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BURY THE GOLD STANDARD? A QUANTITATIVE EXPLORATION

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ABSTRACT

This paper is one of the first to study the present-day properties of the gold standard in a quantitative model commonly used in central banks. We incorporate gold into an otherwise standard estimated New Keynesian model and compare the positive and normative implications of adopting a gold standard to other more commonly advocated policies. We show that under certain conditions, the gold standard is akin to a nominal GDP targeting framework and can at times be considered an improvement. However, unlike more conventional policies, the gold standard must react to shocks to the supply and demand for gold. We estimate the model for the post-2000 period using a novel dataset on the supply of gold and find that following a gold standard would result in dramatic increases in the volatilities of macroeconomic aggregates and a significant deterioration in household welfare. This is because the estimated shocks to gold supply and demand are significantly larger than for other more conventional aggregate shocks. In the end, what buries the gold standard turns out to be instability in the dynamics of gold itself.

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1 Introduction

The gold standard has been dormant in the United States and around the world for close to fifty years. Yet in the popular press and various policy circles, it is very much alive and well. The strengths of the gold standard cited by its proponents are its ability to constrain the creation of new money while also discouraging large fiscal and trade deficits. This tends to help ensure price stability over the very long-run, a fact that is also acknowledged by the former Federal Reserve Chairman Ben Bernanke.[1]

However, the strengths of the gold standard are often cited as its greatest weakness: constraining monetary policy prevents stabilization of output and unemployment in the midst of recessions. To say the latter view is widely held by central bankers and economists alike would be an understatement: a University of Chicago survey of top academic economists from 2012 found that 100% of the respondents were against returning to the gold standard.[2] Such widespread agreement is remarkable, because a thorough review of the optimal monetary policy literature[3] shows that the vast majority of studies (close to 100) find that zero inflation or price stability is optimal in the long-run, which could possibly speak to one of the strengths of the gold standard.

With these conflicting implications in mind, the objective of this paper is to move the largely historical- and prose-based analysis of the strengths and weaknesses of the gold standard toward a more formal modern quantitative framework commonly used by central banks. In particular, we analyze the positive and normative implications of the gold standard in the context of a New Keynesian model in conjunction with a novel dataset of the supply and demand for gold. We then compare the quantitative performance of the gold standard to other more commonly advocated policies, such as a conventional Taylor rule or a nominal GDP targeting rule.

To our knowledge, our study is the first to focus on the present-day implications of the gold standard in a modern, quantitative macro model. Previous papers have largely focused on how the gold standard performed while it was actually implemented in the United States decades ago. For instance, Fagan et al. (2013) estimate a small New Keynesian model for the time period 1879-1914 (classical Gold Standard period) and find that moving to a more conventional Taylor rule would have reduced inflation volatility at the expense of higher real-money and interest rate volatility. They determine that output volatility would be largely unaffected so that the end result was no welfare improvement

1. See Lecture Series Lesson 1 https://www.federalreserve.gov/newsevents/files/bernanke-lecture-one-20120320.pdf.
2. For more details, http://www.igmchicago.org/surveys/gold-standard/.
3. For an overview, see Diercks (2019) and optimalinflation.com.

when moving away from the gold standard.[4] Although we employ a similar small-scale New Keynesian model, unlike them our model explicitly includes gold as an asset households may accumulate.[5] Chen and Ward (2019) focus on a similar time period as do Fagan et al. (2013) and estimate an open economy model for the U.K., Sweden, and Belgium to show that flexible prices were the key channel through which output was stabilized because the economy during this time period was largely agricultural. In contrast to these studies, we focus on how the gold standard would perform in the current environment within the United States by estimating structural parameters from more recent data and allowing for a rich model specification with trend growth.

The Great Depression is another time period in which the gold standard has been heavily studied (e.g. see Bernanke and James (1991), Eichengreen (1995)). The consensus from these historical accounts is that the gold standard restricted monetary policy's ability to stabilize the economy, and therefore contributed to the severity of the Depression. Other studies have focused on determinacy and commitment under the gold standard as in Barro (1979) and Bordo and Kydland (1995). Bordo et al. (2007) use a two-sector real business cycle model to show that a strict inflation targeting framework can also lead to price stability and potentially reduce inflation volatility in the short-run relative to a gold standard. In contrast to these studies, we do a full welfare analysis of competing monetary policy frameworks in a model with nominal rigidities and explicit costs associated with inflation. Furthermore, we introduce a novel gold dataset to further quantify the potential dynamics under a gold standard.

We modify an otherwise textbook New Keynesian model with price and wage rigidity to include gold. Gold enters the budget constraint of households as an asset they can accumulate. Households receive a utility flow from holding gold, with an exogenous variable capturing variations in preference-based demand. Utility from gold is additively separable with respect to other choice variables. Gold production is exogenous, with profits from new discoveries remitted lump-sum back to households. Gold is not used as a factor of production in the output good. Altogether, these assumptions imply that under a typically-assumed monetary rule (e.g. a Taylor rule), gold is irrelevant for the equilibrium dynamics of macro variables. Under such rules, the price of gold fluctuates in response to both gold supply and demand shocks, but also in response to other macro shocks. The endogenous price of gold in the model allows us to study equilibrium dynamics and household welfare under a classical gold standard. Under such a rule, the

4. Their results suggest that welfare would have been slightly lower under a counterfactual Taylor rule regime for this time period.

5. Our setup also employs a second-order approximation for computing welfare, which helps capture the costs of inflation and price dispersion, which are absent in the log-linearization of Fagan et al. (2013).

monetary authority adjusts the nominal interest rate to stabilize the price of gold, rather than according to something like a Taylor rule or a different type of targeting rule (e.g. an inflation target or nominal GDP target).

Our first contribution is to show that under certain modeling assumptions, the gold standard is isomorphic to a nominal GDP targeting rule. To our knowledge, the possible similarities between a gold standard and a nominal spending rule are not well-known. We show that in the absence of gold preference and supply shocks, the gold standard implements policy such that nominal GDP is equated to a fixed ratio of the nominal value of gold in equilibrium. Our simulations suggest that the gold standard will be equivalent to a nominal GDP target mainly in response to supply shocks (e.g. stationary productivity or labor supply shocks). Previous studies such as Garín et al. (2016) have shown that nominal GDP targeting performs well in a model with price and wage rigidities, which bodes well for the relative performance of the gold standard (conditional on no gold-specific shocks).

Our second contribution is to show that in the presence of a positive trend in productivity growth, the gold standard may in fact outperform nominal GDP targeting. Specifically, any scenario in which productivity growth persistently deviates from trend will imply fluctuations in inflation to offset movements in output under the nominal GDP targeting framework. In contrast, the gold standard effectively builds in the change in trend growth that the simple NGDP target does not. In this scenario, inflation will not need to adjust in response to a positive productivity trend shock as output and the supply of gold rise together. Higher supply of gold is effectively met with higher demand.

