# Monitoring Money for Price Stability

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## Abstract

In this paper, we use a simple model of money demand to characterize the behavior of monetary aggregates in the United States from 1960 to 2016. We argue that the demand for the currency component of the monetary base has been remarkably stable during this period. We use the model to make projections of the nominal quantity of cash in circulation under alternative future paths for the federal funds rate. Our calculations suggest that if the federal funds rate is lifted up as suggested by the survey of economic projections made by the members of the Federal Open Market Committee (FOMC), the fall in total currency demanded in the next two years ranges between 50 and 200 billion. Our discussion suggests that specific measures by the Federal Reserve to absorb that cash could be worth considering to make the future path of the price level consistent with the price stability mandate.

**Keywords:** Inflation, Money Demand, Currency in Circulation
**JEL codes:** E31, E41, E51

# 1 Introduction

At the end of 2015, the Federal Reserve increased the target for the federal funds rate for the first time since the outbreak of the financial crisis in the third quarter of 2008. This decision ended an eight-year period of essentially zero short-term nominal interest rates. At the same time, the current forecast of the Federal Open Market Committee (FOMC) is that the federal funds rate will continue growing in the following quarters, stabilizing a value between 3% and 4% over a period of two to three years.[1] This process entails a formal requiem to the liquidity trap period. But it does not entail a departure from the 2% target for inflation that the Federal Reserve has made explicit a few years ago. The most likely prevalent view is that the shocks that justified very low nominal rates are dissipating, so the new conditions require higher nominal interest rates to be consistent with that target.

The purpose of this paper is to use an inventory theoretic model of money demand to compute the path for monetary aggregates that is consistent with the 2% target for inflation, given the expected path for short-term nominal interest rates.[2] Our computations imply that the contraction in nominal monetary aggregates can be substantial. In particular, they imply that up to 150 billion may have to be absorbed by the Federal Reserve within the next two years.

The policy implications of these numbers depend on the adopted view regarding the determination of inflation. This discussion is mostly theoretical.

If one adopts the dominant view in central banks, represented by the Taylor principle, these numbers are just a reflection of intellectual curiosity. Given a path for the short-term nominal interest rates, the price level is uniquely determined by the interaction between the Fisher equation and the Taylor rule. Monetary aggregates do not play a role in either of those two equations. Given that same path for the short-term nominal interest rate and the price level so determined, a money demand equation, if there is such a thing,

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[1]The current forecasts imply long-run values that are lower than the December 2015 forecasts.

[2]We also need to feed into the model the expected path of real output. We use the same forecast that the FOMC uses.

determines the evolution of monetary aggregates. Under this view, there is no reason why the Federal Reserve should modify its policy of focusing exclusively on the short-term interest rate, disregarding any movements in monetary aggregates. According to this view, the numbers in this paper are, indeed, just a reflection of intellectual curiosity – which attracts the interest of very few!

On the other hand, if one adopts a more old-fashioned view, in which the interest rate is an intermediate target to control the monetary aggregates, which themselves eventually affect inflation, the numbers in this paper suggest that explicit mechanisms to absorb cash may be considered as complementary policy tools during the transition to a new long-run value for the federal funds rate.

The evidence during the last two decades, in which central banks in many countries effectively controlled inflation using short-term interest rates and without paying attention to monetary aggregates, could be used as evidence in favor of the dominant view. We believe this is not necessarily the case. We argue in this paper that the changes in monetary aggregates are very small when interest rates are within the range they exhibited during the two decades prior to 2008. On the contrary, the changes that should occur in the next two years are, according to the theory and the evidence presented here, much larger than any changes seen in many decades. Put it differently, the inflation targeting practices have never before been tested during periods of relatively large changes in monetary aggregates, as we argue ought to be the case in the next two years if the FOMC does increase the federal funds rate, as it forecasts so.

Research on monetary aggregates lost steam after the breakdown of the remarkably stable relationships between nominal income and short-term interest rates that were present in the eighties in the United States. However, recent research has shown that once regulatory changes - which also occurred in the early eighties - are taken into account, the stability of the money demand relationship remains intact.[3] At the same time, a comparison

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[3]See Lucas and Nicolini (2015).

across countries shows that instability is not present in many other economies.[4] In this paper, we take the stability of money demand as given and use a simple theoretical model, calibrated to the United States, to quantify the effect of an increasing path of nominal interest rates on the nominal value of monetary aggregates.

In Section 2 we describe the model, which is a simplified version of the one presented in Lucas and Nicolini (2015) (LN hereafter). In Section 3 we calibrate the model for the period 1980 to 2015 and evaluate the performance of the calibrated model to reproduce the evidence from 1960 to 1980. In Section 4 we present the projections for monetary aggregates up to 2021. A final section contains a discussion of the policy implications of the exercise and concludes.

## 2   The Model

The model we use is a simplified version of the one used by Freeman and Kydland (2000). It is a cash-in-advance model with two means of payment: currency and checks. Households consume a continuum of different goods in fixed proportions. Goods come in different "sizes," with production costs and prices that vary in proportion to size. Let $z > 0$ be the size of a good, $F(z)$ the cumulative distribution function of sizes, and let $f(z)$ the corresponding density function, with mean $v = \int_0^\infty z f(z) dz$. To make use of this framework we situate this payments system within a simple general equilibrium cash-in-advance model. We focus on the steady state of a deterministic system.

There is a continuum of identical households with the common preferences

$$E_0 \sum_{t=0}^{\infty} \beta^t U(x_t). \tag{1}$$

Goods are not storable. Each unit of $x$ comprises the full spectrum of goods $z$ in the

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[4]See Benati et al. (2016).

proportions given by the density f:

$$x_t = \frac{1}{v} \int_0^\infty x_t z f(z) \, dz.$$

Each household consists of a producer/seller who produces goods that it sells to other households and a shopper who buys goods from other households. No household can consume its own production.

Goods can be purchased with cash (currency) or check. We assume that there is a fixed cutoff value for $\gamma > 0$ such that goods larger than $\gamma$ are paid for by check and the rest are paid for in cash.[5] There is a constant fixed cost of processing a check. Check processing entails a labor cost that is proportional to the number of checks: $k[1 - F(\gamma)]$.

We assume, in the manner of Baumol (1952) and Tobin (1956), that households choose the number of times they make portfolio adjustments during a period. In particular, we assume that if the household makes $n_t$ exchanges between bonds for transactional assets within the period, it must pay a cost of $\phi v(s^t) n(s^t)^\sigma$ in units of time, where $v(s^t)$ is an exogenous stochastic process and $s^t$ represents the state of the economy at time t. The variable $v(s^t)$ thus introduces randomness in the demand for money. The Baumol-Tobin case obtains when $\sigma = 1$, so the cost is a linear function of the number of trips to the bank. A household has one unit of time each period, divided between bank trips and goods production time. The marginal product of labor (and the real wage) is given by a stochastic process $y(s^t)$. In equilibrium, production will therefore be

$$y(s^t)(1 - \phi v(s^t) n(s^t)^\sigma) = x(s^t) \left[1 + k \left(1 - F(\gamma)\right)\right].$$

At the beginning of a period, a household begins with some nominal wealth $W(s^t)$ that can be allocated to transactional assets (cash $C(s^t)$ and deposits $D(s^t)$), risk-free

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[5]In Freeman and Kydland (2000) and in LN, households endogenously choose that cutoff value. As argued in LN, the model implications for the cash-to-deposits ratio are not exhibited by the data at very low interest rates. We leave the task of modifying the model to account for that behavior to future research.

government bonds $B(s^t)$, or state-contingent nominal assets $Q(s^t, s_{t+1})$ with associated nominal prices $P^Q(s^t, s_{t+1})$. During the first of the $n$ subperiods, one member of the household uses money to buy consumption goods. During this same initial subperiod, another member of the household produces and sells goods in exchange for money. At the end of the subperiod, producers transfer to the bank the proceeds from their transactions. The situation at the beginning of the second sub-period thus exactly replicates the situation at the beginning of the first. This process is repeated $n(s^t)$ times during the period. The choice of this variable $n(s^t)$ will be the only economically relevant decision made by households.

