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Some, but less than intended. The reason is a shift in the behavior of the private sector: Prices adjust more frequently, lowering the potency of monetary policy. We quantitatively investigate this channel across different models, based on a calibration using micro data. By raising the target from 2 percent to 4 percent, the monetary authority gets only between 0.51 and 1.60 percentage points of effective extra policy room for monetary policy (not 2 percentage points as intended). Getting 2 percentage points of effective extra room requires raising the target to more than 4 percent. Taking this channel into consideration raises the optimal inflation target by roughly 1 percentage points relative to earlier computations.

Keywords: timidity trap, zero lower bound, liquidity traps, central bank design, inflation targeting, Lucas proof, price stability.

JEL Classification: E31, E52, E58.

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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.[1] As a result of both these concerns, academics have contemplated raising the inflation target as a strategy to create more monetary policy 'room' to counteract large negative demand shortfalls.[2]

The logic of the argument in favor of a higher target is the following. A higher inflation target should induce higher steady-state inflation. This should increase the steady-state nominal interest rate. Therefore, starting from this steady state, there is more slack away from the ZLB constraint to lower nominal interest rates in recessions, 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, a one-to-one relation between the extra room for policy and the increase in the inflation target should only arise if the private sector does not adapt its behavior to the higher inflation target. However, clearly, an increase in the inflation target constitutes a significant policy action. Thus, it is highly likely that the behavior of the private sector will 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. The first reaction that comes to mind is the possibility that firms will adjust prices more frequently with a higher inflation target. This channel is theoretically plausible, and was first considered in a classic paper by Ball, Mankiw, and Romer (1988).[3] Indeed, when looking at historical U.S. micro data on the frequency of price changes, we find a clear relationship between this frequency and the inflation target over the 1970–2015 period.[4]

[1] And in fact, the U.S. entered another liquidity trap in March 2020, as part of the policy response to the economic downturn generated by COVID-19.

[2] See, for instance, the discussions in Blanchard, Dell'Ariccia, and Mauro (2010), Mishkin (2018), and Cechetti and Schoenholtz (2017). These authors differ with respect to their preferred solution. On secular stagnation, relevant references include Summers (2014) and Eggertsson, Mehrotra, and Robbins (2019). For small open economies, Svensson has suggested an alternative way to escape liquidity traps through the exchange rate, which in the later stage also includes inflation targeting (Svensson 2003; Jeanne and Svensson 2007).

[3] See also Romer (1990).

[4] To this end, we use a recent dataset put together by Nakamura, Steinsson, Sun, and Villar (2018). This dataset is based on micro price data from the Bureau of Labor Statistics (BLS), extended back to the 1970s.

Our main substantive contribution is to show that the strategy of raising the target to generate extra room gets considerable pushback from the private sector due to the increased price flexibility. Indeed, because with more flexible prices the potency of monetary policy decreases, the central bank is then forced to lower the policy rate by more in recessions. Hence, it actually pushes the rate closer to the ZLB. As a result, part of the extra room gained by raising the target is lost due to the way the private sector adapts to the new environment: the *effective* extra room is smaller that the *intended* extra room.[5]

Hence, our paper mainly focuses on the *positive* aspects of the constraint faced by a central bank attempting to simply gain more space away from the ZLB. This differentiates the paper from an active normative literature on the optimal level of the inflation target. Specifically, we have two main goals in this positive investigation. First, we want to produce a paper that can aspire to policy relevance. Thus, we have decided to focus closely on the class of models most commonly used for policy analysis: the class of (extended) New Keynesian (NK) models. A novel methodological contribution of our work is to discipline the extent of increased price flexibility using the micro data put together by Nakamura, Steinsson, Sun, and Villar (2018).[6] The way we do this allows for compatibility with the class of models most used in policy analysis. Second, we want to clearly visualize the mechanism in a simple theoretical framework. This allows for a clear analysis of the role of different monetary policy configurations in the answer to our question. For example, our analysis allows to derive a formal result showing how the monetary authority can raise the inflation target without losing space through the price flexibility backchannel. It also allows us to understand the role of optimal monetary policy in our context. For all these reasons, we start our investigation with a simple NK model, and transition to more realistic models later.

Specifically, in the simple NK model, we posit—in line with the data—that the value of the Calvo parameter (determining the frequency of price changes) is a function of the inflation target. Prices are more flexible (adjust more frequently) for higher targets. Under this assumption, the potency of monetary policy is crucially affected by the price flexibility channel. We refer to potency as the effectiveness of monetary policy when stabilizing output. Because price flexibility increases with the inflation target, the higher the target, the lower the Calvo parameter, and the lower the potency of monetary policy. Thus, for a given negative nominal demand shock, the nominal interest rate needs to fall by more in order to mitigate the effect of shock. At the limit of perfect price flexibility (Calvo parameter tending to zero), nominal demand shocks have no effects. But, this limiting case requires the nominal rate to move one-to-one with the nominal

[5]To be clear, our point is about the behavior of the nominal interest rate *away* from the ZLB. A different implication of increased price flexibility is that, *at the ZLB*, the real interest rate is more affected by deflationary spirals (Eggertsson and Woodford 2003; Werning 2012). Whereas this latter point has implications for our calculations of the optimal inflation target, it is not our focus of attention in this paper.

[6]For completeness, in an extension we also analyze what happens in the context of a state-dependent model. There, the increase in price flexibility is disciplined by the model. We find that this framework delivers similar answers.

shock, i.e. very large amounts.

The relevant question for the policy-maker concerns the strength of these effects in practice. One key contribution of the paper is to show that the variation of the degree of price stickiness observed in the U.S. micro data since the 1970s has powerful implications for the potency of monetary policy and the implied loss of monetary policy room with higher targets. We take different routes to quantify this fall in potency effect, and find that, robustly, it is important to take it into consideration.

In order to illustrate this finding, consider the following simple exercise. Suppose the inflation target in the U.S. were to be raised to the observed average inflation rate during the late 1970s. Given the available micro price data produced by Nakamura, Steinsson, Sun, and Villar (2018), we can compute the average frequency of price changes during this period, and use it to calibrate the corresponding potency of monetary policy, and resulting extra room. Figure 1 plots these using the baseline Coibion, Gorodnichenko, and Wieland (2012) model. As explained, the frequency of price changes is observed over two subsamples (marked by the circles): pre-1984 (higher trend inflation) and post-1984 (lower trend inflation). By linear extrapolation, we obtain that that an hypothetical increase in the target from 2% to 4%, as proposed by Blanchard, Dell'Ariccia, and Mauro (2010), generates an effective extra room of 1.28 pp. (not 2 pp. as intended). Furthermore, in order to get 2 pp. of effective extra room, the target needs to be raised to 4.89% (horizontal and vertical straight lines). Raising the target to the average inflation rate during the late 1970s of 6.73% would generate an effective extra room of 3.49 pp. (upper-right circle). The conclusion is that the higher price flexibility observed in the 1970s has quantitatively relevant implications for the potency of monetary policy, and for the gap between effective and intended extra room.

We confirm this statement by looking across several calibrations of the relation between the target and price flexibility, and across a range of models. In our baseline statistical exercise, we assume a functional form linking the Calvo parameter to the inflation target and estimate it. We use several sources for measures of the inflation target, including Cogley and Sbordone (2008) and Fuhrer and Olivei (2017). We find a strong, positive relationship between the probability of price adjustment and the inflation target during the 1970-2015 period. The economic magnitude is large: Our most conservative estimate indicates that a 1% increase in the inflation target is associated with an increase in the average monthly frequency of price changes in a given year by 0.98%. According to our estimates, when the inflation target 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.) We use this estimated relation in order to calibrate a state-of-the-art NK model, the Coibion, Gorodnichenko, and Wieland (2012) model. This model includes a Phillips curve that explicitly depends on the inflation target[7]. We also consider a menu cost model a la

[7]See, for instance, Cogley and Sbordone (2008) for a derivation.

Dotsey, King, and Wolman (1999) (in which the degree to which price stickiness varies with the inflation target is now disciplined by the model.) We confirm in all exercises that our mechanism is strong and quantitatively relevant.