Our third contribution is to estimate a structural model with a novel quarterly dataset of the gold supply over the past twenty years. This allows us to extract gold-specific shocks which would be relevant under the gold standard. With realistic shocks to the supply and demand of gold, we find a dramatic deterioration in household welfare in comparison to more conventional policies such as Taylor rules or nominal GDP targeting. The latter policies imply that gold supply and demand shocks are irrelevant for equilibrium dynamics, whereas implementation of a gold standard dramatically elevates the importance of these shocks. The intuition for the relative decline in welfare is two-fold: (1) the volatility of gold-specific shocks in the data is much larger than the volatility of other macroeconomic aggregates, and (2) by being forced to stabilize the price of gold in response to these shocks, the volatility of output and inflation must notably increase. Under the gold standard, a negative shock to gold supply requires the central bank to engage in a contractionary action (raising the nominal rate) to keep the price of gold from rising, which pushes output and inflation down. Likewise, the central bank has to

engage in similar actions in response to a positive gold demand shock.

We find that the inflation and output growth volatility under the Gold Standard are almost an order of magnitude higher than under more conventional policies. We construct a counterfactual historical simulation of aggregate variables using smoothed shocks from our estimation under three different policy regimes – a Taylor rule, a nominal GDP targeting rule, and the gold standard. In these simulations, the quarterly output growth volatilities under the Taylor rule and nominal GDP target are 0.61% and 0.43%, respectively. These values are roughly consistent with what we observe in the data over the past twenty years. In contrast, the output growth volatility during the same time period under the gold standard is 3.63%, which is around 8.4 times more volatile.

Likewise, inflation volatility is around 0.92% (annualized) under the Taylor rule and 1.62% (annualized) under nominal GDP targeting. In contrast, the inflation volatility under the gold standard is 14.64% (annualized).[6] These striking differences in volatilities across policies imply a per period welfare loss in consumption equivalent units of about 3.5401% under the gold standard relative to the Taylor rule. This is an economically significant disparity that translates into a permanent difference in real consumption per capita of approximately $1,500 per year.[7] In the latest quarter for which we have data (2020Q1), our counterfactual simulation suggests that the level output would be roughly 10% lower under the gold standard compared to the Taylor rule.

Overall, what buries the gold standard in our model turns out to be the instability in the dynamics of gold itself. Gold supply and demand are not as well behaved as its proponents would suggest. While we show the gold standard to have some potential positives in that it can behave similarly to a nominal GDP target or even improve upon it in certain cases, its weaknesses dominate its strengths. This is why it is important to present arguments within a quantitative framework. Without it, a proper assessment of the trade-offs cannot be formally established and the arguments will continue on indefinitely.

To provide some caveats, we should note that the gold standard studied in our framework is in the context of a closed economy. The gold standard would also likely play an important role from an open economy perspective as it would ensure a fixed exchange

6. Upon first glance, the volatilities for the gold standard that we estimate may seem too extreme. However, the values are not far off from the volatilities observed in the data for the time period 1879-1914, in which the classical gold standard was in effect. For instance, as shown in Fagan et al. (2013), the annualized standard deviation of inflation and quarterly standard deviation of output growth in the data over this time period was 8.60% and 2.33%, respectively. While a number of factors could be playing a role in the observed elevated volatility (e.g. large technology shocks) over this time period, we view our results as not unreasonable given this context.

7. Dollar value calculation based on real consumption per capita in 2012 dollars of $40,566 in 2019Q4.

rate. We also include gold in our model in a relatively simple way, with the explicit intent of having gold be irrelevant for equilibrium dynamics under more conventional monetary regimes such as a Taylor rule. This has the benefit of making the analysis clean and comparable to more conventional models, but we admittedly abstract from complementarities between the production of gold and the production of other goods. Another potential objection could be that the estimated shocks to gold supply and demand are not truly structural with respect to the monetary regime. In particular, under a gold standard, perhaps gold-specific shocks would be far less volatile.[8] Finally, our model abstracts from central bank balance sheet policies and instead focuses on implementing monetary policy by setting short-term interest rates. It is possible that allowing for balance sheet policies would alter conclusions regarding the desirability of a gold standard.[9] With these potential caveats in mind, we nevertheless think that our analysis provides a useful benchmark against which proponents of a return to the gold standard must grapple.

In Section 2, we discuss our novel dataset on the supply of gold that we later use in our estimation. Section 3 presents our model and Section 4 discusses positive implications of alternative monetary policies in the context of that model. In Section 5 we conduct quantitative historical counterfactuals and perform some normative analysis about the relative desirability of different policies. Section 6 concludes.

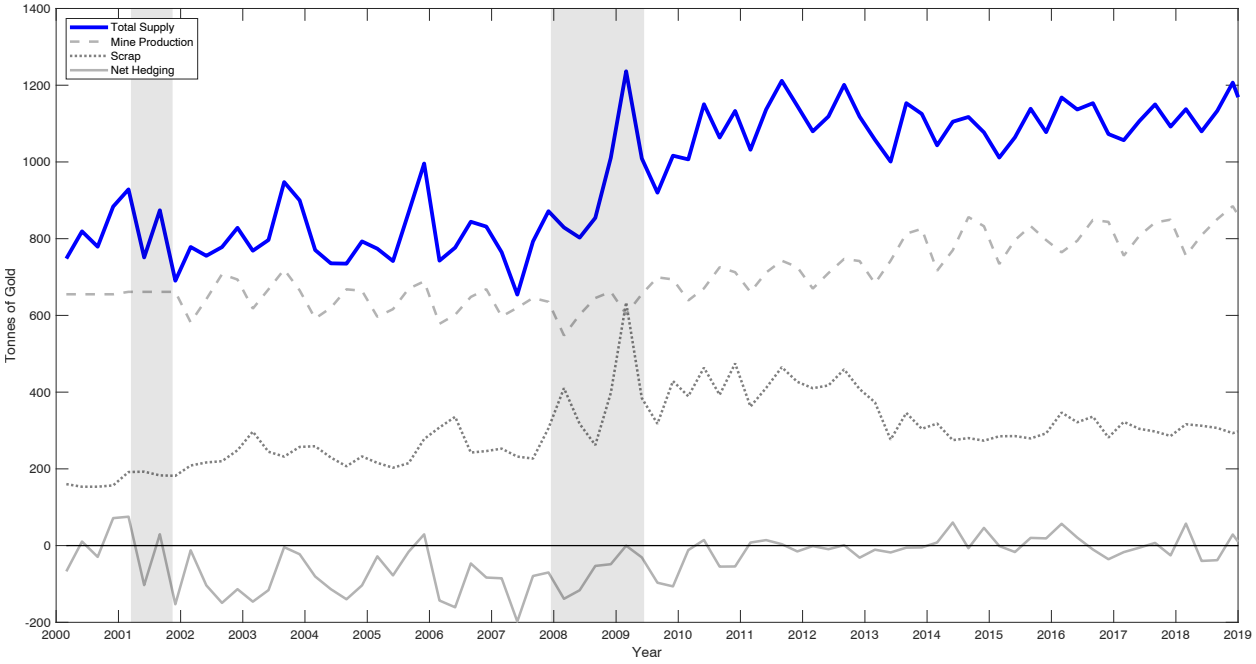
2 Gold data

The novel dataset we use for our analysis is based on gold supply provided by Gold Field Mineral Services. Gold Field Mineral Services (GFMS) provides a survey of world supply of gold on both a quarterly and annual basis. Although the Gold Survey has been conducted in various forms since 1967, GFMS only provides quarterly data through

8. While gold demand may depend more on the monetary regime and therefore be dubiously structural, we view the supply of gold as relatively less subject to this concern. We also study the situation in which only gold supply shocks are active and continue to find that the gold standard performs poorly.

