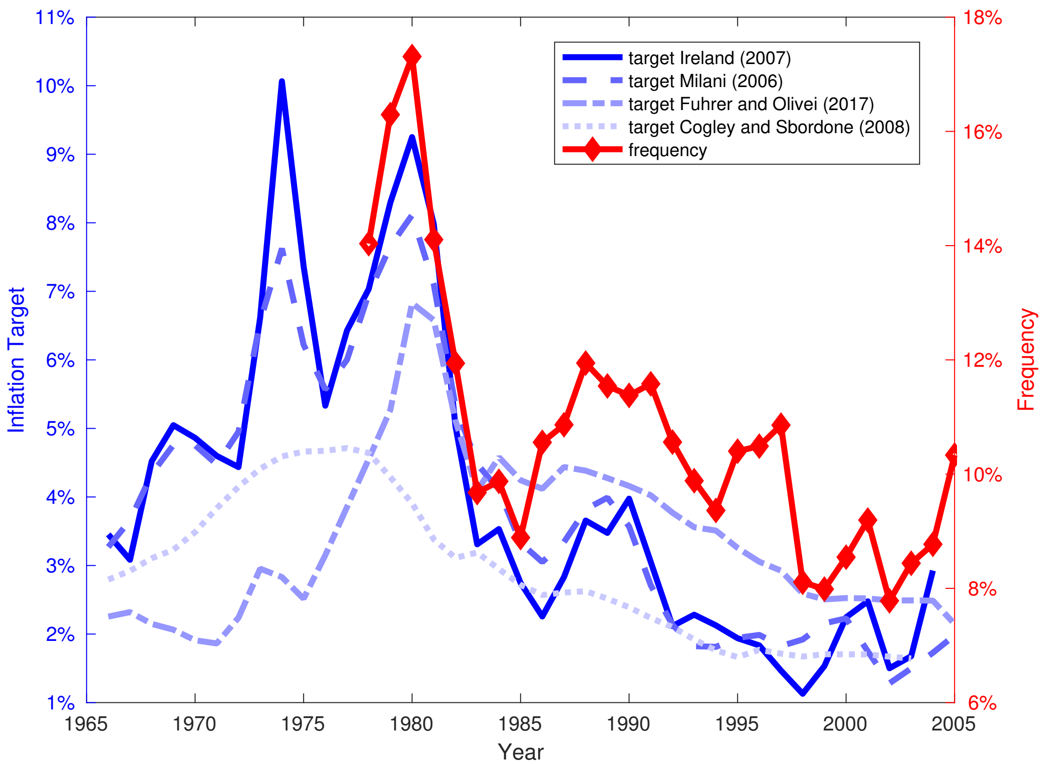
This figure plots the intended gain line in monetary policy room (45-degree line) and the effective gains line (below, solid). The effective gains line takes into consideration the increased price flexibility generated by a higher target. This is obtained using a state-of-the-art DSGE model (Coibion, Gorodnichenko, and Wieland 2012), calibrated using the empirically observed frequency of price adjustment for the U.S., 1978–2014.