In order to explore robustness further, our quantitative efforts also explore a large range of parametrizations of the Coibion, Gorodnichenko, and Wieland (2012) model. How large the loss in potency effect is, is somewhat sensitive—not surprisingly—to model parameters. However, 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 generating 10000 draws from the joint parameter distribution estimated in the Smets-Wouters model. Then, we compute the effective extra room in our main model for each draw, going from 2% to 4% steady state inflation. Our median estimate for effective extra room is 1.416 pp., with a mean of 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 or her intended extra room of 2 pp.

Given these results, a question that emerges is the deep reason behind the relevance of the increased price flexibility for the effective extra room figures we have obtained. Our theoretical analysis provides two answers for this. First, in the theoretical section of the model we derive an explicit formula for the effective extra room. This formula provides quantitative insights. Indeed, it shows that, unless the observed increase in the frequency of price changes is zero, one should expect the fall in potency effect to be quantitatively relevant for the computation of the extra room.[8] The second answer stems from the functional form of the slope of the Phillips curve in NK models.[9]

The specification of the monetary policy reaction function is of independent theoretical and policy interest. We investigate variations of the monetary policy rule and find that its specification 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 analysis has important implications for the optimal inflation target in the presence of the ZLB. The seminal contributions on this topic are by Billi (2011) and Coibion, Gorodnichenko, and Wieland (2012). We follow Coibion, Gorodnichenko, and Wieland (2012) closely. Building on their contribution, we analyze what happens if the ZLB is a chronic threat due to a low level of the natural rate of interest. Importantly, in this exercise, we combine a low natural rate with our empirically motivated relation between the inflation target and the frequency of price

[8] Even though the formula might be slightly different in the context of medium-scale models, we have confirmed its comparative statics prediction. This suggests the logic suggested by the formula carries through. See Section 4 for further details.

[9] This second insight does obviously not apply to our menu cost exercise. However, the first one does, as we have confirmed by comparative statics simulations.

adjustment. Our main finding is that the optimal target is approximately 1 pp. higher due to the loss-in-potency channel. With a lower potency, the nominal interest rate is more volatile. As a result, it falls more in the presence of large negative demand shocks. This provides a motivation for raising the inflation target by more, even though this may increase the welfare costs of inflation. Our exercise quantifies these trade-offs. The key to this result is the *interaction* between a low natural rate and the loss of monetary policy potency.[10]

A related argument for higher inflation in stagnant economies has been made in an important contribution by Schmitt-Grohe and Uribe (2013). There, downward nominal wage rigidity implies that inflation is useful to solve persistent unemployment problems. These authors emphasize temporary inflation, whereas our focus concerns permanent raises to the inflation target. Also, while our models do not emphasize labor market failures, we share a broader concern with the revitalization of stagnant economies.

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 four different, complementary exercises. Taken jointly, these constitute evidence of a strong, positive, and causal relationship between these two variables.

Specifically, we build up towards our main result by first looking at the relation between the frequency and inflation, rather than the inflation target. Second, we establish causality using a benchmark structural approach based on aggregate data. Our main exercise consists on exploring inflation targets, by relying on four different measures produced by other researchers. This includes the highly cited measure by Cogley and Sbordone (2008). Finally, in the online appendix we complement this by looking at other high-frequency estimates of the inflation target and the probability of price adjustment (the Calvo parameter) in the literature.

[10]The literature has recently considered a different approach to generating a positive and sizable optimal inflation target in NK models. Indeed, Adam and Weber (2019) generate an optimal inflation target between 1 and 3 percent in an environment that is free of welfare costs related to the ZLB. Their argument relies on differences in firm trend productivities. More recently, see also Adam and Weber (2020).

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 changes (Figure 14 in their paper). The series is annual, spanning 1978–2014.

Second, we also include several aggregate time series. We use the implicit GDP deflator as our measure of inflation.[11] 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.[12]

Third, to complement a simple measure of the inflation target we obtain from the inflation series mentioned above, we also include four other measures of the inflation target 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 **?**). 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 such as estimates of potential growth and the natural rate of unemployment from the Federal Reserve's Greenbook and Tealbook, along with survey and market inflation expectations, among others. In terms of data availability, all of our inflation target series stop right before the Great Recession (this includes the series by Fuhrer and Olivei 2017.)[13]

[11] Series ID GDPDEF.

[12] Same series IDs as Smets and Wouters (2007).

[13] 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.

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 the inflation target and the frequency of price changes. 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.[14] To this end, and following this distinction, we divide the aggregate inflation series and the frequency of price changes series into two plausible sub-samples: a high trend inflation sub-sample (1978-1984) and a low trend inflation sub-sample (1985-2014).[15]

We use the inflation series to measure the (implicit) target in each subsample by simply computing average inflation.[16] We then use the frequency of price changes and compute its average over each subsample. The question is whether we observe any sizeable change in the frequency of price changes 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 changes (more sticky prices).

Figure 11 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 changes 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 changes 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 changes. 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.[17]

[14] 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%).

[15] 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 changes.

[16] For brevity, we shall use the term "target" instead of "implicit target" throughout the paper. See Svensson (2010) for a comprehensive history of inflation targeting.

[17] $0.72 = \frac{13.32-10.08}{6.73-2.25}$

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

To do so, 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 including 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.[18]

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), or other major macroeconomic shifts across these subsamples.

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).

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 changes 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

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

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 such commonality, a few noticeable differences emerge from the 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 **?**, shown in darker blue). 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 rose to between 5% to 7% in the 1970s. The Cogley and Sbordone (2008) measure is the least volatile and slightly anticipates the Volcker disinflation, whereas the Fuhrer and Olivei (2017) measure turns around precisely in 1979.

As a further look at these data, Figure 9 in the online appendix shows a scatter plot of the average monthly frequency of price changes in a given year against the 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 average monthly frequency of price changes in a given year 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 in the online appendix 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 changes is higher.

A few papers in the recent literature, such as Nakamura and Steinsson (2008), Gagnon (2009) or Alvarez et al. (2018), have considered a related relationship: the relationship between the frequency of price changes and inflation. They all find a positive relationship between the frequency of price changes 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%.[19] 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 et al. (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 the online appendix[20] that our findings are somewhat diminished but remain quantitatively robust when we use the implied elasticity. In Section 4 we present further discussion on the reasons for this.[21]

3 Analytics Based on a Simple New Keynesian Model

The goal of this section is to theoretically analyze the loss of potency of the monetary policy channel within a simple model. We state a few formal results characterizing this channel, and study its relation to optimal policy.

Due to the widespread familiarity with this model, we present directly the log-linearized equations.[22] 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

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

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

[20]Appendix C.

[21]See p. 27.

[22]See Woodford (2003) for a detailed exposition.

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 the inflation target $\overline{\pi}$, $E[\,\cdot\,]$ 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.) In this model output y_t is equal to consumption:

$$y_t = c_t$$

The Phillips curve is

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

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. We use the assumption that firms perfectly index sticky prices to either past inflation or the inflation target in order to get an expression of the Phillips curve similar to the baseline case of a zero inflation target. Below, in the quantitative section 4.2, this assumption is relaxed.

The nominal interest rate rule is:

$$i_t = \phi\pi_t + \nu_t \tag{2}$$

where $\phi > 1$ is the systematic reaction of policy to inflation, and ν_t is an i.i.d. monetary shock.[23] 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:

$$x_t \equiv y_t - a_t$$

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

[23] For a thorough discussion of monetary policy rules and its relation to inflation targeting, see the classic contribution by Svensson (1999).

the output gap is

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

In steady state, the Fischer equation holds:

$$\bar{i} = \bar{r} + \bar{\pi} \tag{3}$$

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 $\bar{\pi}$:*

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

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 $\bar{\pi}$ or ϕ.[24] Moreover, conceptually there is no a priori reason why the Calvo parameter should not take different values depending on major changes to the economic environment.[25]

[24] 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.

[25] Actually, previous studies have found evidence of the opposite. In a landmark paper, Fernandez-Villaverde and Rubio-

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,

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

and using the fact that the slope of the Phillips curve κ is an increasing 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:

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

Ramirez (2007) estimate a set baseline models with time-varying parameters and find support for time-variation in the value of the Calvo parameter.

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*. (We shall come back to this point below.)

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. To 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 the inflation target $\overline{\pi}$. 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.[26] 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 follows.