9. While we focus on implementing the gold standard with monetary policy's influence over short-term interest rates, an alternative approach would be for the central bank to use its balance sheet to manipulate gold holdings to offset supply and demand shocks. There are several obvious problems with relying on balance sheet dynamics to maintain the price of gold: (1) the Federal Reserve might run out of gold, which is essentially what happened as gold flowed out of the United States in the financial crisis of 1933, (2) the current gold-coverage ratio (nominal value of gold held by the U.S. government divided by total Federal Reserve liabilities) is close to 7%, so any large-scale redemption of dollars for gold would wipe out the U.S. government's gold supply, and (3) in a frictionless world in which gold shocks can be perfectly offset by balance sheet manipulation, the gold standard would no longer constrain short-term interest rate policy, which largely defeats its purpose.

FIGURE 1: GOLD FIELD MINERAL SERVICES (GFMS) SUPPLY OF GOLD FROM 2000 TO 2019



Notes: The plot shows the total world supply of gold from 2000 to 2020 in tonnes. The supply of gold (solid blue) is divided into three categories, with mine production (dashed), scrap (dotted), and net hedging (solid gray). The data is based on Global Field Mineral Services Gold Survey of Refinitiv, Thomson Reuters.

Thomson Reuters Eikon terminal dating back to 2000, giving us approximately 80 quarters in which to estimate supply and demand shocks when combined with gold prices.

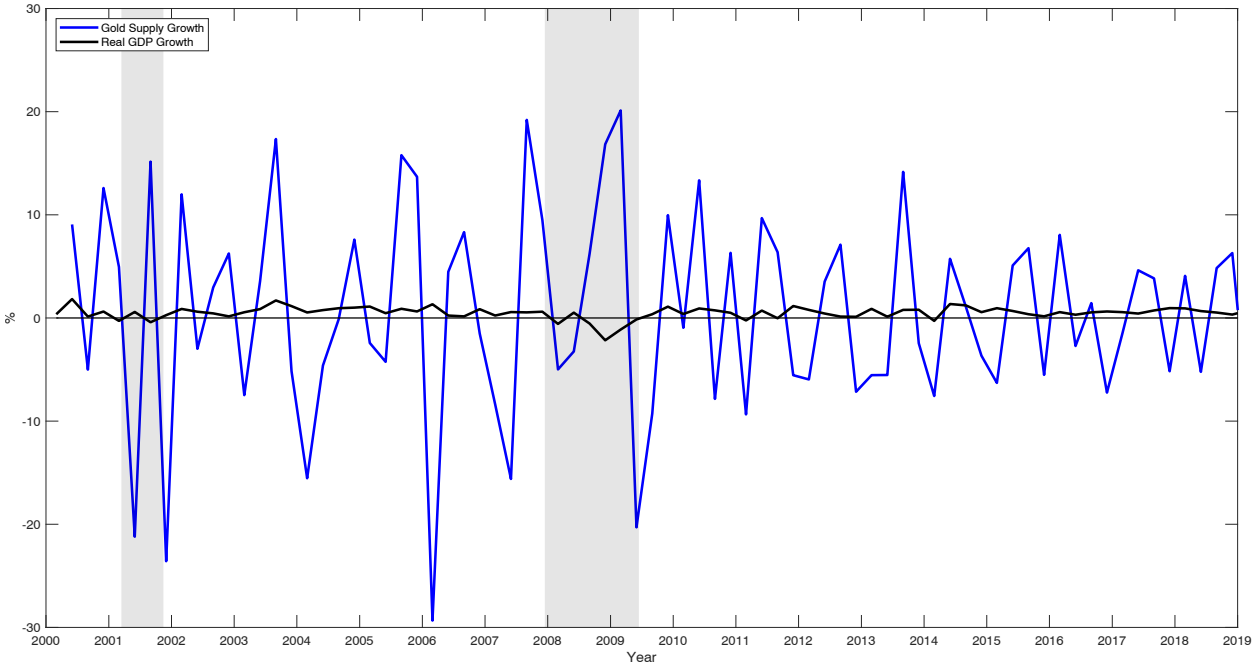
While the relatively short sample may be a potential concern, annual data dating back to 1980 shows similar volatility in the gold supply relative to the post-2000 period. Furthermore, compared to the post-2000 period, historical data dating back to 1801 implies that production based on mining is close to three times as volatile over the full 220 year sample.[10] This suggests that the time period that we focus on may be closer to a lower bound in terms of the historical volatility of the gold supply.

The GFMS survey is the primary source for world physical gold supply. Their physical gold supply figures (which we explicitly use in our analysis) are often cited in the Mineral Yearbook developed by the U.S. Geological Survey, which is a bureau of the United States Department of the Interior. According to GFMS, the informational content of the survey is derived from visits and discussions with local traders, producers, refiners, fabricators and central bankers from countries around the world.

Supply is broken down into three categories: (1) Mine Production, (2) Scrap, and

10. Special thanks to the Metals Research team at Refinitiv for providing the annual data and the historical mining data dating back to 1801.

FIGURE 2: QUARTERLY GROWTH OF GOLD SUPPLY AND REAL GDP FROM 2000-2019



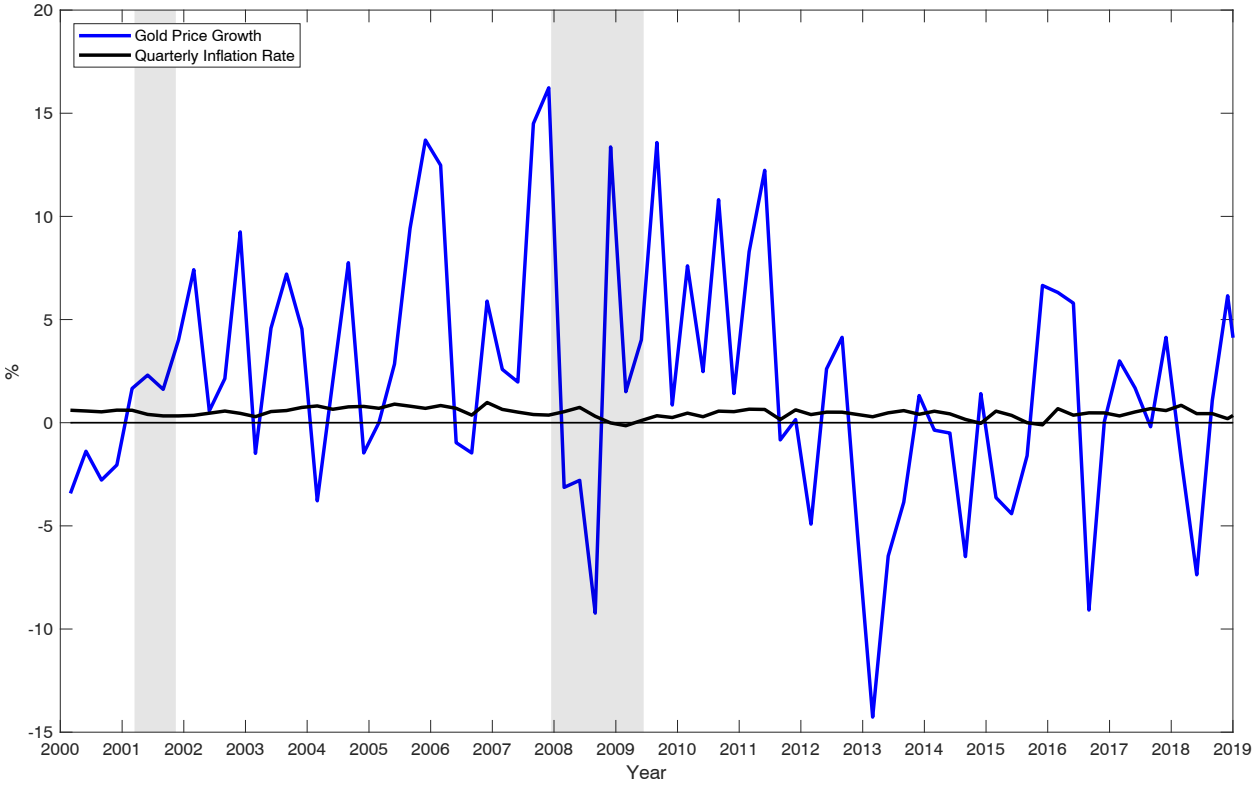
Notes: The plot shows the growth in the total world supply of gold (solid blue) from 2000 to 2019 on a quarterly basis in comparison to quarterly real GDP growth for the United States (solid black). The data is based on Global Field Mineral Services Gold Survey of Refinitiv, Thomson Reuters.