In this model, there is a natural distinction between the monetary aggregate $M_1(s^t)$, which is the sum of cash used for transactions and deposits, and the monetary base, which is the sum of all dollars available. Indeed, at the beginning of a period, a household begins with $H(s^t)$ dollars. These holdings are the economy's entire stock of base or outside money. These dollars are divided into currency and bank deposits, $\theta^d D(s^t)$, where $D(s^t)$ is the level of demand deposits and $\theta^d < 1$ is the associated reserve ratios for deposits. These reserves, deposited at banks or at the central bank, are augmented with loans by the bank to increase the household's deposits, against which checks can be written, to a maximum level $D(s^t)$. As has been the case in the United States until 2008, we assume that these reserves held by banks do not pay any interest.[6]

Finally, we assume that currency is subject to risk of theft or loss: we assume that a fraction $\tau \geqslant 0$ of each unit of currency held vanishes each period. Payments by either kind of deposit account are secure from these losses.[7] For symmetry, we denote $\theta^c = 1/(1 - \tau) > 1$ as the number of units of cash required to be held to be able to make a dollar's worth of purchases.

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[6]For a discussion on the origins of this tax on reserves, see Goodfriend and Hargraves (1983). This policy changed in 2009 when the Federal Reserves started paying interest on reserves. We will explore in the last section the effect of interest-bearing reserves.

[7]Allowing for $\tau > 0$ implies that real money balances exhibit a satiation point at zero interest rates. This is important to match the data in the next section.

Given this environment, the portfolio and cash-in-advance restrictions faced by the representative agent are given by

$$H(s^t) + B(s^t) + \sum_{s_{t+1}} Q(s^t, s_{t+1})P^Q(s^t, s_{t+1}) \leqslant W(s^t)$$

and

$$\left[\theta^c \Omega(\gamma) + \theta^d (1 - \Omega(\gamma))\right] P(s^t)x(s^t) \equiv G(\gamma)P(s^t)x(s^t) \leqslant n(s^t)H(s^t)$$

where $G(\gamma) = \left[\theta^c \Omega(\gamma) + \theta^d (1 - \Omega(\gamma))\right]$ and

$$\Omega(\gamma) = \frac{1}{v}\int_0^\gamma zf(z)\,dz$$

is the value of all transactions paid for in cash, expressed as a function of the cutoff level $\gamma$. This specification is consistent with viewing each household as operating its own "bank" but still subject to a government-imposed reserve requirement. This allocation can be decentralized by explicitly assigning different functions to households and banks.[8]

Finally, wealth next period will be given by

$$W(s_t) \leqslant H(s^t) + B(s^t)(1 + r(s^{t+1})) + Q(s^t, s_{t+1}) + P(s^t)y(s^t)(1 - \phi v(s^t)n(s^t)^\sigma)$$
$$- P(s^t)x(s^t)\left[1 + k(1 - F(\gamma))\right] - (\theta^c - 1)P(s^t)x(s^t)\frac{\Omega(\gamma)}{n(s^t)} + T(s^t),$$

where $T(s^t)$ is a transfer made by the central bank. In what follows, we assume that monetary policy is given by sequences of short term nominal interest rates, $r(s^{t+1})$. The transfers $T(s^t)$ must then be consistent with the chosen sequence of policy rates.[9]

It is convenient to normalize all variables in each period by dividing the equations by the monetary base, $H(s^t)$. We denote the so-normalized variables with lowercase letters. In

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[8]See LN for details.

[9]In what follows, we will focus the discussion on interest rates and inflation only. It is well known that problems of the indeterminacy of price levels may arise with interest rate rules. We abstract from that issue in this paper.

addition, we indicate the dependence of variables on the state of nature at time t, $s^t$ by subindices.

The problem of the consumer can therefore be written as

$$V_t(w_t) = \max_{\{x_t, n_t, m_t, b_t\}} E_t \left[ U(x_t) + \beta V_{t+1}(w_{t+1}) \right]$$

subject to

$$h_t + b_t \leqslant w_t,$$

$$\alpha G(\gamma) p_t x_t \leqslant n_t h_t,$$

$$w_{t+1}(1 + \mu_{t+1}) \leqslant h_t + (1 + r_{t+1}) b_t + p_t y_t (1 - \phi v_t n_t^\sigma) + \mu_{t+1}$$
$$- p_t x_t \left[ 1 + k[1 - F(\gamma)] + (\theta^c - 1) \frac{\Omega(\gamma)}{n_t} \right],$$

where $\mu_{t+1}$ is the growth rate of the monetary base between periods t and t + 1, and $\alpha$ is a constant of proportionality that determines the average levels of money balances.

If we let $\lambda_t$ and $\delta_t$ be the Lagrange multipliers, the first order conditions are given by

$$x_t: \quad U'(x_t) - \delta_t \alpha G(\gamma) p_t - \beta \frac{V'_{t+1}(w_{t+1})}{1 + \mu_{t+1}} p_t \left[ 1 + k[1 - F(\gamma_t)] + (\theta^c - 1) \frac{\Omega(\gamma)}{n_t} \right] = 0,$$

$$n_t: \quad -\beta \frac{V'_{t+1}(w_{t+1})}{1 + \mu_{t+1}} \left( p_t y_t \phi \sigma v_t n_t^{\sigma-1} - (\theta^c - 1) \frac{p_t x_t}{n_t^2} \Omega(\gamma) \right) + \delta_t h_t = 0,$$

$$h_t: \quad -\lambda_t + \delta_t n_t + \beta \frac{V'_{t+1}(w_{t+1})}{1 + \mu_{t+1}} = 0,$$

$$b_t: \quad -\lambda_t + \beta V'_{t+1}(w_{t+1}) \frac{1 + r_{t+1}}{1 + \mu_{t+1}} = 0.$$