Figure 2: Inflation and the Frequency of Price Changes Over Subsamples



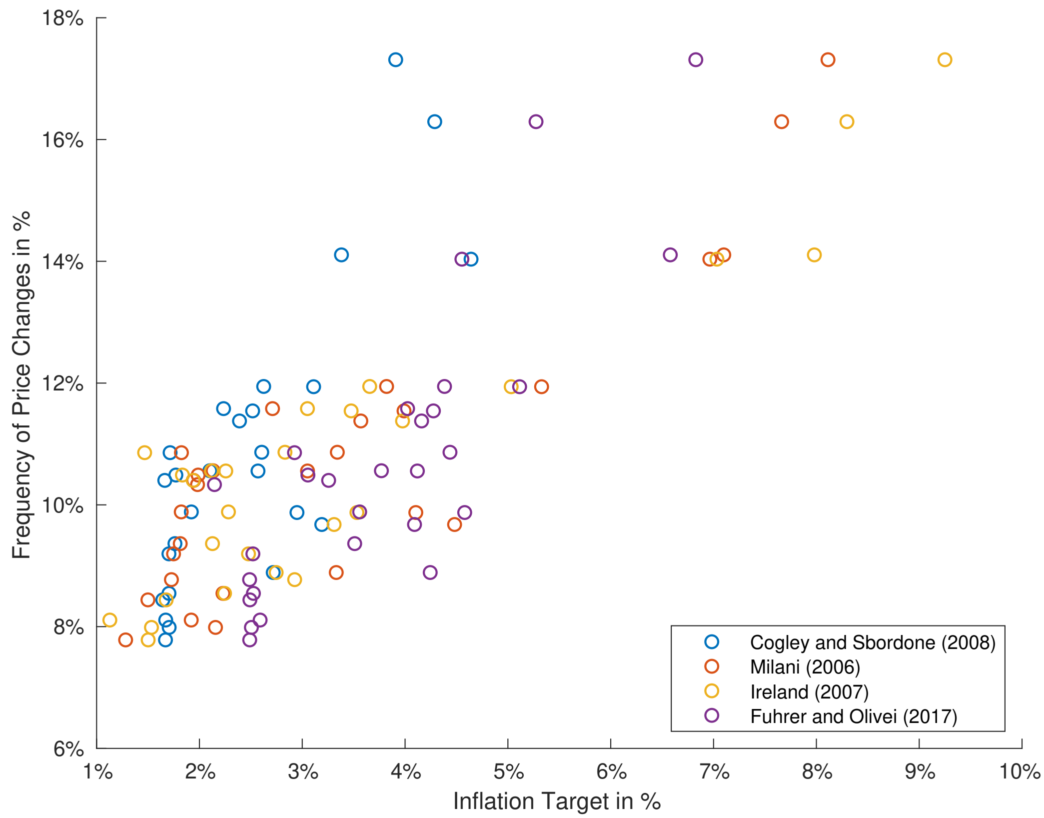
This figure shows U.S. inflation measured by the GDP deflator (left axis, blue solid line) and the monthly frequency of U.S. consumer price adjustment from Nakamura, Steinsson, Sun, and Villar (2018) (right axis, red dashed line). The subsamples are the pre- and post-Volker disinflation (pre-1984 and post-1984) periods.

Figure 3: Inflation Target and Frequency of Price Adjustment



This figure plots the times series, by year, of the average monthly frequency of price changes (red dashed line, right axis) against estimated inflation targets for the U.S. The frequency of price changes is based on micro price data from the Bureau of Labor Statistics (BLS), generously shared by Nakamura, Steinsson, Sun, and Villar (2018) (Figure 14 in their paper). Second, data on the time-varying inflation target comes from four different sources: the inflation target series underlying Figure 4 in Ireland (2007), the series underlying Figure 1 in Milani (2006), the series underlying Figure 3 in Fuhrer and Olivei (2017), and the series underlying Figure 1 in Cogley and Sbordone (2008).

Figure 4: Scatter Plot: Frequency of Price Changes and Inflation Target Measures



This figure shows a scatter plot, by year, of the average monthly frequency of price changes against estimated inflation targets for the U.S. The frequency of price changes is based on micro price data from the Bureau of Labor Statistics (BLS), generously shared by Nakamura, Steinsson, Sun, and Villar (2018) (Figure 14 in their paper). Second, data on the time-varying inflation target comes from four different sources: the inflation target series underlying Figure 4 in Ireland (2007), Figure 1 in Milani (2006), Figure 3 in Fuhrer and Olivei (2017) and Figure 1 in Cogley and Sbordone (2008).