(3) Net Hedging Supply. Mine production makes up the vast majority of new supply, typically representing approximately 70 to 90% on an annual basis. It reflects the production of new gold based on underground reserves. The top producing countries have recently been China and Australia, which collectively make up about 20-25% of world production.

The scrap category captures recycling or mobilization of existing above-ground stocks of metal. This typically makes up about 20 to 30% of overall supply on an annual basis. It plays an important role due to the relatively large existing stock of gold in the form of jewelry and electronics that use gold in their production. Net hedging supply measures the effect of forward sales, loans, and options positions in the physical market for gold. It can often have a negative effect on total supply, sometimes reducing supply by 10 to 15%.

Figure 1 shows the various categories along with the total supply on a quarterly basis from 2000 through 2019. A few items are worth noting. The average growth rate of the gold supply over this time period is about 0.5% on a quarterly basis, which is very close to average real GDP growth over a similar horizon. However, the volatilities of the two series are dramatically different. Figure 2 shows the growth rate of the world gold

Figure 3: Quarterly Growth of Gold Price and Inflation from 2000-2019



Notes: The plot shows the growth in the gold price (solid blue) from 2000 to 2019 on a quarterly basis in comparison to quarterly inflation for the United States (solid black). The data is based on Global Field Mineral Services Gold Survey of Refinitiv, Thomson Reuters.

supply on a quarter-over-quarter basis in comparison to the growth rate of real GDP for the United States. The volatility of the gold supply is an order of magnitude higher. This extreme volatility will play an important role in the welfare analysis that we do later in the paper, as the gold standard will be forced to react to this sharp volatility to stabilize the price of gold.

Figure 3 shows the growth rate of the price of gold on a quarter-over-quarter basis in comparison to the inflation rate for the United States. Similar to the previous figure, the volatility of the gold price growth is relatively large, which will likely imply sizable gold demand shocks when we estimate the model.

3 Model

We present a New Keynesian model that facilitates a comparison between monetary regimes including the gold standard, a nominal GDP target, and interest rate setting

via a Taylor rule. The model features monopolistically competitive labor and final good markets, nominal wage and price rigidities modeled via Calvo pricing, and nonstationary productivity growth. Relative to the standard New Keynesian model, we include gold as an asset the household may accumulate and from which it derives a utility flow. Gold production is exogenous, with profits from new gold discoveries remitted back to households lump-sum. In the subsections below, we describe the household problem, the production and labor markets, and the conduct of monetary policy in detail.

3.A Households

There exists a representative household with separable preferences in consumption, labor, and gold. The problem of the household can be written:

$$\max_{\{C_t,N_t,G_t,B_t\}_{t\geq 0}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\nu_t \left[\log\left(C_t\right) - \psi_t \frac{N_t^{1+\chi}}{1+\chi} + \theta_t \ln\left(G_t\right) \right] \right)$$

subject to the following constraint:

$$P_t C_t + P_{G,t} G_t + B_t \leq MRS_t N_t + R_{t-1} B_{t-1} + P_{G,t} G_{t-1} + \Pi_{R,t} + \Pi_{G,t} + \Pi_{U,t} \tag{3.1}$$

where ν_t is an intertemporal preference (demand) shock, ψ_t is a labor supply preference shock, and θ_t is a gold demand shock. The discount factor is given by $\beta \in (0,1)$ and χ represents the inverse of the Frisch elasticity of labor supply.

Constraint (3.1) is a standard flow budget constraint. A household enters the period with a stock of bonds, B_{t-1}, and can choose a new stock of bonds, B_t, which pays out the gross nominal interest rate R_t in period $t+1$. The household enters a period with a previously chosen stock of gold, G_{t-1}. It can accumulate more or less gold to take to $t+1$ via choosing G_t. The market price of gold is $P_{G,t}$, which the household takes as given. Consumption is denoted by C_t, and the price of the consumed good is P_t. The household decides the amount of labor to supply, N_t, which earns the wage MRS_t, the nominal remuneration for supplying labor to labor unions. $\Pi_{R,t}$ is the nominal dividend from ownership in production firms, $\Pi_{G,t}$ is the nominal dividend from ownership in the gold producer, and $\Pi_{U,t}$ is the nominal dividend from ownership in labor unions.

The household first order conditions are:

$$\psi N_t^{\chi} = \frac{1}{C_t} mrs_t \tag{3.2}$$

$$1 = \beta R_t \mathbb{E}_t \frac{\nu_{t+1}}{\nu_t} \frac{C_t}{C_{t+1}} \Pi_{t+1}^{-1} \tag{3.3}$$

$$P_{G,t} = P_t C_t \frac{\theta_t}{G_t} + \beta \mathbb{E} \frac{\nu_{t+1}}{\nu_t} \frac{P_t C_t}{P_{t+1} C_{t+1}} P_{G,t+1} \tag{3.4}$$

where mrs_t is the real wage from supplying labor to unions. Equation (3.2) is a standard labor supply equation, and (3.3) is a standard Euler equation. Equation (3.4) is the first order condition with respect to gold holdings. It says that the cost of acquiring gold today is equal to the marginal benefit today plus the marginal benefit in the future, both in terms of utils of consumption. Given that gold is a stock with an intertemporal return, this condition is a familiar asset pricing equation with a forward-looking gold price. $\beta \frac{\nu_{t+1}}{\nu_t} \frac{P_t C_t}{P_{t+1} C_{t+1}}$ is the household's nominal stochastic discount factor. $\Pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate.

3.B Labor Markets

There are two dimensions to the labor market. The household supplies N_t to a continuum of labor unions indexed by $h \in [0, 1]$. The unions differentiate labor and sell the labor to a labor packer, which sells aggregated labor bundles to a representative wholesale firm.