The envelope condition is

$$V'_t(w_t) = \lambda_t.$$

The first equation will only be used to determine the values for the multipliers, so we

ignore it from now on. The first order condition with respect to $b_t$ implies

$$\beta \frac{V'_{t+1}(w_{t+1})}{1 + \mu_{t+1}} = \frac{\lambda_t}{1 + r_{t+1}},$$

so replacing the optimal conditions with respect to $n_t$ and $h_t$, we obtain

$$\delta_t h_t = \frac{\lambda_t}{1 + r_{t+1}} \left[ p_t y_t \phi \sigma v_t n_t^{\sigma-1} - (\theta^c - 1) \frac{p_t x_t}{n_t^2} \Omega(\gamma) \right],$$

$$\lambda_t = \delta_t n_t + \frac{\lambda_t}{1 + r_{t+1}}.$$

Replacing the second equation into the first implies

$$h_t = \frac{n_t}{r_{t+1}} \left[ p_t y_t \phi \sigma v_t n_t^{\sigma-1} - (\theta^c - 1) \frac{p_t x_t}{n_t^2} \Omega(\gamma) \right].$$

In equilibrium we have $h_t = 1$, so the previous condition, plus the two feasibility constraints imply

$$r_{t+1} = n_t \left[ p_t y_t \phi \sigma v_t n_t^{\sigma-1} - (\theta^c - 1) \frac{p_t x_t}{n_t^2} \Omega(\gamma) \right],$$

$$\alpha G(\gamma) p_t x_t = n_t,$$

$$y_t (1 - \phi v_t n_t^\sigma) = x_t [1 + k [1 - F(\gamma)]].$$

Using the last two equations to eliminate $p_t$ and $x_t$, we obtain

$$r_{t+1} = \frac{1}{\alpha G(\gamma)} \left[ \frac{\sigma \phi v_t n_t^{1+\sigma}}{1 - \phi v_t n_t^\sigma} [1 + k [1 - F(\gamma)]] - (\theta^c - 1) \Omega(\gamma) \right], \qquad (2)$$

which solves for $n_t$ as a function of $r_{t+1}$. Note that in the Baumol-Tobin case ($\sigma = 1$), we obtain an extended squared root formula for the equilibrium value of $n$.

Given the solution for the (unobservable) value for $n_t$, we can then use the cash-in-

advance equation and obtain

$$\frac{M_t}{x_t P_t} = \frac{\alpha}{n_t}.$$

It trivially follows that in equilibrium, money, cash, and deposits are decreasing functions of the nominal interest rate.

Equation (2) can be written as

$$r_{t+1}^* \equiv r_{t+1} + \frac{(\theta^c - 1)\, \Omega\,(\gamma)}{\alpha G\,(\gamma)} = \frac{[1 + k\,[1 - F\,(\gamma)]]}{\alpha G\,(\gamma)} \frac{\sigma \phi v_t n_t^{1+\sigma}}{1 - \phi v_t n_t^\sigma}.$$

The right hand side of the equation, defined as $r_{t+1}^*$, is the nominal interest rate plus a constant, which is adjusted for the opportunity cost of holding cash, $(\theta^c - 1)$. If this opportunity cost were zero, the solution for $n_t$ would go to zero if the nominal interest rate went to zero, and therefore real money balances would go to infinity. This would conflict with the recent evidence in the United States, and that is why we consider the case in which $(\theta^c - 1) > 0$.

Notice that the term $\phi v_t n_t^\sigma$ measures a fraction of the welfare cost of inflation (the other fraction is given by $k\,[1 - F\,(\gamma)]\,x_t$). Estimates of the welfare cost of inflation for interest rates in the range we will be discussing in the numerical section are, at most, 1% of GDP. If we use the approximation $1 - \phi v_t n_t^\sigma \simeq 1$, the previous equation becomes

$$r_{t+1}^* = \frac{[1 + k\,[1 - F\,(\gamma)]]}{\alpha G\,(\gamma)} \sigma \phi v_t n_t^{1+\sigma},$$

which implies the familiar log-log real money demand specification. The Baumol-Tobin case is the one obtained by assuming that the function $\phi$ is linear, or $\sigma = 1$, which implies an interest rate elasticity of 1/2.

# 3 Calibration and evaluation

In this section, we take the model to the data. For the monetary aggregates, we will identify cash in the model with the cash component of $M_1$. For deposits, we will consolidate into a single figure demand deposits, NOW (negotiable order of withdrawal) accounts and money market demand accounts (MMDA).

This decision requires some explanation, since it represents a point of departure from LN, where MMDA and the other deposits serve different functions.[10] The main reason for the simplified version we adopt here is that the main focus of our analysis is the component of the monetary aggregate that is directly controlled by the monetary authority: the monetary base. This monetary base is composed, as in the model above, by cash outside banks and reserves inside banks. Since the Federal Reserve can now pay interest on reserves, it has a direct instrument to control the cash inside banks. In addition, the Federal Reserve has developed additional tools to absorbe reserves, as described and analyzed in Martin et. al. (2014). Finally, the option to impose a reserve requirement is always available. We therefore view the current policy framework with respect to the reserves component of the monetary base at the Federal Reserve System as consistent with the mandate of price stability. Since the main focus of our numerical exercises is cash outside banks, we do not believe that consolidating demand deposits and MMDA into a single aggregate as problematic. A second reason to treat all deposits as part of a single aggregate is that the distinction between demand deposits and MMDA became blurred in the middle of the nineties with the development of the sweep programs. These programs essentially entailed the development of software that automatically moved funds back and forth from demand deposits to MMDA. Some of these sweep accounts A fraction of these programs were adopted by customers to profit from the fact that interest rates paid in MMDA were typical higher than in the standard demand deposits. But part of these

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[10]From the theory in LN, it follows that the right way to measure a monetary aggregate that includes cash and all these deposits is by the simple sum of the components, even though the components are not perfect substitutes.

programs were just ways for banks to reduce the legal reserves requirement. There was no reserves requirement for MMDA, so banks found it profitable to briefly park funds from demand deposits in MMDA when they had to determine the stock of deposits in order to compute the total required reserves.[11]

The model has very few parameters. First, for the function $f(z)$, we use the same one used in LN,

$$f(z) = \frac{\eta}{(1+z)^{1+\eta}},$$

and set $\eta = 2.56$ as in LN. Then we set $\theta^d = 0.05$, which is an average of the reserves held for deposits and MMDA. In addition, following Alvarez and Lippi (2009) who estimated the opportunity cost of cash using survey data from Italy, we set $\theta^c = 1.02$.