Figure 5: Trend Inflation and Duration of Price Spells

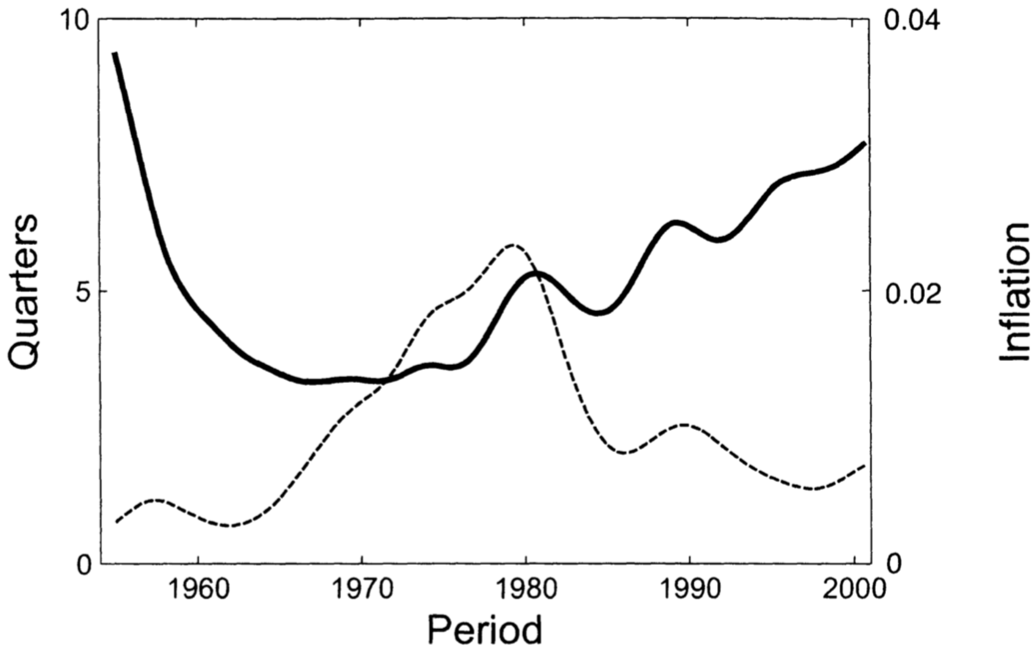
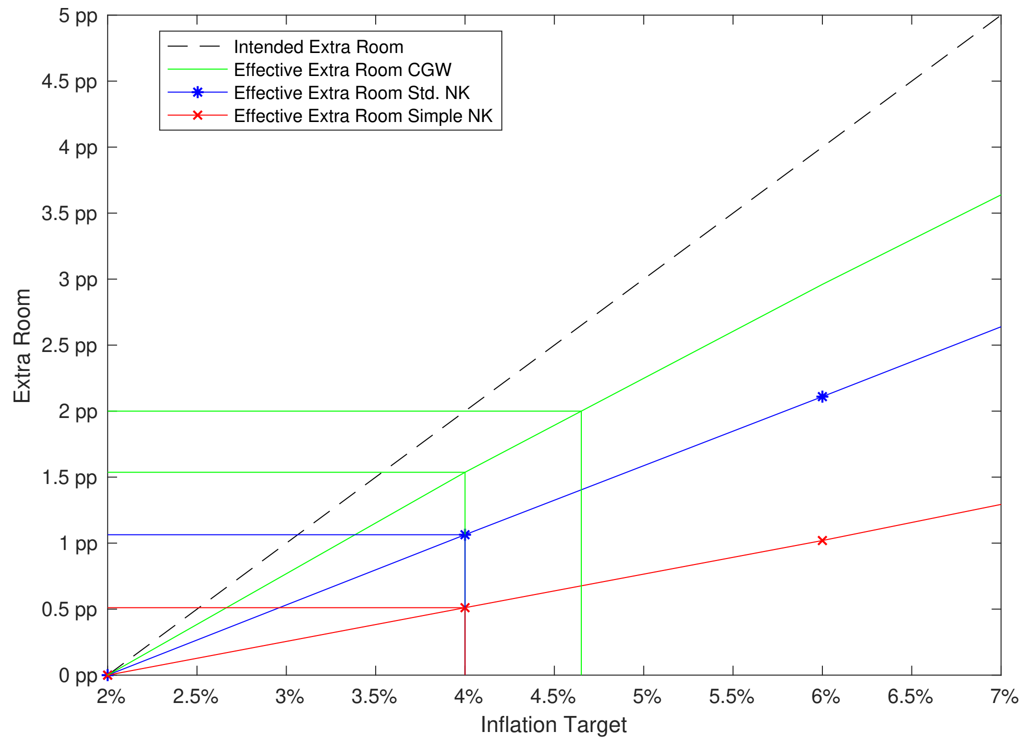