1. Labor Packer The labor packer combines differentiated union labor, $N_{U,t}(h)$, into labor available to the wholesale firm. It pays $W_t(h)$ for variety h of labor and sells combined labor to the wholesale firm at W_t. The technology packing differentiated union labor into final labor is:

$$N_{P,t} = \left[\int_0^1 N_{U,t}(h)^{\frac{\epsilon_w - 1}{\epsilon_w}} dh \right]^{\frac{\epsilon_w}{\epsilon_w - 1}} \tag{3.5}$$

with an elasticity of substitution $\epsilon_w > 1$. The packer is competitive and earns no profit. Profit maximization gives rise to a demand curve for differentiated labor and a wage index:

$$N_{U,t}(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\epsilon_w} N_{P,t} \tag{3.6}$$

$$W_t^{1-\epsilon_w} = \int_0^1 W_t(h)^{1-\epsilon_w} dh \tag{3.7}$$

2. Unions The unions purchase labor from the households at the rate MRS_t and sell differentiated labor, $L_{U,t}(h)$, to the labor packer at the rate $W_t(h)$. The typical union's nominal dividend is

$$\Pi_{U,t}(h) = W_t(h) N_{U,t}(h) - MRS_t N_{U,t}(h) \tag{3.8}$$

Labor unions are subject to a Calvo-style nominal rigidity. Each period, there is a $1-\phi_w$ probability that a union may adjust its wage, where $\phi_w \in [0,1)$. Unions may index non-updated wages to steady state trend inflation, Π, via the parameter $\gamma_w \in [0,1]$. Unions maximize their present discounted value of flow profits where discounting comes from the household's stochastic discount factor. Solving the union maximization problem reveals that all updating unions choose the same reset wage, $w_t^\star$. The real reset wage can be expressed as:

$$w_t^\star = \frac{\epsilon_w}{\epsilon_w - 1}\frac{f_{1.t}}{f_{2,t}} \tag{3.9}$$

where

$$f_{1,t} = mrs_t w_t^{\epsilon_w} L_{P,t} + \phi_w E_t \Lambda_{t,t+1} \Pi^{-\epsilon_w \gamma_w} \Pi_{t+1}^{\epsilon_w} f_{1,t+1} \tag{3.10}$$

$$f_{2,t} = w_t^{\epsilon_w} L_{P,t} + \phi_w E_t \Lambda_{t,t+1} \Pi^{(1-\epsilon_w)\gamma_w} \Pi_{t+1}^{\epsilon_w - 1} f_{2,t+1} \tag{3.11}$$

In these expressions, $\Lambda_{t,t+1} = \beta \frac{\nu_{t+1}}{\nu_t}\frac{C_t}{C_{t+1}}$ is the household's real stochastic discount factor.

3.C Production

Similar to the labor market, there are multiple layers to the production side of the economy. There exists a continuum of retail firms that produce differentiated output indexed by $j \in [0,1]$, $Y_t(j)$. Differentiated output is transformed into a final good, Y_t , by a competitive final goods firm using the following technology:

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon_p - 1}{\epsilon_p}} \right)^{\frac{\epsilon_o}{\epsilon_p - 1}} \tag{3.12}$$

where the parameter $\epsilon_p > 1$ measures the degree of substitutability among differentiated output. The price of the final output is denoted by P_t and the prices of differentiated outputs are $P_t(j)$. Profit maximization by the competitive firm gives rise to demand for each differentiated output and an aggregate price index:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon_p} Y_t \tag{3.13}$$

$$P_t^{1-\epsilon_p} = \int_0^1 P_t(j)^{1-\epsilon_p} dj \tag{3.14}$$

1. Retail Firms Retail firms buy output from a wholesale producer and differentiate it, $Y_t(j) = Y_{w,t}(j)$, where w indexes the wholesale firm. Wholesale output is purchased at price $P_{w,t}$ and is sold at $P_t(j)$ to the final goods firm. Nominal profit for the retail firm is given by:

$$\Pi_{R,t}(j) = P_t(j) Y_t(j) - P_{w,t} Y_{w,t}(j) \tag{3.15}$$

Retail firms are not able to freely adjust their price in a given period á la Calvo. In particular, there is a $1-\theta_p$ probability each period, $\theta_p \in [0,1]$, that a firm can adjust its price, which we denote $P_t^\star(j)$. Otherwise it charges the most recently chosen price. Firms given the opportunity to adjust their price will do so to maximize the expected present discounted value of profit returned to households. Non-updating firms may index their prices to steady state trend inflation via $\gamma_p \in [0,1]$. It is straightforward to show that all updating firms will choose a common reset price, $P_t^\#$. The reset price in real terms, $p_t^\# = \frac{P_t^\#}{P_t}$, may be written as

$$p_t^\# = \frac{\epsilon_p}{\epsilon_p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{3.16}$$

where $x_{1,t}$ and $x_{2,t}$ are expressed as

$$x_{1,t} = p_{w,t} Y_t + \phi_p E_t \Lambda_{t,t+1} \Pi^{-\epsilon_p \gamma_p} \Pi_{t+1}^{\epsilon_p} x_{1,t+1} \tag{3.17}$$

$$x_{2,t} = Y_t + \phi_p E_t \Lambda_{t,t+1} \Pi^{(1-\epsilon_p)\gamma_p} \Pi_{t+1}^{\epsilon_p - 1} x_{1,t+1} \tag{3.18}$$

where $p_{w,t} = \frac{P_{w,t}}{P_t}$ and may be interpreted as real marginal cost.

2. Wholesale Firms There is a representative wholesale firm that produces output according to $Y_{w,t} = A_t L_{P,t}$. Its profit is:

$$\Pi_t^w = P_{w,t} A_t L_{P,t} - W_t L_{P,t} \tag{3.19}$$

Profit maximization gives rise to the labor demand condition $w_t = p_{w,t} A_t$, where w_t is the real wage where A_t is the stochastic level of productivity with gross growth rate $Z_t = \frac{A_t}{A_{t-1}}$. The growth rate of productivity obeys the following process:

$$\ln(Z_t) = (1 - \rho_Z) \ln(Z) + \rho_Z \ln(Z_{t-1}) + \sigma_Z \epsilon_{Z,t} \tag{3.20}$$

where ρ_Z is the autoregressive parameter, Z is the known non-stochastic steady state gross growth rate, and $\epsilon_{Z,t}$ is an innovation drawn from a standard normal distribution. The innovation is scaled by σ_Z, which measures the standard deviation.

3.D Gold Producing Firm

There exists a firm that receives an exogenous change in the endowment of gold, which it sells to households. Thus, the gold producing firm has no inputs. Nominal profits are:

$$\Pi_{G,t} = P_{G,t} (G_t - G_{t-1}) \tag{3.21}$$

The gold producing firm receives profit on the new exogenous flow, which is redistributed back to the household. The gold stock evolves according to:

$$G_t = A_t \hat{G}_t \tag{3.22}$$

where $\hat{G}_t$ is an exogenous stationary AR(1) process. To ensure balanced growth, the stock of gold follows the economy's productivity trend but fluctuates around the trend due to changes in $\hat{G}_t$.