We then choose $\gamma$ so that the ratio of cash to money holdings is 18%, which corresponds to the median cash to money holdings in the United States from 1983 to 2016. In addition, we set the level parameter $\alpha$ so that the real money demand is 27 percentage points of GDP when the interest rate is 4.3%, which are the median values observed in the United States from 1983 to 2016.[12]

To calibrate the parameters of the transaction technologies $k$ and $\phi$, we set the stochastic component of the transaction cost to $v(s^t) = 1$ and use estimates of the welfare cost of inflation. Lucas (2000) estimates, using a log-log specification like the one we use here, that the welfare cost of inflation at an interest rate of 4% is about 1% of GDP. We assume that half of that amount is accounted for by the costs incurred by banks - which is part of GDP - and the other half is accounted for by the transactions time wasted by households, which is not accounted for in GDP figures. Thus, we use the equations
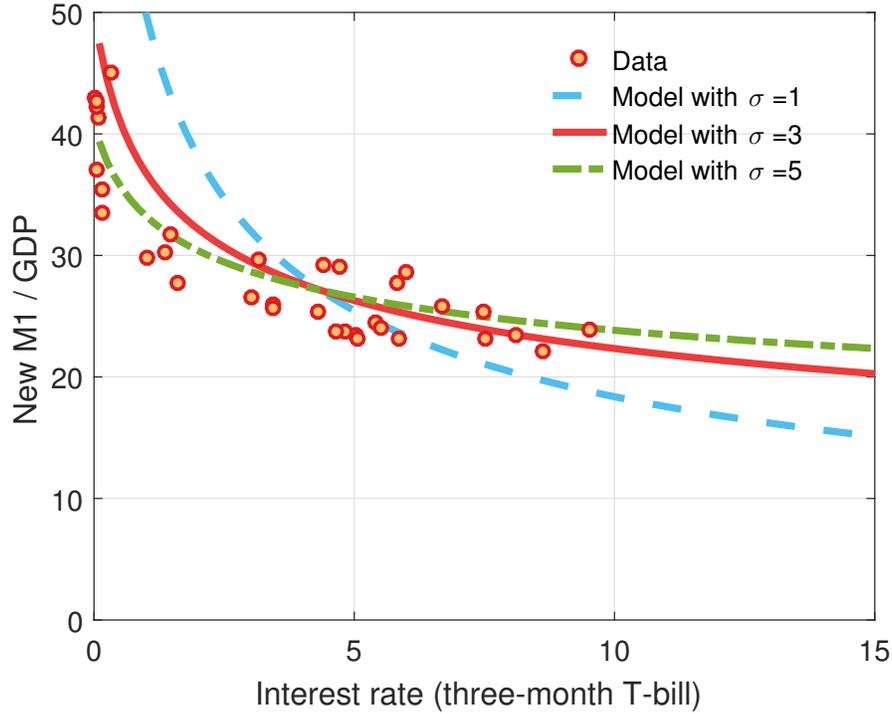
$$k^d \left[ 1 - F(\gamma) \right] = 0.005$$

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[11]The effect of the sweep programs on the ratio of measured demand deposits to MMDA can be seen in LN, Figure 5.

[12]For the short-term interest rate, we use the three-month T-bill rate.

Figure 1a: New M1/GDP and interest rate: 1983-2016.



and

$$\phi(n(0.04))^\sigma = 0.005$$

to calibrate those two parameters.

Finally, we choose the value for σ so as to obtain a good match of the slope of the money demand curve to the data. Figure 1a plots the resulting theoretical curve, together with the data for the period 1983-2016 for the ratio of total money to GDP. Figure 1b does the same for the ratio of cash to GDP. As it can be seen, the intermediate value of σ = 3 provides a good fit to the data, so that is the value we use.

## 3.1  Evaluation

We can now feed into the calibrated model the nominal interest rates for the previous subperiod, 1960 to 1982. In Figure 2a we depict the cross plot between the short-term nominal interest rate and the values for the ratio of money to output in the United States

Figure 1b: Currency/GDP and Interest rate: 1983-2016.
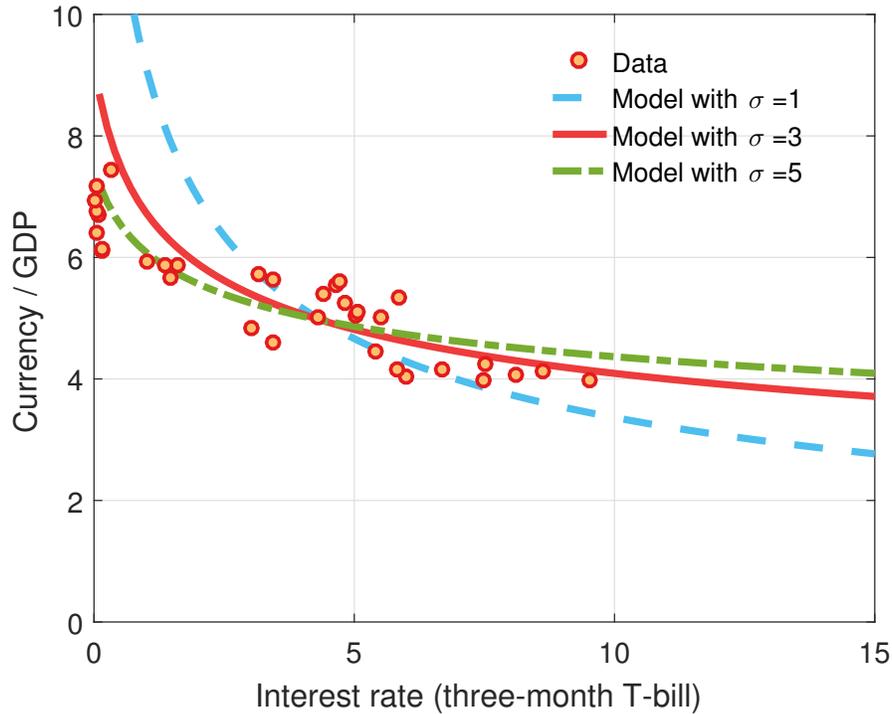
for that subperiod. We also plot the theoretical curve that has been calibrated for the previous subperiod. As can be seen, the curve clearly overestimates the ratio of money to output. We do not find this feature very surprising, since the model assumes that deposits do pay interests, but this was not the case during this period. Indeed, after the Great Depression, the banking sector was heavily regulated. One piece was Regulation Q, that capped the interest rates that banks could pay for the demand deposits. Thus the model understates the true opportunity cost of holding deposits. The difference between the data and the curve is, according to the model, the effect of Regulation Q on real money balances. But given our focus on cash, we do not pursue this issue further. In Figure 2b we repeat the exercise, but for cash over GDP. The match is remarkably good.[13]

Before moving ahead, we would like to illustrate a property of the theoretical curve (supported by the data) that lies behind the results of the paper: the high (absolute) sensitivity of the cash-to-output ratio to changes in the nominal interest rate when the

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[13]For a detailed discussion of the effects of Regulation Q during the period, see LN, which also discuss the reason why the effect of Regulation Q on the demand for cash was negligible.