Figure 2.20
HP-Trend Price Rigidity vs. HP-Trend Inflation

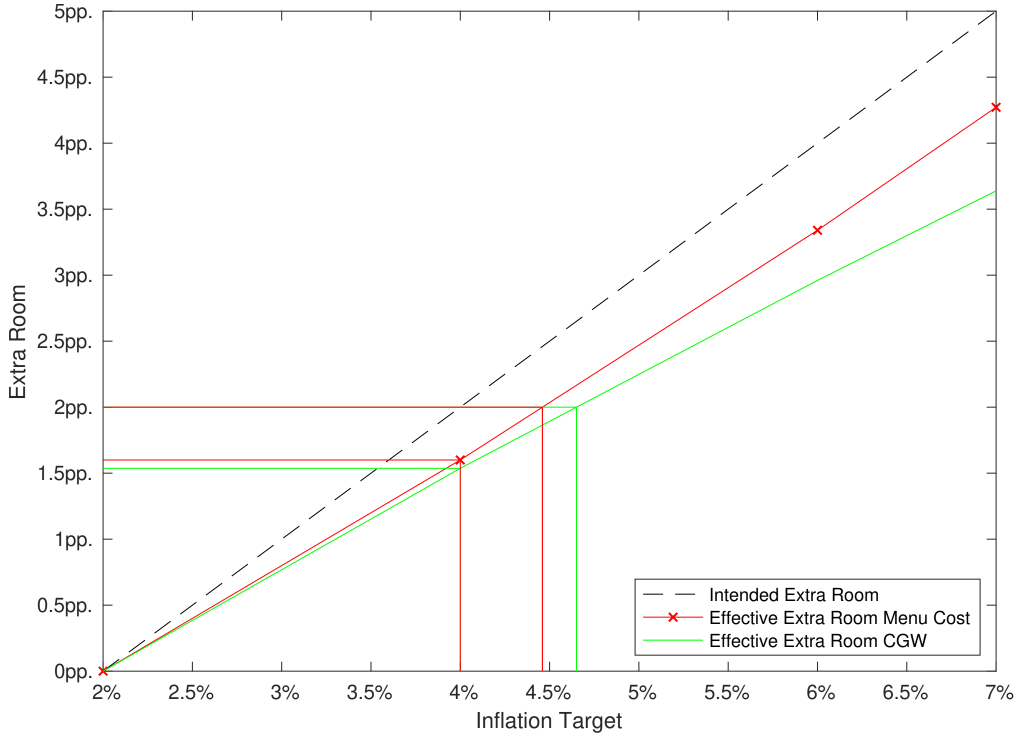
Source: Fernandez-Villaverde and Rubio-Ramirez (2007).

Figure 6: Intended and Effective Policy Room when Raising the Inflation Target



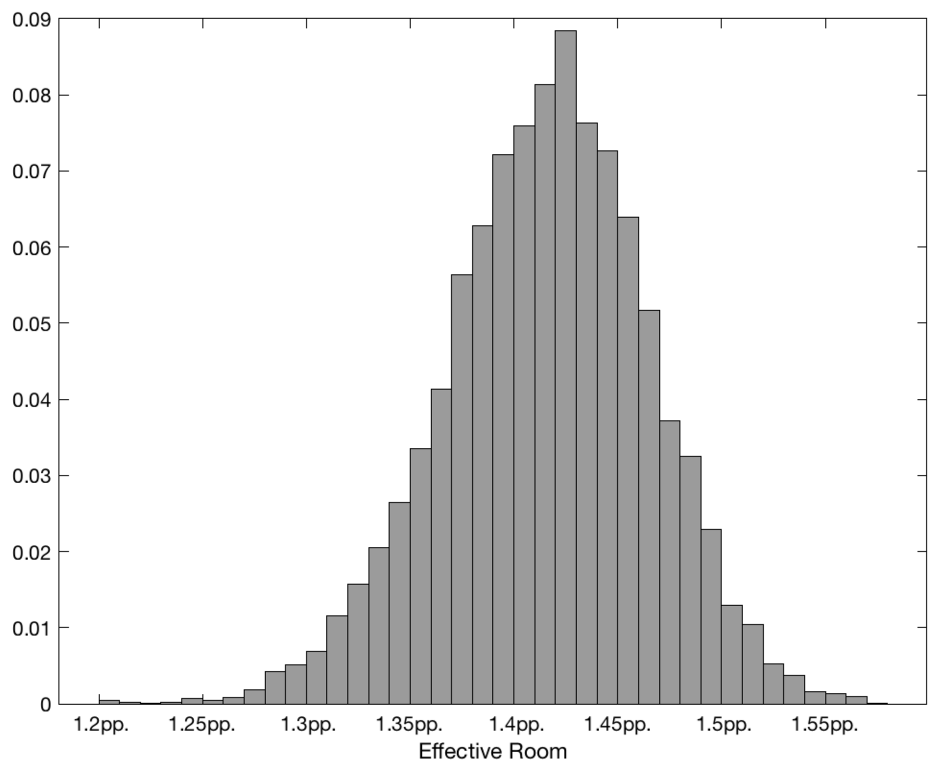
This figure plots the effective policy room gained in percentage points (pp.) against the inflation target, when moving away from a 2% baseline up to 7%. To compute effective room, we consider a large, negative demand shock $\zeta_t < 0$ that makes the nominal interest rate drop to zero upon impact, for a 2% target. We fix the size of this shock, and we ask, for different values of $\overline{\pi}$ by how much the interest rate can fall before hitting the ZLB. The difference is the effective policy room. We compute it for two version of the simple New Keynesian Model (see body for details) and Coibion, Gorodnichenko, and Wieland (2012).