3.E Monetary Policy

The monetary authority can conduct monetary policy by setting nominal interest rates through a Taylor Rule or have nominal interest rates react endogenously to support a gold standard or nominal GDP target. In the case of the Taylor rule, we assume the nominal rate follows:

$$\log(R_t) = (1-\rho_R)\log(R) + \rho_R \log(R_{t-1}) + (1-\rho_R)\theta_\pi(\pi_t - \pi) + \sigma_R \epsilon_{R,t} \tag{3.23}$$

where the autoregressive parameter ρ_R governs interest rate smoothing, θ_π governs the reaction of the nominal interest rate to deviations in the inflation rate from steady state, and $\epsilon_{R,t} \sim N\left(0, \sigma_R^2\right)$ is an i.i.d. monetary policy shock with a standard deviation of σ_R.

If the central bank instead follows a nominal GDP growth target, then the nominal interest rate reacts endogenously to support a constant nominal GDP growth rate:

$$\Pi_t \frac{Y_t}{Y_{t-1}} = Z\Pi \tag{3.24}$$

Alternatively, this rule can be expressed as:

$$\pi_t + \log(Y_t) - \log(Y_{t-1}) = \pi + \log(Z) \tag{3.25}$$

where π_t is the net inflation rate and π is the steady state net inflation rate. Under a nominal GDP target, inflation plus real GDP growth equals the sum of steady state inflation and trend productivity growth, which are both constant.

If the central bank were to follow a gold standard, then the nominal rate would endogenously adjust to ensure that the nominal gold price grows at a constant rate:

$$\frac{P_{G,t}}{P_{G,t-1}} = \Pi \tag{3.26}$$

If the net steady state inflation rate was zero, then a gold standard would commit the

central bank to a constant gold price, P_G.

3.F Other Exogenous Processes

The labor supply shock, ψ_t, intertemporal preference shock, ν_t, the gold preference shock, θ_t, and the stationary gold supply shock, $\hat{G}_t$, all follow an AR(1) process with a known non-stochastic steady state:

$$\ln(\psi_t) = (1-\rho_\psi)\ln(\psi) + \rho_\psi \ln(\psi_{t-1}) + \sigma_\psi \epsilon_{\psi,t} \tag{3.27}$$

$$\ln(\nu_t) = (1-\rho_\nu)\ln(\nu) + \rho_\nu \ln(\nu_{t-1}) + \sigma_\nu \epsilon_{\nu,t} \tag{3.28}$$

$$\ln(\theta_t) = (1-\rho_\theta)\ln(\theta) + \rho_\theta \ln(\theta_{t-1}) + \sigma_\theta \epsilon_{\theta,t} \tag{3.29}$$

$$\ln(\hat{G}_t) = (1-\rho_{\hat{G}})\ln(\hat{G}) + \rho_{\hat{G}} \ln(\hat{G}_{t-1}) + \sigma_{\hat{G}} \epsilon_{\hat{G},t} \tag{3.30}$$

The autoregressive parameters, ρ_ψ, ρ_ν, ρ_θ, and $\rho_{\hat{G}}$, lie between zero and one. The innovations, $\epsilon_{\psi,t}$, $\epsilon_{\nu,t}$, $\epsilon_{\theta,t}$, and $\epsilon_{\hat{G},t}$, are drawn from standard normal distributions. These innovations are scaled by σ_ψ, σ_ν, σ_θ, and $\sigma_{\hat{G}}$, which measure the standard deviation of the innovations.

3.G Equilibrium and Aggregation

Aggregate inflation and the aggregate real wage are given by:

$$1 = (1-\phi_p)(\Pi_t)^{1-\epsilon_p} + \phi_p \Pi_t^{\epsilon_p - 1} \tag{3.31}$$

$$w_t^{1-\epsilon_w} = (1-\phi_w)\left(w_t^{\#}\right)^{1-\epsilon_w} + \phi_w \Pi_t^{\epsilon_w - 1} w_{t-1}^{1-\epsilon_w} \tag{3.32}$$

Market clearing in the goods market requires wholesale output to be equal to the sum of retail output, taking the demand function as given:

$$Y_t v_t^p = Y_{W,t} \tag{3.33}$$

Similarly, labor market clearing requires the labor supplied by households to be equal to the labor used by the union.

$$L_t = L_{P,t} v_t^w \tag{3.34}$$

where price and wage dispersion, v_t^p and v_t^w respectively, are defined as:

$$v_t^p = \left(1 - \phi_p\right) \left(\Pi_t\right)^{-\epsilon_p} + \theta_p \pi_t^{\epsilon_p} v_{t-1}^p \tag{3.35}$$

$$v_t^w = \left(1 - \phi_w\right) \left(\frac{w_t^\#}{w_t}\right)^{-\epsilon_w} + \phi_w \Pi_t^{\epsilon_w} \left(\frac{w_t}{w_{t-1}}\right)^{\epsilon_w} v_{t-1}^w \tag{3.36}$$

Bonds are in zero supply in equilibrium, $B_t = 0$. Therefore, the aggregate resource constraint in the economy is:

$$Y_t = C_t \tag{3.37}$$

Given the stance of monetary policy, an equilibrium in our model consists of allocations and prices such that the household maximizes its utility subject to its budget constraint, firms maximize profits, markets clear, and aggregation holds.

3.H Stationarizing the Model

The model is driven by one non-stationary process, so most variables, excluding the interest rate, inflation, real gold price, labor hours, and real marginal cost, will be trending. All grow at the common growth factor, A_t. Dividing the variables that grow over time by the common growth factor ensures model stationarity. We note stationarized versions of variables with a hat circumflex, e.g. $\hat{Y}_t = Y_t / A_t$.

4 Implications of a Gold Standard

This section highlights some implications of monetary policy under a gold standard. We show, under certain conditions, that a gold standard is akin to a nominal GDP target. In particular, if shocks to gold supply and demand are absent, then a gold standard is isomorphic to a nominal GDP target conditional on most shocks, and it may be better than a nominal GDP target conditional on permanent shocks to trend productivity growth. But, undesirably, a gold standard forces endogenous policy changes in response to shocks to gold supply and demand. Depending on the magnitude of these shocks, this could reduce the desirability of the gold standard relative to other policy rules.