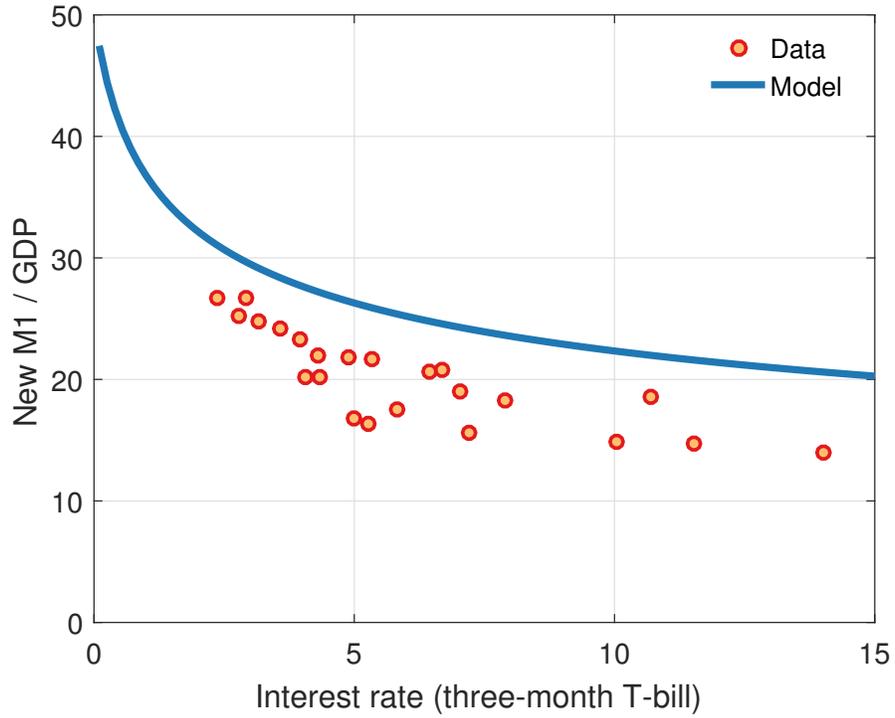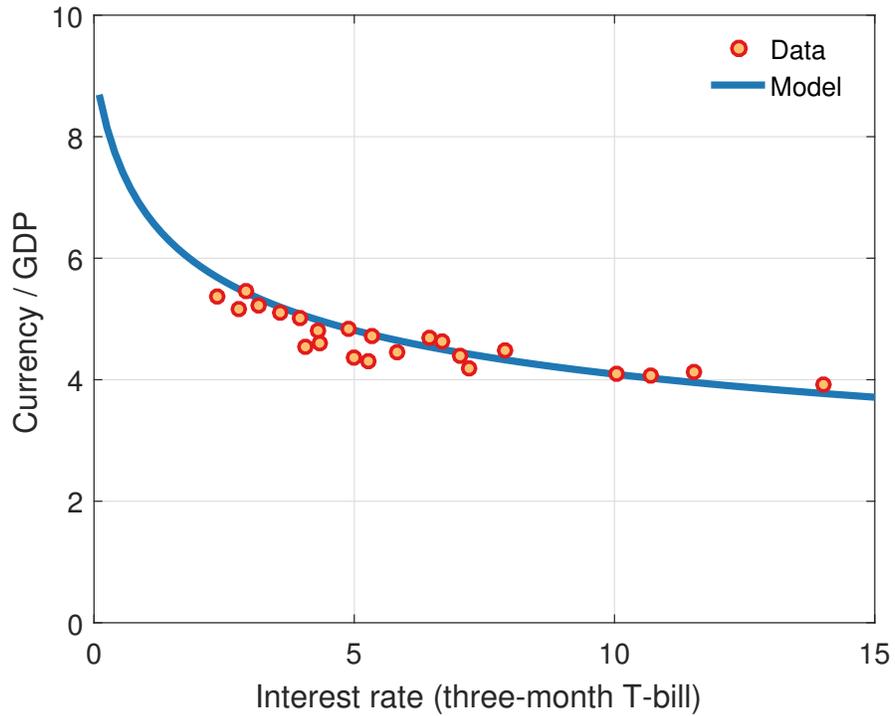Figure 2a: New M1/GDP and interest rate: 1960-1982.



Figure 2b: Currency/GDP and Interest rate: 1960-1982.

interest rate gets close to zero. Note that for movements in the interest rate between 6% and 2.5%, where the short-term rate stayed in the United States from 1990 to 2007—with the relatively short-lived exception of the early 2000s—the ratio of cash to output oscillates, according to the theoretical line, between 4.2% and 5%. These changes are not very large. However, for movements between 2.5% and 0, the range is between 5% and almost 8%. Put differently, the size of the change in the cash-to-output ratio is very large, precisely for changes that had not been experienced before, particularly during the Great Moderation, the period in which the inflation target policy was very successful. We will discuss this issue further in the conclusions.

Even though we developed a stochastic model, the curves depicted in Figures 1a, 1b, 2a, and 2b are the solution to the deterministic model when $v(s^t) = 1$ in equation (2). The interpretation that we pursue in this simple calculation is that the difference between the solid red line in Figure 1b and each observation is explained by the stochastic component $v(s^t)$. The time series of the computed errors corresponding to Figure 1b are depicted in Figure 3.

Figure 3: Residual: data - model prediction.
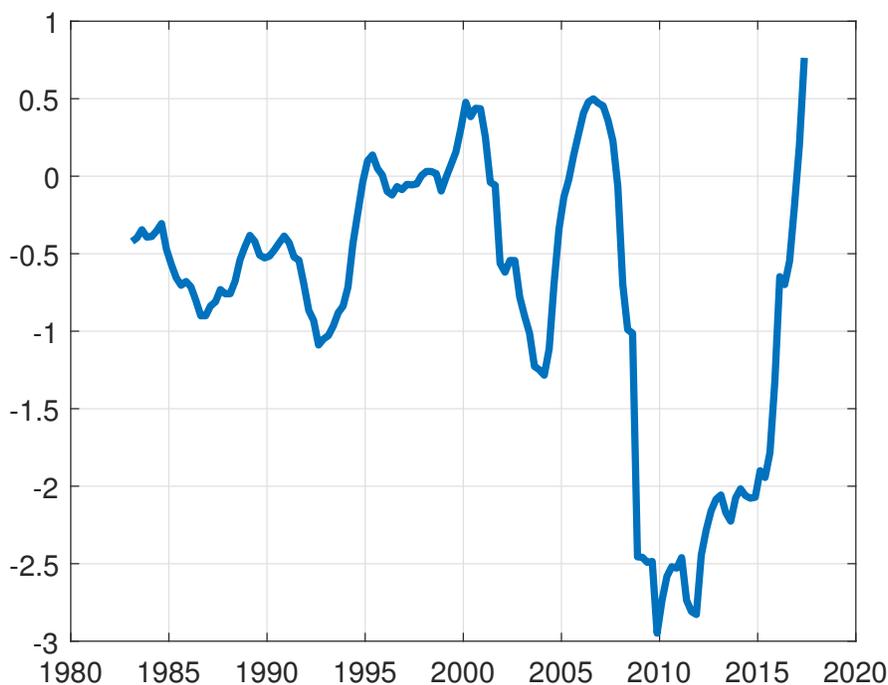
As can be seen, the errors are very persistent. This finding should hardly be surprising: the empirical literature on money demand recognized long ago that the errors in money demand equations are highly persistent.[14] We will use the statistical properties of these errors in order to make probabilistic statements regarding the future behavior of the cash-to-output ratio and the future behavior of the nominal quantity of cash in the United States. We explain in detail how we do this in the following section.

# 4   Results

In this section we compute the evolution of the cash-to-output ratio and the nominal value for total cash in the United States, under alternative scenarios. To do so, we feed into the model projections for the short-term nominal interest rate, real output, and inflation. For the short-term nominal interest rate, we use three versions of the projections recently made by the FOMC in June of 2017.[15] The benchmark projection uses a path for the short-term rate that is consistent with the central tendency of the projections. We added "dovish" and a "hawkish" alternatives. The three paths for the short-term rate are depicted in Figure 4.

In addition, we feed into the model the midrange projections for real output growth, also from the summary of the FOMC; they essentially imply 2% growth of real output. Finally, we also feed into the model the path for the target inflation rate of the Federal Reserve: 2% per year.