Figure 7: Intended and Effective Slack when Raising the Inflation Target, Using a Menu Cost Model



This figure plots the effective policy room gained in percentage points (pp.) against the inflation target, when moving away from a 2% baseline up to 7%. To compute the effective room, we consider a large, negative demand shock $\zeta_t < 0$ that makes the nominal interest rate drop to zero upon impact, for a 2% target. We fix the size of this shock, and we ask, for different values of $\overline{\pi}$ by how much the interest rate can fall before hitting the ZLB. The difference is the effective policy room. We assume a menu cost pricing mechanism following Dotsey, King, and Wolman (1999), and present the comparison to Coibion, Gorodnichenko, and Wieland (2012).

Figure 8: Distribution of Effective Policy Room Gains when Raising the Target from 2% to 4%



This figure plots the empirically relevant distribution of effective room when going from a target of 2% to 4%. We draw 10000 joint draws from the joint parameter distribution estimated in the Smets-Wouters model for the following parameters: the Frisch elasticity of labor supply, the discount factor, the habit parameter, the steady-state growth rate, the interest rate smoothing coefficients, all systematic response-parameters in the Taylor rule. Then, we compute effective room in our main model for each draw, going from 2% to 4% steady state inflation. Effective slack is computed as described in Figure 6.

B Online Appendix: Estimation

For the estimation exercise, our analysis directly follows Smets and Wouters (2007) and the treatment in Bhattarai and Schoenle (2014). We refer the reader to the Smets and Wouters (2007) paper for a detailed description of their well-known model and data sources. Since our main goal is to obtain a joint distribution of key parameters from an empirically widely used and estimated model, we only focus on a description of key elements of the estimation and computation.

The data we use are the same as in Smets and Wouters (2007): The quarterly data range from 1966:QI through 2004:QIV and include the log difference of real GDP, real consumption, real investment, real wage, and the GDP deflator, log hours worked, and the federal funds rate. Each observable serves to pin down one of seven shocks. Our exercise in Table 1 additionally restricts the estimation to the post-1984 sub-period only.

Our Bayesian estimation and model comparison procedure for linearized models is entirely standard. As such, we evaluate the likelihood function using the Kalman filter, and compute the mode of the posterior. We use a Metropolis-Hastings algorithm to sample from the posterior distribution, with a scaled inverse Hessian as a proposal density for the Metropolis-Hastings algorithm.

We calibrate a few parameters as in Smets and Wouters (2007), and choose the same prior densities. The only exception concerns the price and wage markup shocks: Smets and Wouters (2007) combine the true markup shocks and various structural parameters (in particular, the price and wage Calvo parameters) when estimating markup shocks while we estimate the "true" markup shocks with appropriately rescaled priors. This difference is not essential, however, for the identification of parameters. We also find that a model with no price indexation fits the data better, and hence we set the parameter to zero. Overall, our parameters estimates come out to be extremely close to those of Smets and Wouters (2007).

Last, in order to compute an empirically relevant distribution of effective policy room, we do the following: First, we load our MCMC draws and disregard the first 10% as burn-in. Second, we draw 10,000 random sets of parameters from the estimated joint distribution of parameters. Finally, for each set of draws, we compute the effective, extra policy room we get when we move from

2% to 4% steady state inflation. The results are summarized in the histogram in Figure 8 in the main body of the paper.