4.A Gold Standard Properties

The gold pricing equation, (3.4), can be written:

$$P_{G,t} = P_t \hat{Y}_t \frac{\theta_t}{\hat{G}_t} + \beta \mathbb{E}_t \frac{\nu_{t+1}}{\nu_t} \frac{P_t \hat{Y}_t}{P_{t+1} \hat{Y}_{t+1}} Z_{t+1}^{-1} P_{G,t+1} \tag{4.1}$$

where variables denoted with the hat circumflex are stationarized. By iterating forward, (4.1) can be written:

$$P_{G,t} = P_t \hat{Y}_t \underbrace{\left[\frac{\theta_t}{\hat{G}_t} + \mathbb{E}_t \sum_{j=1}^{\infty} \beta^j \frac{\nu_{t+j}}{\nu_t} \frac{\theta_{t+j}}{\hat{G}_{t+j}} \prod_{k=1}^{j} Z_{t+k}^{-1} \right]}_{\eta_t} \tag{4.2}$$

Let the bracketed term be denoted by η_t, which contains the exogenous gold demand, supply, trend growth shocks, and intertemporal preference shocks. Equation (4.2) states that the real price of gold, $\frac{P_{G,t}}{P_t}$, is proportional to stationarized GDP, where the proportionality term is η_t. η_t is itself a stochastic random variable. It can be written recursively:

$$\eta_t = \frac{\theta_t}{\hat{G}_t} + \beta \mathbb{E}_t \frac{\nu_{t+1}}{\nu_t} \frac{1}{Z_{t+1}} \eta_{t+1} \tag{4.3}$$

Log-linearizing (4.3) about the non-stochastic steady state, where $\widetilde{x}_t = \ln x_t - \ln x$ for generic variable x_t with non-stochastic steady state value x, we have:

$$\widetilde{\eta}_t = \left(1 - \frac{\beta}{Z}\right)\left(\widetilde{\theta}_t - \widetilde{\hat{G}}_t\right) + \frac{\beta}{Z}\mathbb{E}_t\left(\widetilde{\nu}_{t+1} - \widetilde{\nu}_t - \widetilde{Z}_{t+1}\right) + \frac{\beta}{Z}\mathbb{E}_t\widetilde{\eta}_{t+1} \tag{4.4}$$

Other factors held constant, increases in θ_t (the demand for gold) put upward pressure on the price of gold, while increases in gold supply, $\hat{G}_t$, do the opposite. Anticipated increases in productivity, Z_{t+1}, put downward pressure on the price of gold as households substitute from gold into the consumption good. Positive preference shocks, ν_t, have a similar effect – households substitute from future consumption goods into current goods, thereby substituting away from gold, resulting in a lower price of gold.

A gold standard targets a fixed growth rate of the price of gold, equal to the steady state inflation rate. Dividing equation (4.2) by its previous value, we have:

$$\Pi = \Pi_t \frac{Y_t}{Y_{t-1}} Z_t^{-1} \frac{\eta_t}{\eta_{t-1}} \tag{4.5}$$

Taking logs:

$$\pi_t + \log(Y_t) - \log(Y_{t-1}) = \pi + \log(Z_t) - (\log(\eta_t) - \log(\eta_{t-1})) \tag{4.6}$$

Targeting a constant growth rate of the price of gold, equal to the steady state inflation rate, causes nominal GDP growth to equal the steady state trend inflation rate, π, plus the net trend growth rate, $\log(Z_t)$, less $\log(\eta_t) - \log(\eta_{t-1})$. It is useful to compare (4.6) to a standard nominal GDP targeting rule, which would have:

$$\pi_t + \log(Y_t) - \log(Y_{t-1}) = \pi + \log(Z) \tag{4.7}$$

(4.7) and (4.6) differ along two dimensions. First, in a conventional nominal GDP target, the central bank targets a constant real growth rate of output, $\log(Z)$, whereas in the gold standard, the target growth rate of real output varies with shocks to potential, $\log(Z_t)$. Second, relative to a nominal GDP target, the gold standard is perturbed by $\log(\eta_t) - \log(\eta_{t-1})$. Using (4.4), this may be written:

$$\log(\eta_t) - \log(\eta_{t-1}) = \left(1 - \frac{\beta}{Z}\right)\left(\widetilde{\theta}_t - \widetilde{\theta}_{t-1} + \widetilde{\hat{G}}_t - \widetilde{\hat{G}}_{t-1}\right) \tag{4.8}$$

$$+\frac{\beta}{Z}\left(\mathbb{E}_t\widetilde{\nu}_{t+1}-\mathbb{E}_{t-1}\widetilde{\nu}_t\right)-\frac{\beta}{Z}(\widetilde{\nu}_t-\widetilde{\nu}_{t-1})-\frac{\beta}{Z}\left(\mathbb{E}_t\widetilde{Z}_{t+1}-\mathbb{E}_{t-1}\widetilde{Z}_t\right)+\frac{\beta}{Z}\left(\mathbb{E}_t\eta_{t+1}-\mathbb{E}_{t-1}\eta_t\right)$$

It is useful to discuss the conditions under which $\log(\eta_t)-\log(\eta_{t-1})=0$. This will be obtained if four requirements are met. First, the demand shifter for gold must be constant, i.e. $\widetilde{\theta}_t=\widetilde{\theta}_{t-1}$. Second, the gold supply shock must be constant, i.e. $\widetilde{\widetilde{G}}_t=\widetilde{\widetilde{G}}_{t-1}$. Third, the intertemporal preference shock must be constant, i.e. $\widetilde{\nu}_t=\widetilde{\nu}_{t-1}$. Finally, trend productivity must follow a random walk. It is not required that there be no shocks to trend productivity growth, just that these shocks are i.i.d., so that $\mathbb{E}_t\widetilde{Z}_{t+1}=\mathbb{E}_{t-1}\widetilde{Z}_t=0$. If these four conditions are met, then η_t will be constant. In this circumstance, a gold standard will be equivalent to a nominal GDP target, with the exception that the gold standard adjusts for fluctuations in the economy's trend productivity growth, whereas a conventional nominal GDP target does not.[11]

4.B Economic Dynamics

We argued above that a gold standard and a nominal GDP target may be similar under certain assumptions, but that following a gold standard necessitates fluctuations in nominal GDP due to shocks to gold supply and demand, among other factors. Here, we assess the desirability of a gold standard relative to other rules by showing impulse responses to different kinds of shocks.

Table 1 shows the parameter values used to generate the results. The household discount factor is chosen to match a steady state annual interest rate of 2 percent. The goods and labor market elasticities are set such that there is a 10 percent markup over marginal cost. The Calvo and Taylor rule parameters are standard. In the data, the average value of the stock of gold to real GDP is 1 percent and we set the real gold price of 10. The persistence and volatility of the exogenous processes are arbitrarily set to plausible values. We estimate these parameters in the following section.

We show the economic dynamics from various shocks in Appendix A. Figure 5 plots the impulse responses to a shock to the growth rate of trend productivity. The economic dynamics, specifically output and inflation, under the gold standard are quantitatively similar to the Taylor Rule. This is not the case with a nominal GDP target. As discussed above, the gold standard is similar to a NGDP target, but it adjusts for changes in trend growth. Instead of targeting a constant growth rate, $\ln Z$, nominal GDP adjusts with changes in the growth rate, $\ln Z_t$, under a gold standard. Since nominal GDP under a

11. An additional requirement, that we have built in to our preference specification, is that utility over consumption be log; i.e. that the elasticity of intertemporal substitution be one.