Lemma 2 (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 more flexible prices. This observation allows to go back to our original question regarding the link between the inflation target and

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

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 $\epsilon \longrightarrow 0$):

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

We shall focus on the case

$$\epsilon \longrightarrow 0$$

which leads to the shock η^0, corresponding to the zero lower bound. Notice that our point is more general and a similar analysis can be applied to *any* lower bound on the interest rate.

Suppose then that η^0 hits economy 2. The question at hand is: By how much does i_2 move? And what is the remaining room? To answer this question, consider first the following definition.

Definition 2 *The* ***effective extra 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, in order to compute the effective extra room, one needs to take into consideration the change in the response of the policy rate. The key insight is that this is given by the change in the potency $\mathfrak{P}$, formally expressed as follows.

Proposition 1 (Formula for Extra Room) *Consider the shock $\eta^0 < 0$. Then,*

1. *The effective extra policy room is given by*

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

2. *The effective extra room is strictly smaller than the intended extra room:*

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

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

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

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 extra room then is equal to the intended extra room (equivalently, the change in the target $\Delta\overline{\pi}$), 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.

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

Corollary 1 (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.

Another question raised by these results is whether the monetary authority could engineer a way to increase the inflation target 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 2 (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 infinitely 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 responds very aggressively to 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 order to answer this question one needs a welfare criterion, which well-known, textbook, steps show that it boils down to minimizing welfare losses arising from inflation and output gap volatility; up to a quadratic approximation, welfare losses are:

$$\mathcal{L} = -\frac{1}{2}\left\{\left(1+\frac{\psi+\alpha}{1-\alpha}\right)\left(Var(y_t)+\frac{\varepsilon}{\kappa}Var(\pi_t)\right)\right\}$$

As the following result states, under output gap shocks solely, the optimal policy under commitment can be shown to amount to setting the nominal interest rate such that the real rate is equal to the natural rate. Thanks to the divine coincidence, this can be obtained as the interest rate rule (2) penalizes inflation deviations from target infinitely ($\phi \longrightarrow \infty$).[27]

Lemma 3 *Assume $\nu_t = 0$, $\forall t$. At the limit when $\phi \longrightarrow \infty$:*

$$\pi_t = 0; \quad x_t = 0; \quad i_t = \eta_t$$

$$\mathcal{L} = 0$$

(The proof is immediate by taking the limit of the explicit solution above.) In this case, clearly, 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. Therefore, the inflation target can be raised without losing monetary room through the loss of potency channel. The intuition is that a finite loss of potency is irrelevant when the monetary authority is infinitely hawkish.[28]

Although quite interesting as a theoretical benchmark, this a result with limited interest in practice. There are two reasons for this. First, a policy rate that moves one-to-one with nominal demand shocks is presumably unrealistically volatile. To give a sense of the magnitudes, consider a large shock capable of approaching an economy to the ZLB (a 2008 financial crisis or COVID

[27]How to obtain this rule is well known, see for example Svensson (2010).
[28]Notice the close link to Corollary 2.

lockdown scenario). This shock is likely to be close to -10%.[29] So, facing such a shock, the nominal rate would need to fall by 10 pp., a large amount.[30]

The second reason is simply that in realistic settings central banks do use inflation as a guide for policy, but have a bounded reaction to its fluctuations due to uncertainty regarding measurement or external shocks. Thus, the effects of price flexibility are likely to be present. Said differently, realistic interest rate rules as the one considered in the next section fit the data better.[31]

4 Quantitative Importance

We now show our quantitative results by studying three models conventionally used in policy analysis. First, we consider a textbook 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 consider a textbook New-Keynesian model with standard parameter values. We find a large and substantial gap between the intended and effective extra policy room as we increase the target.

[29] This is used purely for illustration. The idea is that a year after the 2008 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%.

[30] Notice, within the spirit of the paper, the difficulties of avoiding the ZLB under optimal policy. 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 in the presence of a large shock.

[31] The reader might wonder what would happen in the presence of markup shocks, which are typically used to justify the tradeoff between inflation and output gap volatility perceived by actual central banks. Even though this is not the focus of our paper, this tradeoff should crucially depend on the degree of price stickiness when markup shocks are microfounded. Therefore, raising the inflation target appears to have the virtue of easing this tradeoff via the increased price flexibility generated by raising the target (that is, a form of divine coincidence is again valid for $\mathfrak{f} \longrightarrow 1$.)

4.1.1 Model Setup

We consider two versions of this model. Both versions are identical to the model described in the previous section, with one slight difference. The first version features a Taylor rule, that is:

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

where ϕ_π is the weight the policy-maker places on inflation[32] and ϕ_y the weight he places on output, 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, $\phi_y = 0$ in the monetary policy rule, that is

$$i_t = \phi_\pi \pi_t + \nu_t \tag{5}$$

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_y 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 the literature.[33] For the Calvo parameter, we postulate the function (1) estimated above for the monthly frequency of price changes. 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 changes and the inflation target (Specification II based on Ireland 2007). This implies the following equation for the Calvo parameter at quarterly frequency:

$$\theta = (1 - (0.0742 + 0.98\overline{\pi}))^3 \tag{6}$$

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

4.1.2 Model Results

We now show that quantitatively, the effective extra room is substantially smaller than the intended extra room. To arrive at this result, we consider the same experiment as 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. Consistent with Definition 2, 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 0.51 percentage points (pp.) in

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

[33] Similar to Galí (2015), 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 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 (3)), the *effective* extra room is only 0.51 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 extra room is obtained.

The results are shown in Figure 4. 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 NK model; the blue curve represents the effective extra room according to the standard NK model. 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 $\phi_y > 0$, monetary accommodation is less necessary. Thus, the effective extra room is higher (1.06 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 5.79%, 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). Our model shares the common features of these and other modern NK DSGE models. The main deviation from the bare-bone NK model lies in incorporating trend inflation under imperfect indexation in the first place. We outline the relevant features of the model setup in the following and then discuss our quantitative exercise of increasing the inflation target.

4.2.1 Consumers

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

$$\max E_t \left[\sum_{j=0}^{\infty} \beta^j \left\{ \log\left(C_{t+j} - hC_{t+j-1}\right) - \frac{\varphi}{1+\varphi} \int_0^1 N_{i,t+j}^{\frac{1+\varphi}{\varphi}} di \right\} \right] \tag{7}$$

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 (7) 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 aggregate 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 at a 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 policy-maker 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 main simulation ($\epsilon_t^g = 0$).

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 extra room we get as we increase the target in this quantitative medium-scale model. Table 5 (online appendix) summarizes the parameters we use to calibrate the model.

Our main result continues to hold in this realistic model calibration. The green, dashed line in Figure 4 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 the effective extra room is only 1.56 pp. The intended extra room is 2 pp. Thus, the policy-maker is only able to achieve 76.5% of his or her intended extra room.

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 the effective extra room for each draw when going from 2% to 4% steady state inflation.

Figure 6 illustrates the resulting, empirical distribution of the effective extra 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 or her intended extra room of 2 pp. In effect, his or her median effective extra room is only 70.8% of the intended extra 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 (endogenous) 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

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

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 NK 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 follows the implementation in Coibion et al. (2012). It implies a menu cost of approximately 7% of steady-state output.

While our calibration is reasonable, one may pick other targets in order to calibrate menu costs. An obvious alternative might be to target a longer duration of 3.9 quarters at 2% inflation, as implied by our main estimated relationship between the frequency of price changes and the inflation target. However, we find that such a target implies a more than 10 times larger menu cost in terms of economic resources which is unrealistically prohibitively large.

With our preferred menu cost calibration at hand, we 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 probability of price adjustment now endogenously increases. Again, we ask how much effective extra room we get as we move to higher targets.

Our main result continues to hold in this model calibration that includes endogenous price adjustment. Figure 5 shows our main finding. Under the exact same parametrization used by Coibion, Gorodnichenko, and Wieland (2012) (I), we find that increasing the inflation target from 2% to 4% only provides 1.60 pp. of effective extra room, not the full intended extra room of 2 pp. The policy-maker's action, similar in magnitude as before, only achieves 79.5% of the intended extra policy room. This is a sizable gap between effective and intended extra room, albeit a bit smaller than what was obtained above in the context of NK models.