Thus, using the equation

$$\frac{C(s^t)}{x(s^t)P(s^t)} = \theta^c \Omega\left(\gamma\right) \frac{\alpha}{f(r^*(s^t), \nu(s^t))},$$

the model generates projections for the expected value of the cash-to-output ratio. Given the evolution of this ratio and the projections for real output and prices mentioned above,

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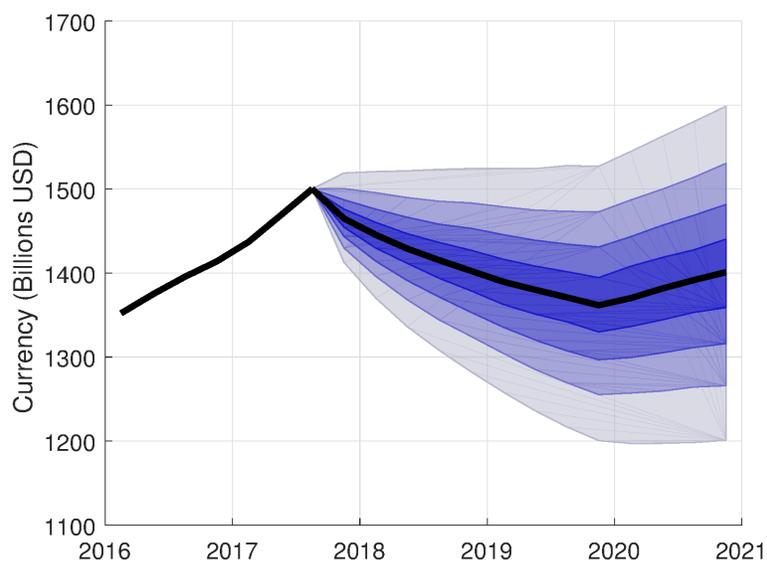[14]See Benati et al. (2016) for a recent exercise in a sample of over 30 countries.

[15]For details, see https://www.federalreserve.gov/monetarypolicy/fomcprojtabl20170614.htm.

Figure 4: Interest rate projections.
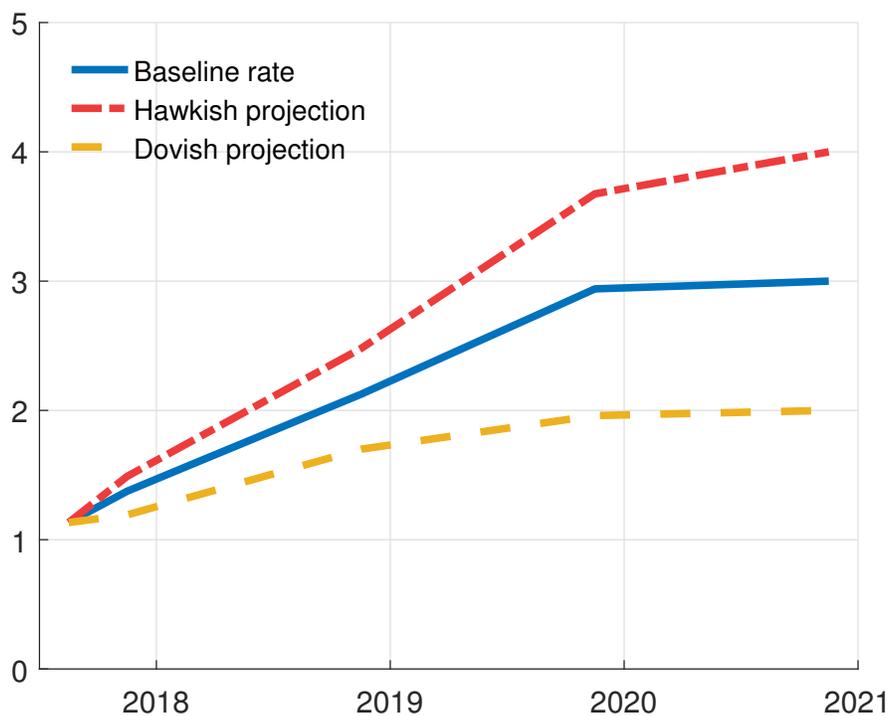


we can simulate the nominal value for cash.

Figure 5a: Baseline projection.



The solutions to that equation for the three scenarios are indicated by the black lines in

Figures 5a, 5b, and 5c.[16] In addition, we also used the statistical properties of the error in

[16]Figures A.1, A.2, and A.3 in Appendix A, show the projections for the cash-to-output ratios in the three
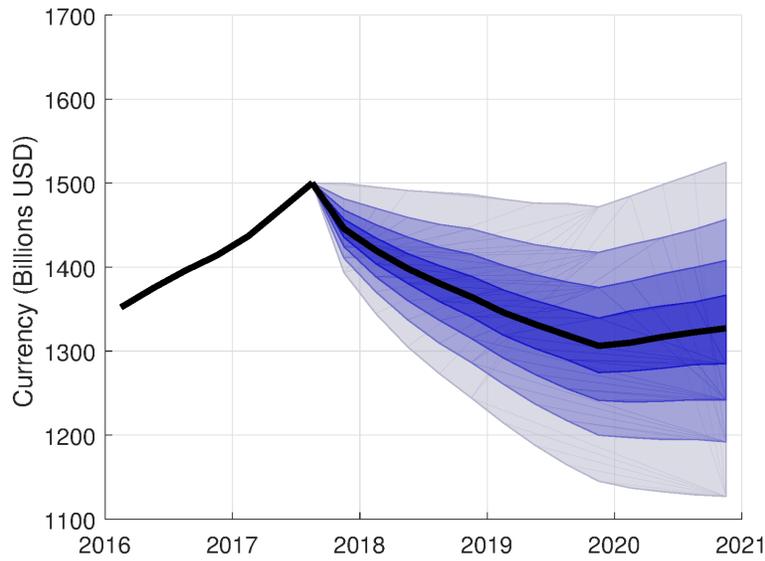
18

Figure 5b: Hawkish projection.
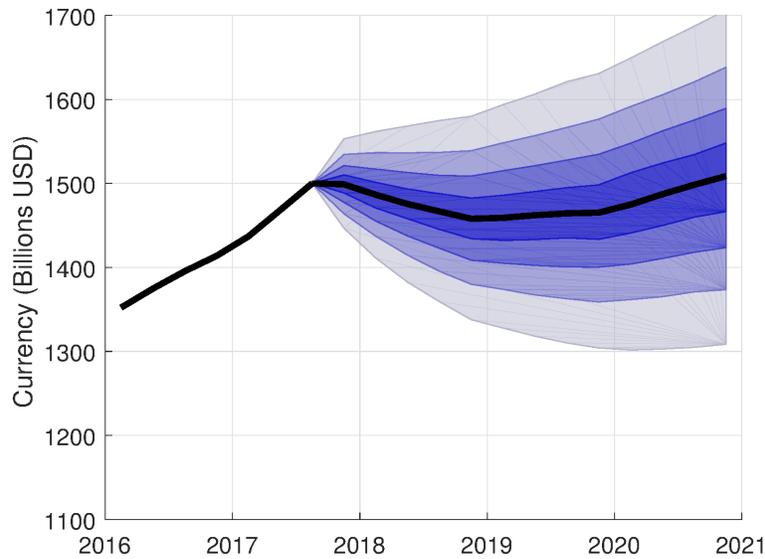


Figure 5c: Dovish projection.

Figure 3 to plot confidence bands around the point estimates provided by the theoretical model. Specifically, we used the persistence of the error and the standard deviations to compute probability distributions for each point estimate in every period. Each band corresponds to a decile, starting at 10% above and ending at 90% below.

scenarios.

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## 4.1 Paying interest on reserves

The calibration used earlier ignored the recent change in the treatment of reserves: bank reserves have paid interest since 2009. This decision completely changed the equilibrium behavior of banks, for which reserves are currently very close substitutes for short-term government bonds. In order to incorporate this modification, we run the model projections adjusting the calibrated value for $\theta^d$. If we assume that only one-half percent of deposits must be held as cash, so $\theta^d = 0.005$, then the evolution of cash in the benchmark scenario is as presented in Figure 6.

Figure 6: Currency using the baseline interest rate projection and a lower $\theta_d$.
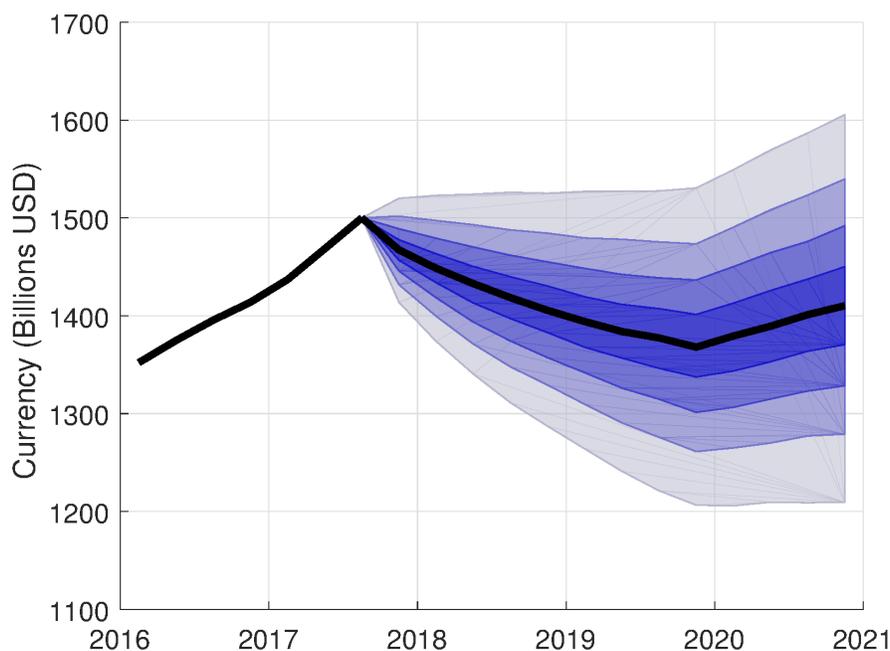


As can be seen, the differences between Figure 5a and Figure 6 are very minor, as could be expected given that the change in the calibrated value of $\theta^d$ is relatively small.

# 5 Conclusions

In this paper, we estimate that if the FOMC follows its expected path for the federal funds rate and if output grows at about a 2% rate per year in the next three years, as the FOMC

expects, the total value of currency in circulation should drop, on average, about $150 billion from Q3 2017 to Q3 2019, implying an unprecedented absorption of cash. In a more dovish scenario, the contraction of cash would amount to only $50 billion from Q3 2017 to Q3 2018, while in a more hawkish one, the average contraction would be $200 billion, also in the period Q3 2017 to Q3 2019.

Do these numbers imply that the target for inflation is in jeopardy? The answer depends on the mechanism for the price-level determination that comes out of the theory, an issue that we will now discuss. But first note that the theory developed in Section 2 is totally silent with respect to that issue. Indeed, the theory restricts the comovements between short-term nominal interest rates and a measure of money to total output; see Equation (2). In doing so, it also restricts the comovements between the nominal interest rate and the growth of money and inflation, which we interpreted as the policy instrument. But the theory is silent with respect to causal relationships.

A dominant view with respect to the determination of the price level, particularly in central banks, is the Taylor principle: a set of rules for the policy rate such that increases in current inflation increase the interest rate more than one to one. According to this view, the policy rules for the short-term interest rate that satisfy the Taylor principle uniquely pin down the sequence of price levels and therefore uniquely determine current and future inflation. If the theory includes an equation similar to (2), then that equation determines the value for monetary aggregates. According to this view, interest rates cause inflation, which in turn cause money. For proponents of this view, the numbers in this paper are just a reflection of intellectual curiosity. An alternative view, the fiscal theory of the price level, argues that decisions regarding fiscal policy—which is absent in the analysis above—determine the price level. As before, if the theory includes an equation similar to (2), then that equation determines the value for monetary aggregates as a residual.A third view could be articulated: changes in the policy rate determine how the relevant monetary aggregates change over time, which in turn determines the price level through an equation

such as (2). This view is is consitent with the conceptual framework behind the Monetary History of the United States by Friedman and Schwartz (1963).

We believe that a fair assessment of the literature is that there is no conclusive evidence regarding the exact mechanism by which monetary policy affects inflation, particularly during periods in which some of the potentially relevant variables (such as monetary aggregates) change much more than usual. As long as prudence suggests not completely disregarding any of these potential channels, the analysis of the paper points towards giving proper attention to mechanisms that may allow the Federal Reserve to vacuum up the excess cash that the expected path of short-term rates will most likely generate.

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# A The evolution of Currency/GDP