This latter effect is however not a generic feature of state-dependent models. For example, raising the parameter to internal habit formation from 0.70 to 0.90 (the value estimated via GMM by Fuhrer 2000) produces the following results (II). Increasing the inflation target from 2% to 4% only provides 1.30 pp. of effective extra room. The policy-maker's action, similar in magnitude as before, only achieves 65.0% of the intended extra policy room. Thus, the gap between the effective and the intended extra room is wider than in the baseline NK model by Coibion, Gorodnichenko, and Wieland (2012).

4.4 Discussion

As we have shown through a range of exercises, it is actually hard to find that the effective extra policy room when raising the target is close to the intended extra room. We have been able to identify two reasons for this finding.

The first is tightly linked to NK models. In fact, the loss of potency is given by the slope of the Phillips curve κ. This slope is an hyperbolic function of the Calvo parameter θ, and its slope is quite steep around the relevant range (say, for values around 0.60 and 0.80). Thus, a modest change in the probability of price adjustment is actually able to produce a significant change in the slope κ.

The second reason is more general, and it is an insight that comes from the formula for the effective extra room presented in Proposition 1. According to the formula, the difference between the effective and intended extra room, $\mathfrak{R}^{eff}(\eta^0) - \Delta\overline{\pi}$, is given by the product of the change in potency $\Delta\mathfrak{P}$, and the absolute value of the shock η^0. The key is that the latter is very large, because by definition it is a shock that brings the nominal rate to the ZLB. Thus, the change in potency would need to be negligible for $\mathfrak{R}^{eff}(\eta^0) - \Delta\bar{\pi}$ to be close to zero.[34] Thus, in all likelihood, one should expect that even modest changes in the probability of price adjustment when raising the target generate sizable differences between the effective and the intended extra room.[35]

4.5 The Optimal Inflation Target

While the main goal of our paper lies in pointing out the effects of an increased inflation target for the effective extra monetary policy room, we complement our positive analysis by showing that it also matters for normative analysis. We find that the optimal inflation target is approximately 1 percentage point higher near a 0 natural rate of interest if one allows the frequency of price changes to vary with the inflation target.

Using the Coibion, Gorodnichenko, and Wieland (2012) framework, we calibrate the frequency of price changes to respond to the inflation target as is implied by our estimated empirical relationship. Then, we vary the steady-state real interest rate, denoted r^*, between 0% and 5% and solve for the corresponding optimal inflation target $\bar{\pi}$.[36] We do so under 2 specifications: First, holding the frequency of price changes fixed, and second, allowing for the frequency to adjust according to our estimated relationship with the inflation target (6).[37] In line with our simple model, we only consider demand shocks in these simulations. Compared to Coibion et al. (2012), we raise the volatility of government and preference shocks to $\sigma_g = 0.0078$ (from $\sigma_g = 0.0052$) and $\sigma_q = 0.0036$ (from $\sigma_q = 0.0024$) such that we quantitatively match the relevant ranges of r^* and $\bar{\pi}$ in more recent studies as Andrade et al. (2019).

Our findings show a very clear effect of allowing the frequency of price changes to react to the inflation target, especially when the natural rate of interest is low. Figure 7 summarizes our key findings graphically. We see the varying-frequency specification has a steeper, more negative slope than the fixed-frequency specification. A lower natural rate of interest is associated with a higher optimal inflation target if we allow for the endogenous relationship. The intuition is the same as in Andrade et al. (2019): First a fall in r^* means a higher risk of hitting the ZLB so the inflation target increases to mitigate that risk. Second, the cost of hitting the ZLB increases if

[34] Numerical explorations confirm that for actual sizes of the shock in our simulations, the change in the potency would need to be much smaller that what we measure in the data (and simulate with the menu cost model) in order to have $\mathfrak{R}^{eff}(\eta^0) - \Delta\bar{\pi} \approx 0$.

[35] Because strictly speaking the formula holds only for the simple NK model, this reasoning may be misleading. However, we have indeed verified that the gap between the effective and intended gains largely depends on the size of the shock for all models.

[36] In our description, we use the terms 'steady-state real interest rate' and 'natural rate' interchangeably.

[37] Moreover, we choose the exogenous Calvo parameter such that it matches the frequency of price changes implied by our estimated relationship at the Coibion et al. (2012) baseline ratio of the steady state nominal rate to optimal inflation, which occurs at a natural rate of 3%. In other words, the two lines intersect at a natural rate of 3%.

we allow for more price flexibility because it amplifies the destabilizing real-interest rate effect at the ZLB.[38] Quantitatively, our main finding is that for a natural rate near 0 – arguably a relevant rate in the current environment – the optimal target that is approximately 1 percentage point higher if we allow the frequency of price changes to vary.[39]

5 Conclusion

There are two ways of interpreting our results.

A conservative interpretation is that our 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.[40]

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.

A more general contribution of our empirical and modeling efforts is to provide insights into the effectiveness of monetary policy and the volatility of nominal interest rates. Our application to liquidity traps seems of first order in the current environment, however, our results can be applied to other questions. For example, one possible application could look into the reasons for the highly volatile interest rates in the 1970s and early 1980s. We leave it to future work to explore these questions in the context of this framework.

[38] A closely related paper is by Blanco (2017), who exploits this channel in a menu cost setting.

[39] Given the steady-state relation of the real rate, the discount factor, and growth, the natural (or steady state) real rate can be varied by varying either the discount factor the the steady-state growth of productivity. This result is obtained by varying the discount factor. Figure 12 in the online appendix repeats the exercise by varying the steady-state growth rate of productivity. The results are similar.

[40] On a related vein, see Bernanke (2020). As commented therein, our argument suggests that such moderate increases could turn out to be of questionable use, after all.

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A Main 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

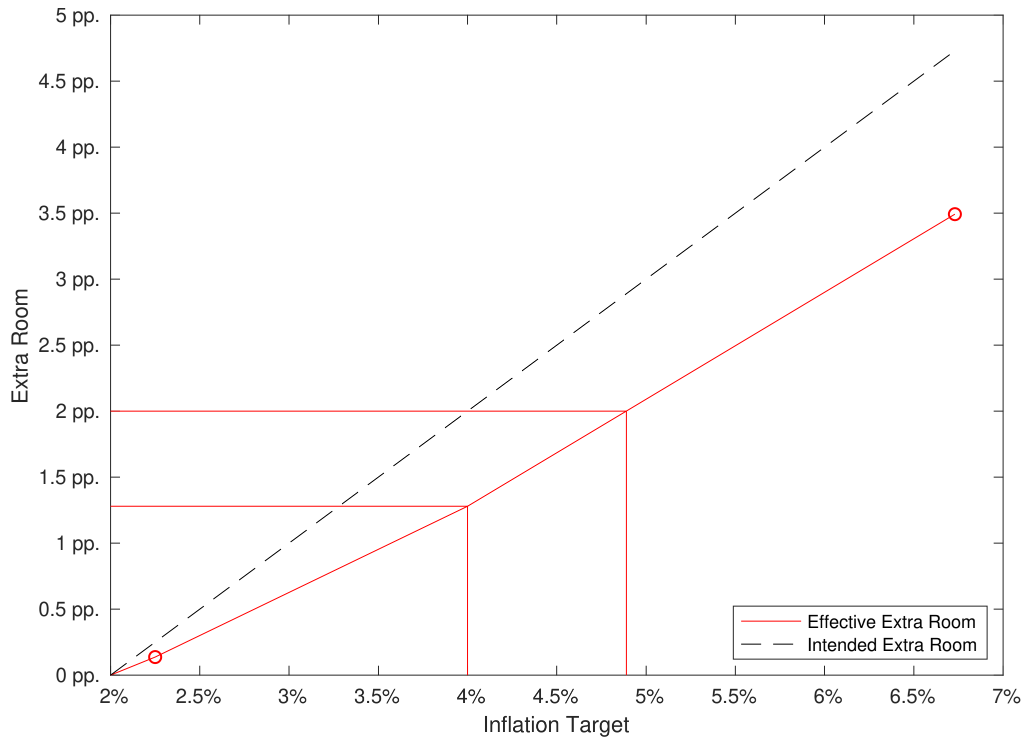
The table shows structural parameter estimates of the inflation target $\overline{\pi}$ and the Calvo parameter of price adjustment θ in the Smets and Wouters (2007) model over subsamples, U.S. data.

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

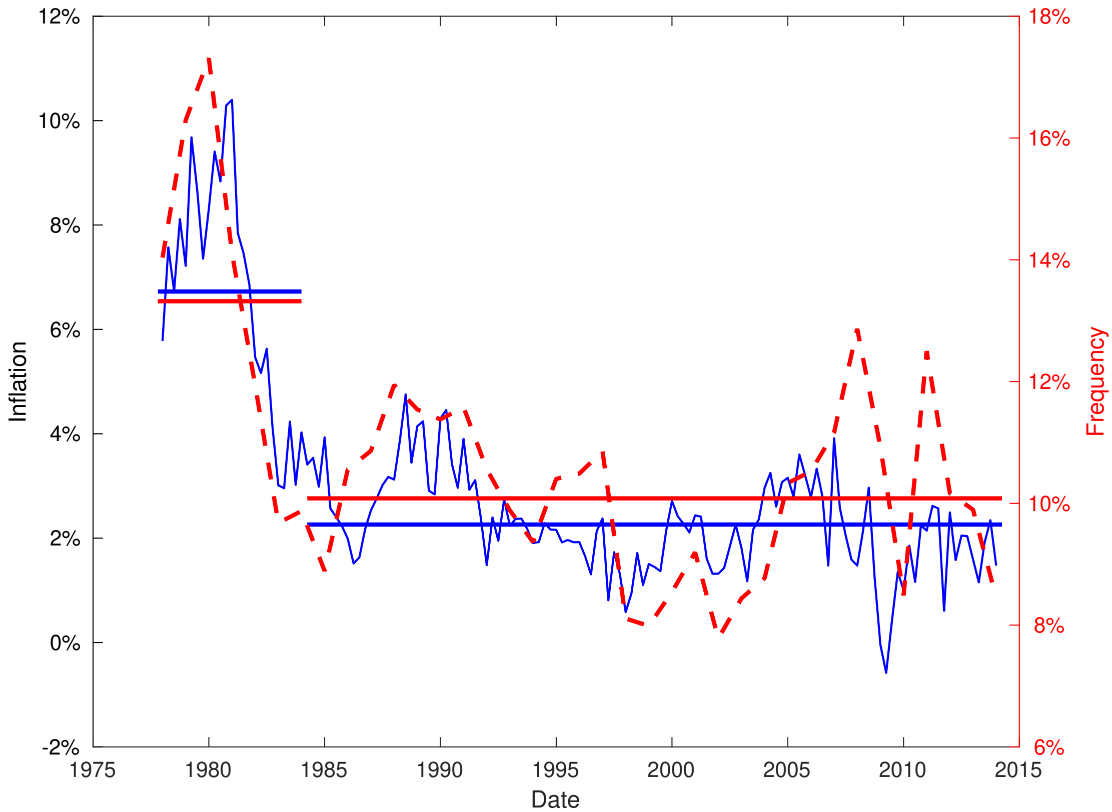
The table shows estimates of the following specification: $f_t = \beta_0 + \beta_1 \overline{\pi}_t + \epsilon_t$, where f_t is the annual average monthly frequency of price changes in %, and $\overline{\pi}_t$ the annual inflation target, also in %. We estimate this specification separately for our 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 **?**); 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.
** denotes significant at the 5% level.

Figure 1: Effective Extra Policy Room Obtained by Raising the Target



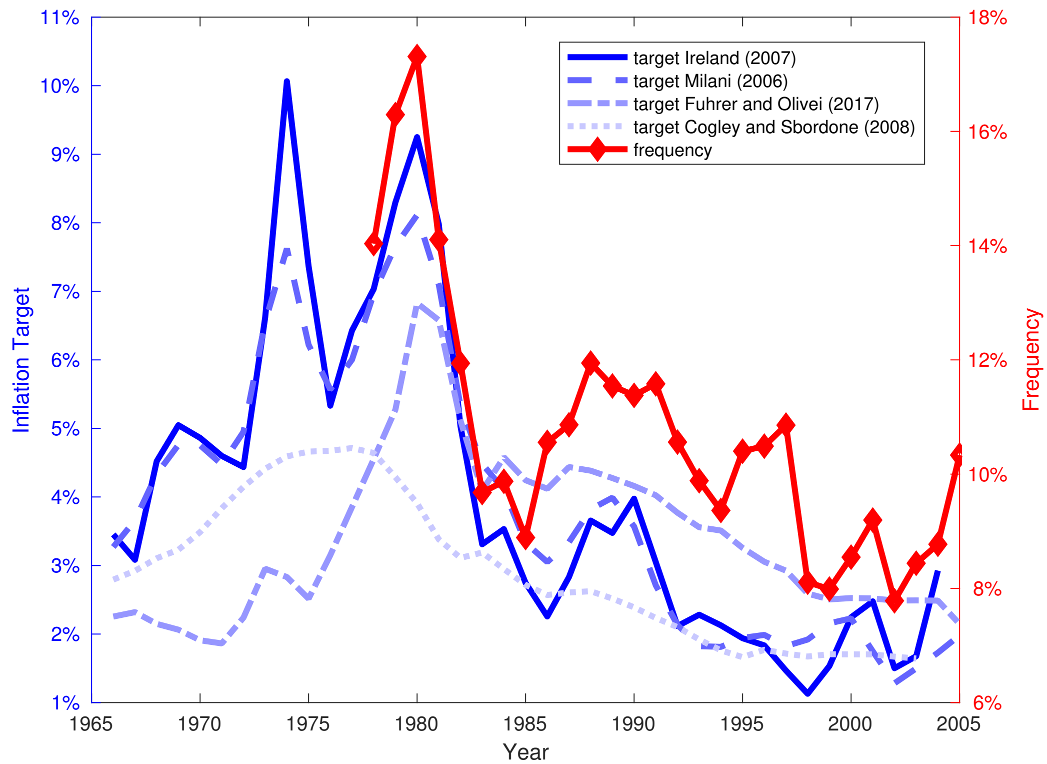
This figure plots the intended extra room line in monetary policy room (45-degree line) and the effective extra room line (below, solid). The effective extra room line takes into consideration the increased price flexibility generated by a higher target. This is obtained using a state-of-the-art DSGE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

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



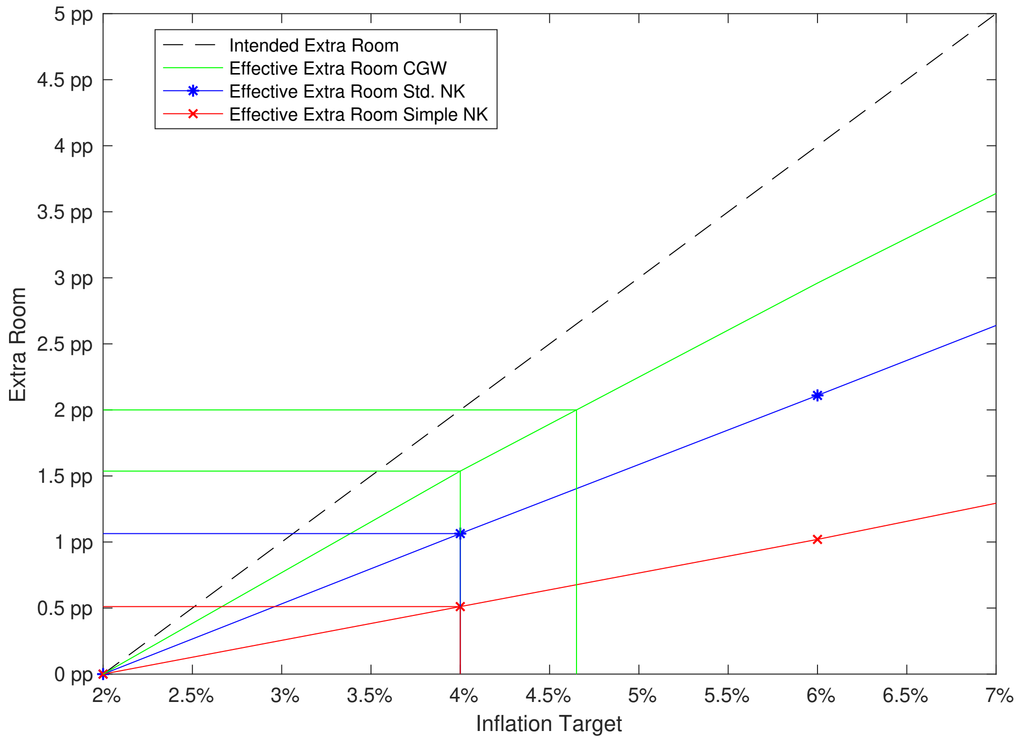
This figure shows U.S. inflation measured by the GDP deflator (left axis, blue solid line) and the average monthly frequency of U.S. consumer price changes from Nakamura, Steinsson, Sun, and Villar (2018) (right axis, red dashed line). The subsamples are the pre- and post-Volker disinflation (pre-1984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