This appendix displays the evolution of cash-to-output ratio in the three scenarios for the short-term nominal interest rate.
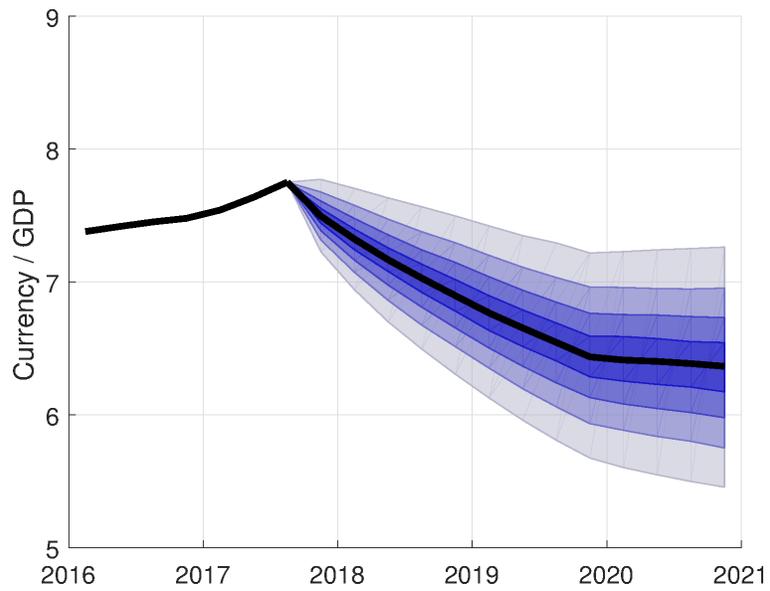
Figure A.1: Baseline projection.
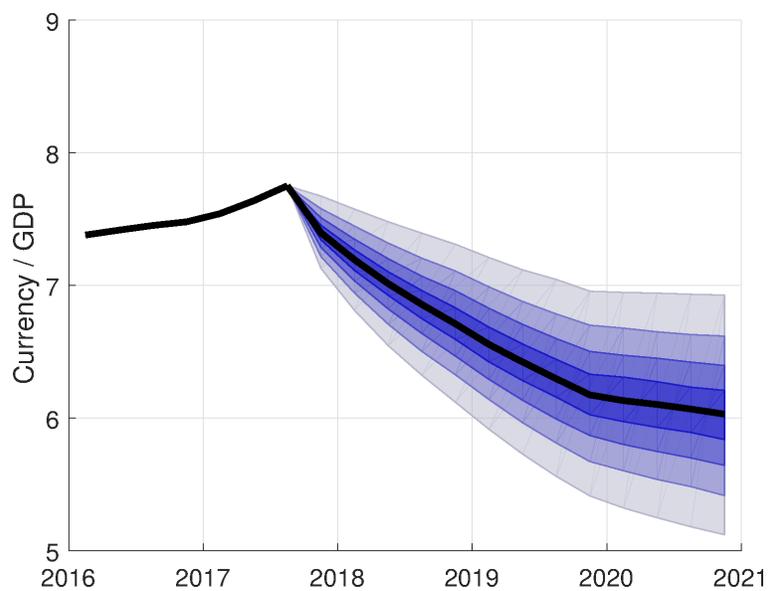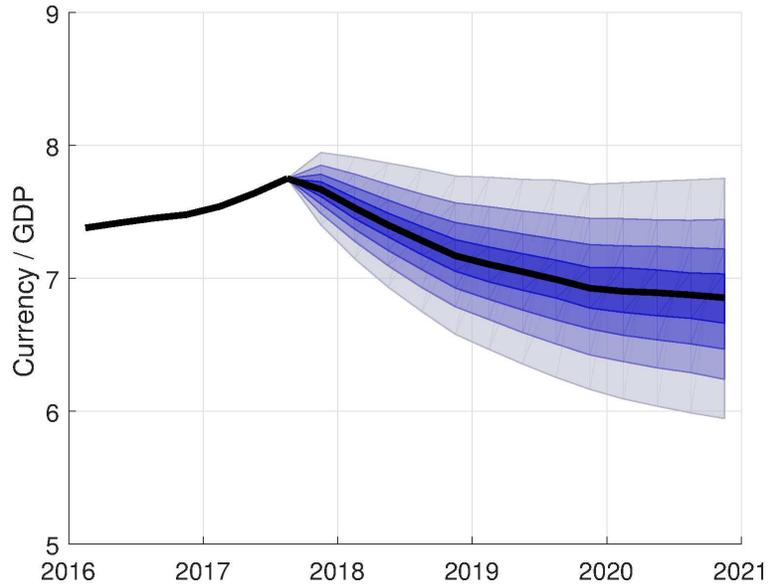


Figure A.2: Hawkish projection.
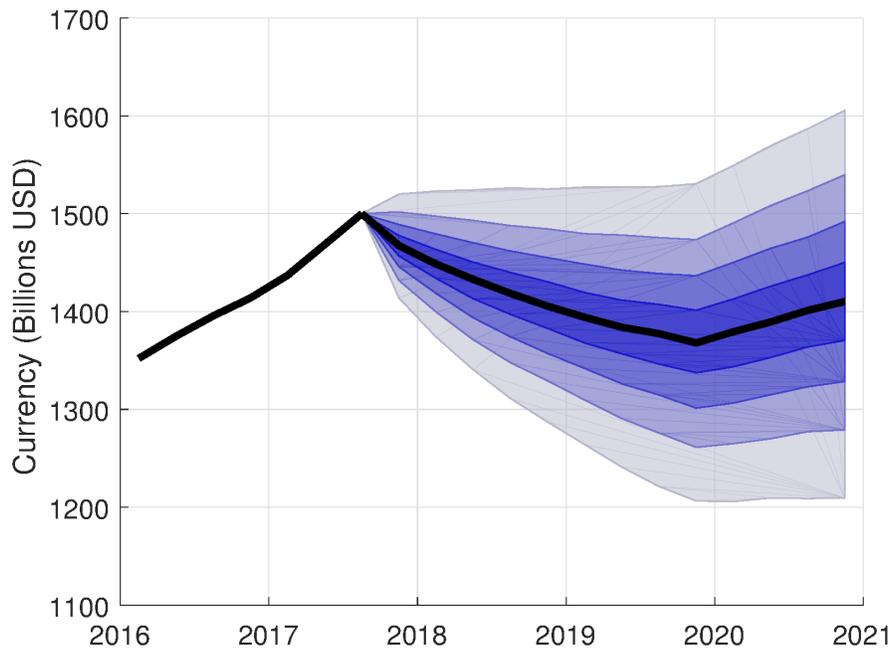
Figure A.3: Dovish projection.



# B  Changing the calibration period

We calibrated the model using data from 1983 to 2007 and the results are virtually identical. Figure B.1 shows the evolution of cash under the baseline interest rate scenario.

Figure B.1: Baseline interest rate projection and a different calibration period.

# C Robustness to changes in the parameter $\gamma$

This appendix shows robustness exercises changing the parameter $\gamma$. In the baseline calibration $\gamma$ is chosen to match an observed (median) ratio of cash to money holdings of 18%. We redo the exercises in the paper using a higher and a lower value of $\gamma$. These values of $\gamma$ are chosen so that the ratio cash to money in the model is equal to the median plus and minus two standard deviations of cash to money ratio observed over the period 1983-2016 (23.4% and 13%, respectively). Figures C.1 and C.2 show cash projections under the baseline interest rate scenario for the two values of $\gamma$.

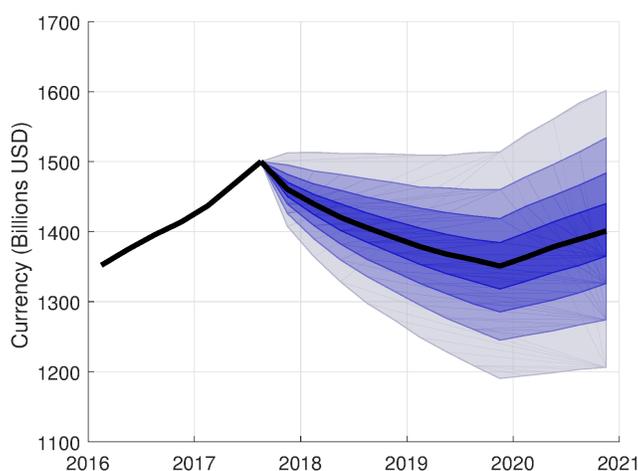Figure C.1: Baseline interest rate projection and higher $\gamma$.



Figure C.2: Baseline interest rate projection and lower $\gamma$.