Figure 3: Inflation Target and Frequency of Price Changes



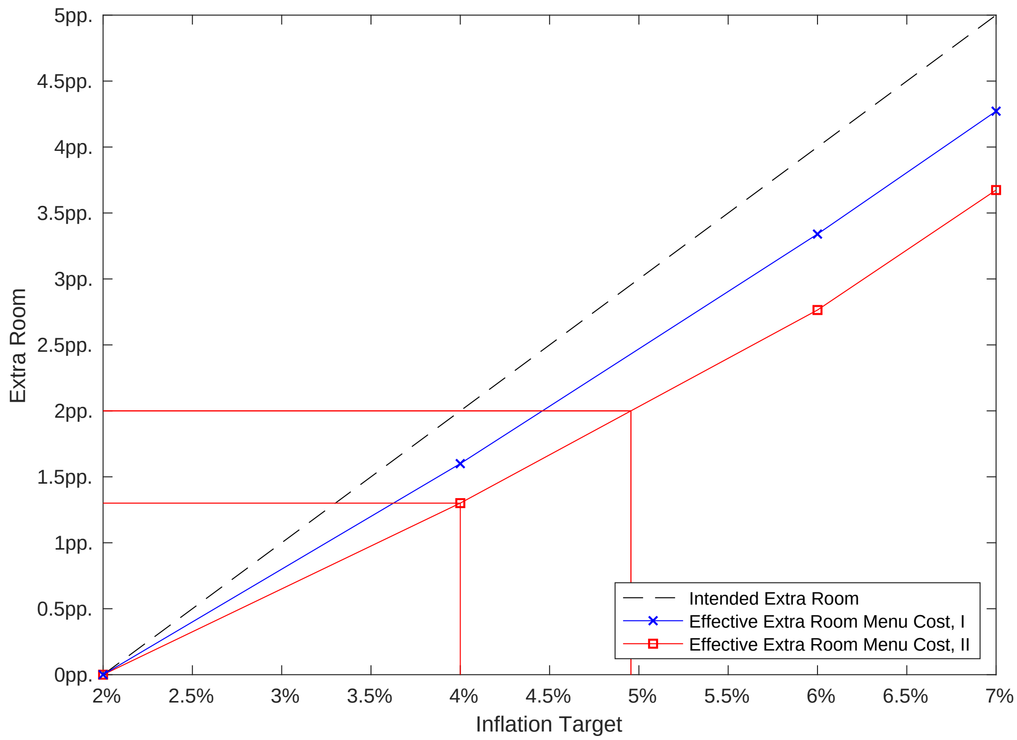
This figure plots the times series, by year, of the average monthly frequency of price changes (red dashed line, right axis) against estimated inflation targets for the U.S. The frequency of price changes is based on micro price data from the Bureau of Labor Statistics (BLS), generously shared by Emi Nakamura (Figure XIV in Nakamura et al. 2018). 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 (2019), the series underlying Figure 3 in Fuhrer and Olivei (2017), and the series underlying Figure 1 in Cogley and Sbordone (2008).

Figure 4: Effective Extra Policy Room Obtained by Raising the Target



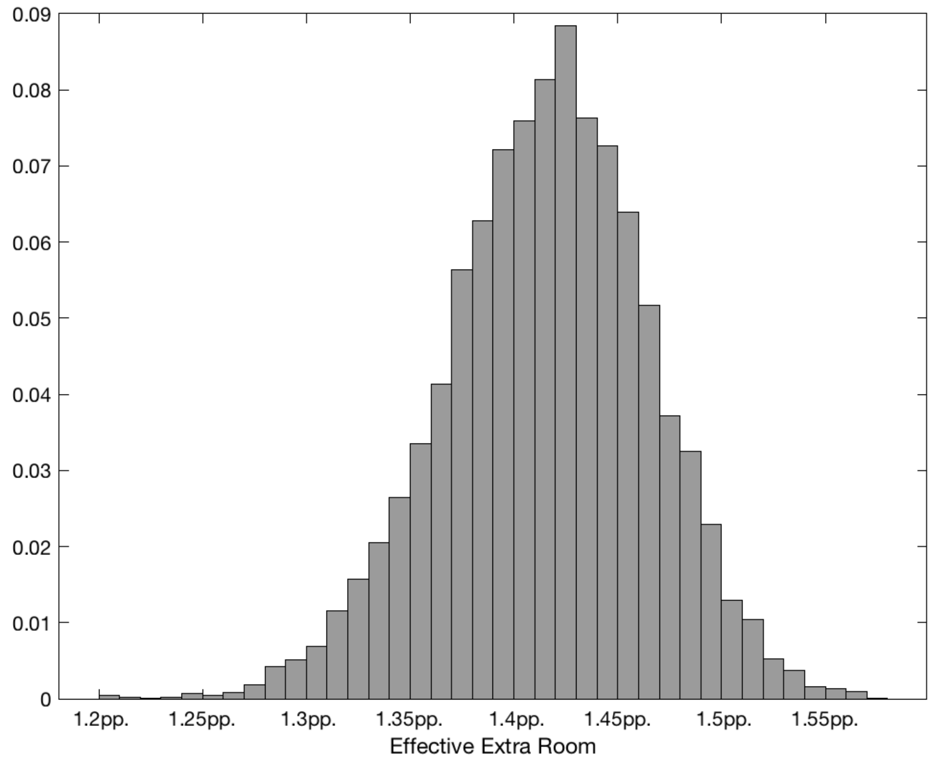
This figure plots the effective extra policy room gained in percentage points (pp.) against the inflation target, when moving away from a 2% baseline up to 7%. To compute the effective extra room, we consider a large, negative demand shock $\zeta_t < 0$ that makes the nominal interest rate drop to zero 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 extra 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 5: Effective Extra Policy Room Obtained by Raising the Target, Using a Menu Cost Model



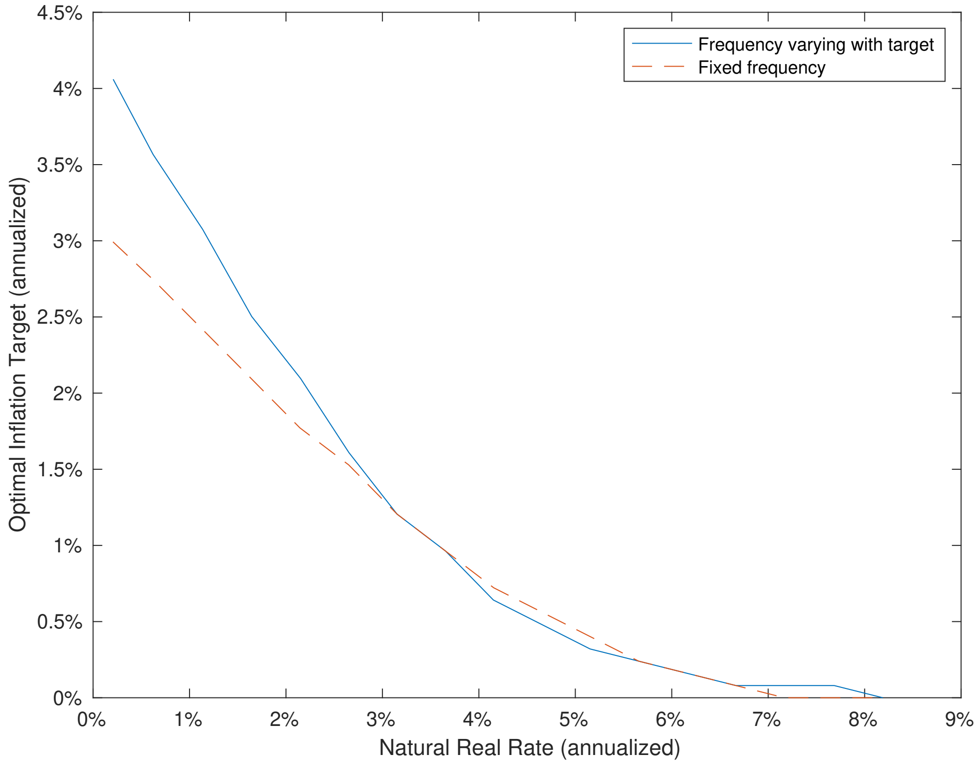
This figure plots the effective extra policy room gained in percentage points (pp.) against the inflation target, when moving away from a 2% baseline up to 7%. To compute the effective extra room, we consider a large, negative demand shock $\zeta_t < 0$ that makes the nominal interest rate drop to zero 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 extra room. We assume a menu cost pricing mechanism following Dotsey, King, and Wolman (1999). Case I presents the exact parametrization used by Coibion, Gorodnichenko, and Wieland (2012); Case II presents an alternative parametrization..

Figure 6: Distribution of Effective Extra Room Obtained by Raising the Target from 2% to 4%



This figure plots the empirically relevant distribution of effective extra 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 the effective extra room in our main model for each draw, going from 2% to 4% steady state inflation. The effective extra room is computed as described in Figure 4 (also explained in the body.)

Figure 7: Optimal Inflation Target



This figure plots the optimal inflation target against the (steady-state) natural rate of interest. We generate this relationship for two scenarios: 1) fixed frequency of price adjustment (blue, solid) and 2) frequency of price adjustment that varies with the inflation target (red, dashed). The natural rate of interest is changed by changing the discount factor (the online appendix shows the alternative case of changing the steady-state growth rate. See the body for a full explanation.)

[FOR ONLINE PUBLICATION]

Online Appendix For: "Raising the Inflation Target: How Much Extra Room Does It Really Give?"

Jean-Paul L'Huillier and Raphael Schoenle

June 23, 2020

B 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) probability of price adjustment, and for the (time-varying) inflation target. We regress the former on the latter in order to see if these 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 probability of price 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.[41]

For convenience, we reproduce Figure 2.20 from Fernandez-Villaverde and Rubio-Ramirez (2007) (Figure 10), 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 level at less 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 probability of price adjustment, and $\overline{\pi}_t^{FVRR}$ is the target (converted, for convenience, to annual).

[41] 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.

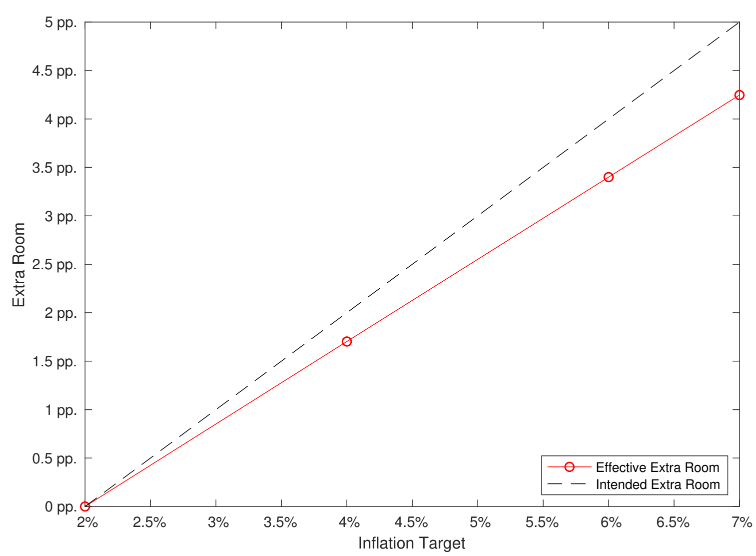
Table 4 presents the results. The first column presents the baseline regression over the whole sample considered by FVRR. The estimated elasticity β_1 is significant at the 1% level, and positive. The second and third column consider the robustness over the post-1970 and post-1984 subsamples. In both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

C The Relationship Between the Frequency of Price Changes and Inflation

A few papers in the recent literature have considered the relationship between the frequency of price changes and inflation. Consider for example the early regressions by Nakamura and Steinsson (2008) and Gagnon (2009), and more recently Alvarez et al. (2018). While such investigation does not consider the relationship of interest in our model, namely with the inflation target, the literature still finds a positive relationship between the frequency of price changes and inflation. This finding is supportive and complementary to our main empirical result, though quite distinct. As discussed, 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.

Nonetheless, we repeat our main quantitative exercise based on an estimated relationship between the frequency of price changes and inflation. In particular, we use the inflation data from Alvarez et al. (2018) and re-estimate our main specification 1 for "low" inflation rates as defined in Alvarez et al. (2018) as less than 14%. We then feed the estimated relationship into our model as before. Figure 8 shows our findings. As we increase the inflation target, we see once again that the effective extra room is less than the intended extra room. The gap between the two is smaller than what what is obtained by looking at the U.S. data, but it is quantitatively meaningful nonetheless. We discuss on p. 27 the reasons for this.

Figure 8: Robustness to Alternative Main Relationship



D 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, 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 extra 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 6 in the main body of the paper.

E Extra Tables and Figures

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 $\overline{\pi}_t$ 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 **?**); 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.
** denotes significant at the 5% 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%

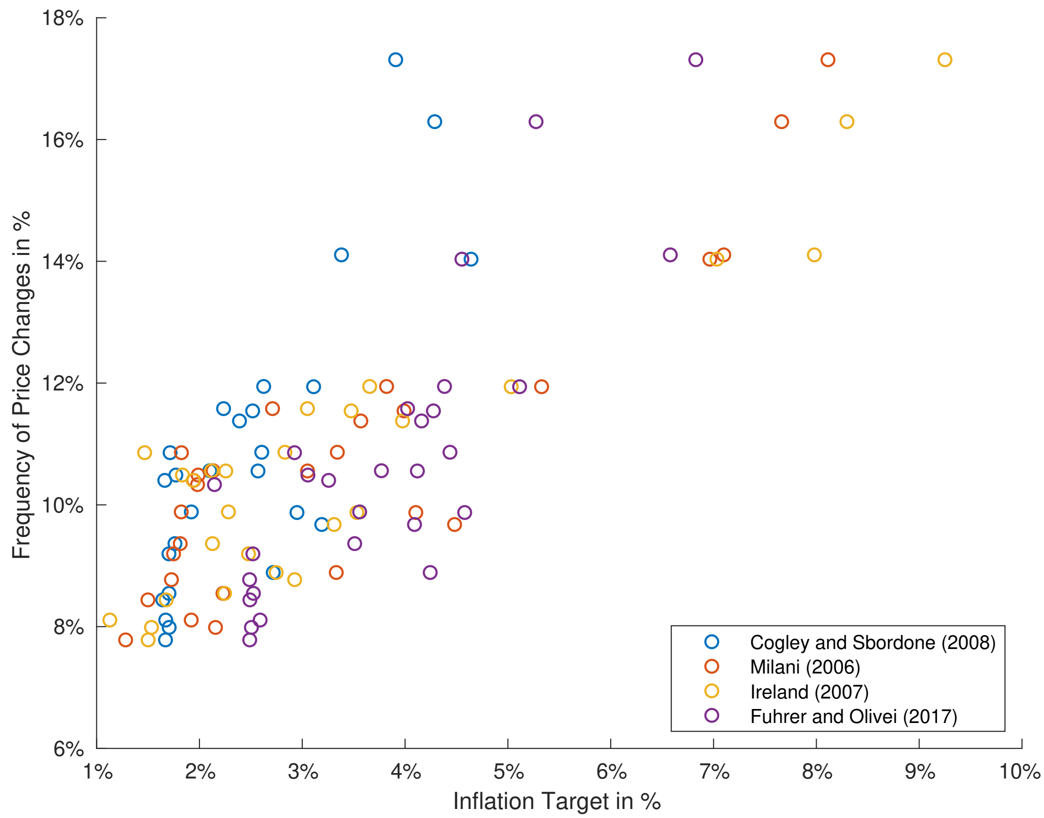
The table shows estimates of the following specification: $f_t^{FVRR} = \beta_0 + \beta_1 \overline{\pi}_t^{FVRR} + \epsilon_t$, where f_t^{FVRR} is the quarterly frequency quarterly average of price changes estimated by Fernandez-Villaverde and Rubio-Ramirez (2007) in %, and π_t^{FVRR} the annual inflation 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 9: 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 Emi Nakamura (Figure XIV in Nakamura et al. 2018). 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 **?**), Figure 3 in Fuhrer and Olivei (2017) and Figure 1 in Cogley and Sbordone (2008).

Figure 10: Trend Inflation and Duration of Price Spells

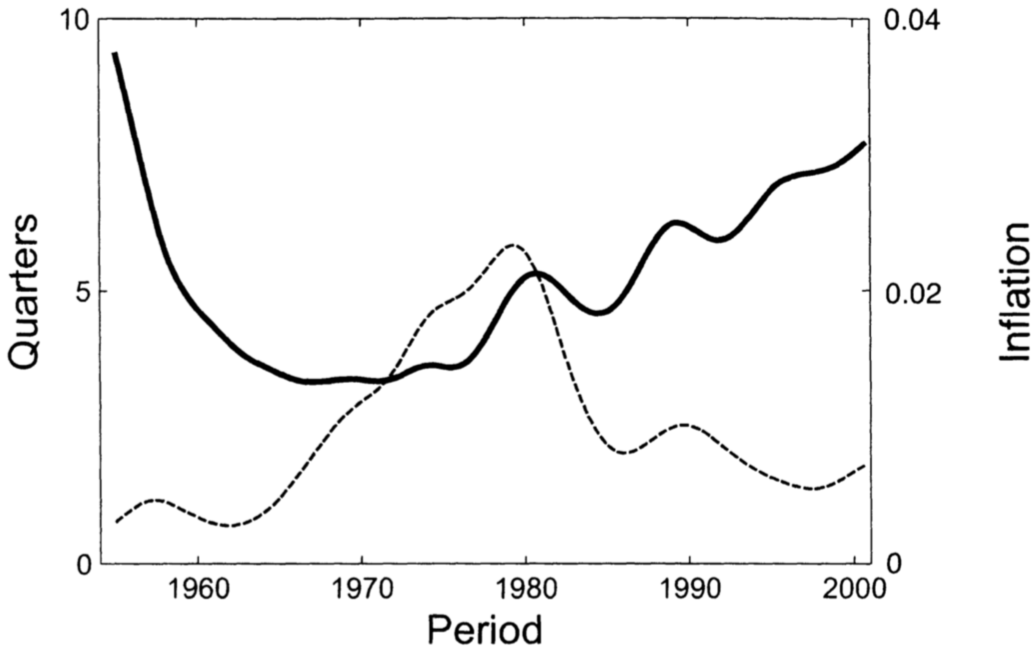
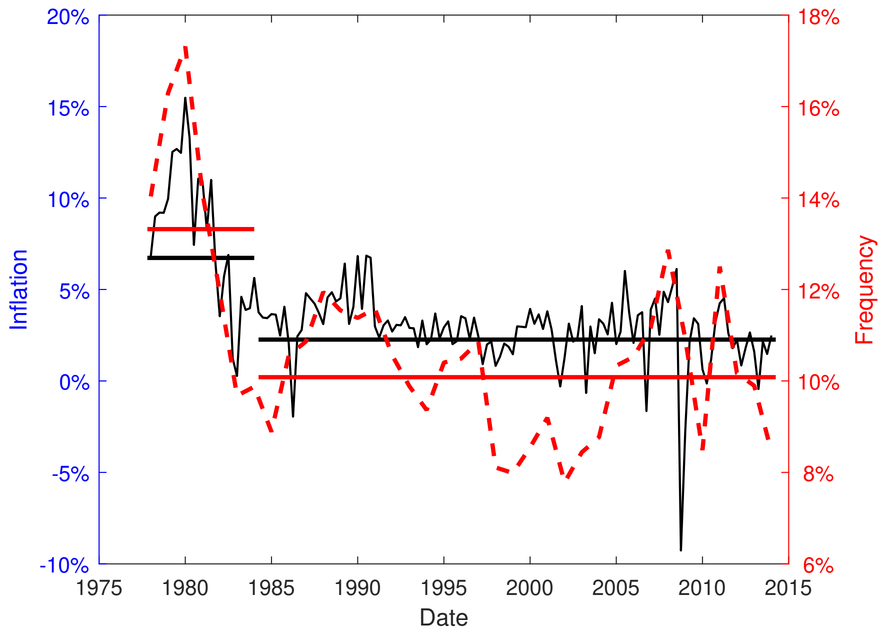


Figure 2.20
HP-Trend Price Rigidity vs. HP-Trend Inflation

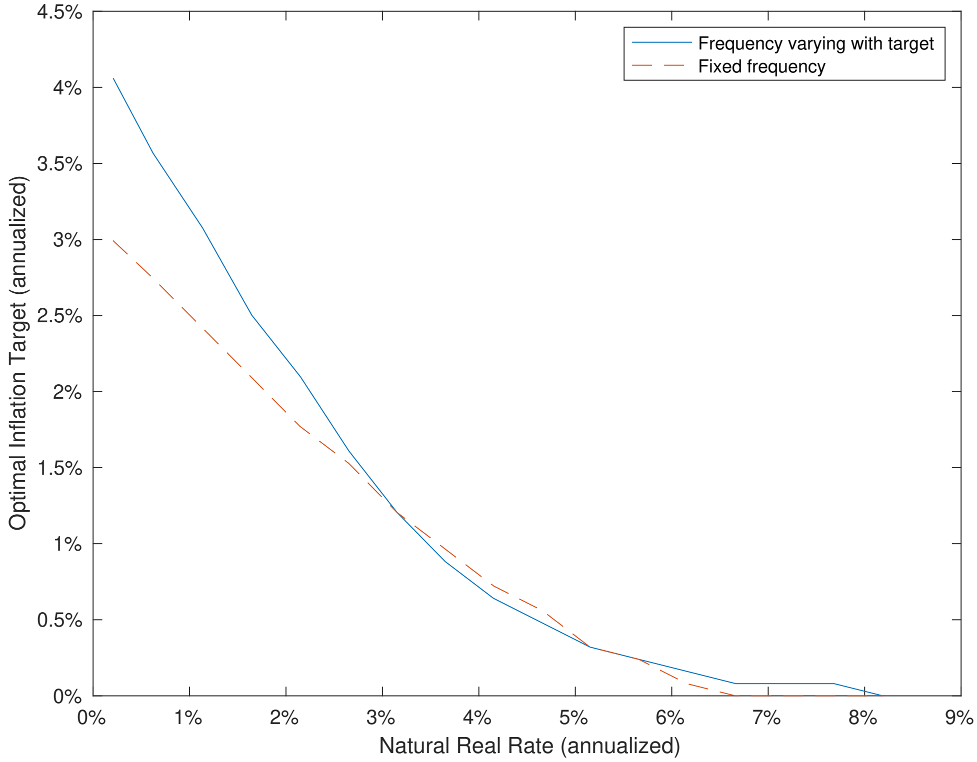
Source: Fernandez-Villaverde and Rubio-Ramirez (2007).

Figure 11: Inflation and the Frequency of Price Changes Over Subsamples: CPI Inflation



This figure shows U.S. inflation measured by the CPI (left axis, black solid line) and the average monthly frequency of U.S. consumer price changes 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 12: Optimal Inflation Target: Alternative Experiment



This figure plots the optimal inflation target against the (steady-state) natural rate of interest. We generate this relationship for two scenarios: 1) fixed frequency of price adjustment (blue, solid) and 2) frequency of price adjustment that varies with the inflation target (red, dashed). The natural rate of interest is changed by changing the steady-state growth rate. See the body for a full explanation.)