Table 1: Model Parameters

Parameter	Description	Value
β	household discount factor	0.99
χ	inverse frisch elasticity	1
ϵ_p	goods market elasticity of substitution	11
ϵ_w	labor market elasticity of substitution	11
θ_p	calvo parameter - retailers	0.75
θ_w	calvo parameter - labor unions	0.75
θ_π	policy rate response to inflation	1.5
Π_{ss}	steady state quarterly gross inflation rate	1.005
Z_{ss}	steady state quarterly gross growth rate	1.005
$\frac{G}{Y}$	steady state gold stock relative to output	0.01
$P_{g,ss}$	steady state relative price of gold	10
γ_w	wage indexation	0
γ_p	price indexation	0
Exogenous Processes		
ρ_G	gold supply persistence	0.9
ρ_θ	gold demand persistence	0.9
ρ_Z	trend growth persistence	0.75
ρ_v	intertemporal preference persistence	0.9
ρ_ψ	intratemporal preference persistence	0.9
ρ_R	Taylor rule persistence	0.8
s_G	standard deviation - gold supply shock	0.01
s_θ	standard deviation - gold demand shock	0.01
s_Z	standard deviation - trend growth shock	0.01
s_v	standard deviation - intertemporal shock	0.01
s_ψ	standard deviation - intratemporal shock	0.01
s_R	standard deviation - monetary policy shock	0.0025

NGDP target does not adjust to the trend, a permanent productivity shock that leads to an expansion of output requires a greater decline in the price level. For permanent productivity shocks, the results suggest that either the gold standard or a Taylor rule are preferable to a NGDP target.[12]

Figure 6 highlights the impulse responses to a shock to household preferences over labor supply. Given that this shock does not affect η_t above, the nominal GDP target and the gold standard are identical. The labor supply shock causes output to fall and inflation to rise as households supply less labor to firms. Nominal interest rates rise under the Taylor rule since the policy rate is responding to the rise in inflation. This causes output to decline by more relative to a nominal GDP target or gold standard. Under these two regimes, there is no change in the policy rate, as the decline in output and the rise in the price level offset to keep nominal GDP at target.

Next, we show the impulse responses to an intertemporal preference shock, shown in Figure 7. This shock leads the household to value the present more relative to the future. Consequently, there is an increase in aggregate demand, resulting in output and inflation rising under a Taylor rule. Under this rule, the price of gold falls as households substitute away from gold to consuming the output good. Under a nominal GDP target, the nominal interest rate rises to offset the household's relative impatience, leaving inflation and output unaffected. Under the gold standard, the central bank raises its policy rate by less so as to keep the gold price fixed, which results in output expanding by more relative to a nominal spending target.

The shocks to demand and supply for gold are shown in Figures 8 and 9. Under a Taylor rule or nominal GDP target, the shocks do not affect output nor inflation. Under a gold standard, a shock to gold demand causes the central bank to engage in contractionary monetary policy. The nominal rate increases to keep the price of gold from rising above target, which pushes output and inflation down. We see the opposite pattern after a gold supply shock. When there is a shock to gold supply, the central bank engages in expansionary monetary policy to keep the nominal price of gold fixed. The nominal rate falls to keep the price of gold from falling below target, which pushes output and inflation higher.

In summary, conditional on shocks that do not affect the proportion of the price of gold to nominal GDP, the gold standard is equivalent to a nominal GDP target. This relationship breaks down when there are permanent changes to trend growth, intertemporal preference shocks that impact the utility valuation of the present relative to the

12. Though we do not consider it, note that a stationary productivity shock would result in an equivalence between the gold standard and a nominal GDP target.

future, or shocks to gold demand and supply. Conditional on a permanent productivity shock, the gold standard performs better than a nominal GDP target, because nominal GDP internalizes changes in the trend under a gold standard. However, a nominal GDP target and the Taylor rule are both preferable to a gold standard conditional on gold demand and supply shocks. When these shocks occur, the central bank is forced to engage in contractionary or expansionary monetary policy to keep the nominal price of gold pegged.

5 Quantitative Analysis

Relative to other popular policy rules, a gold standard performs well conditional on certain shocks and poorly conditional on others, particularly shocks to the demand and supply of gold itself. The overall desirability of a gold standard therefore depends upon the parameter values of the shock processes. In this section, we quantitatively estimate the parameters related to shock processes using Bayesian methods. We use the estimated model both to conduct a counterfactual historical simulation as well as calculate conditional welfare metrics for different policy rules.

We estimate the parameters of the model using standard Bayesian methods. For the estimation, we assume that monetary policy has been conducted via a Taylor rule, which is common in the macro literature. The parameters to be estimated include parameters related to preferences, the parameters of the Taylor rule, and the parameters governing the exogenous processes. These parameters, along with the prior distributions, are shown in Table 2. The prior distributions are chosen to be consistent with the existing literature.

The estimated model with the Taylor rule includes six exogenous shocks, so we need at least six observables. Our observable variables include the growth rates of real GDP, real wages, and gold supply, the inflation rate, the inflation rate for the price of gold (as measured from the same data source that we use for gold supply), and the short-term policy rate as measured by the effective Federal Funds rate. Our data is at a quarterly frequency and the interval is from 2000 Q1 to 2020 Q1. To account for the zero lower bound period in the sample, we use the Wu-Xia shadow rate in place of the effective Federal Funds rate where relevant (Wu and Xia 2016). The steady state trend growth in productivity and steady state inflation rate are not estimated, but are rather calibrated to match the mean quarterly growth rates in output and the average inflation rate in the data.

Table 2: Model Estimation

	Prior			Posterior		
Coefficient	Prior Density	Prior Mean	pstdev	Post. Mean	5%	95%
β	Beta	0.99	0.01	0.9994	0.9987	1.0000
χ	Normal	1	0.2	0.5920	0.1768	1.0174
θ_p	Beta	0.6	0.1	0.5318	0.4401	0.6217
θ_w	Beta	0.6	0.1	0.2972	0.2135	0.3745
γ_p	Beta	0.5	0.25	0.4957	0.1103	0.9122
γ_w	Beta	0.5	0.25	0.4948	0.1009	0.8940
ρ_G	Beta	0.5	0.2	0.7959	0.6997	0.8951
ρ_Z	Beta	0.5	0.2	0.1168	0.0404	0.1893
ρ_θ	Beta	0.5	0.2	0.9917	0.9896	0.9938
ρ_v	Beta	0.5	0.2	0.9378	0.9132	0.9687
ρ_ψ	Beta	0.5	0.2	0.9950	0.9915	0.9990
ρ_R	Beta	0.5	0.2	0.8091	0.7640	0.8546
θ_π	Normal	1.5	0.1	1.7455	1.6082	1.8936
σ_G	I-Gamma	0.1	0.0033	0.1	0.0975	0.1021
σ_Z	I-Gamma	0.01	0.0033	0.0112	0.0094	0.0130
σ_θ	I-Gamma	0.15	0.0033	0.1501	0.1475	0.1526
σ_v	I-Gamma	0.01	0.0033	0.0147	0.0103	0.0197
σ_ψ	I-Gamma	0.01	0.0033	0.0242	0.0162	0.0309
σ_R	I-Gamma	0.003	0.0033	0.0021	0.0017	0.0026

The estimated parameters for the Taylor rule and the non-gold shock processes are quite standard. In particular, there is substantial interest-smoothing and the policy rate reacts strongly to inflation. Trend productivity growth is estimated to be close to a random walk. The autocorrelation of gold demand preference shocks is estimated to be quite high, and the standard deviations of innovations to gold demand and supply are both estimated to be quite large.

Using the sequence of shocks derived in the estimation, we perform a historical counterfactual from 2000 Q1 to 2020 Q1. We compare the estimated model with a Taylor rule to the cases where monetary policy supports either a gold standard or a nominal GDP target. For each policy, we assume that the economy's initial state is 2000 Q1 and then experiences the sequence of smoothed shocks that we estimate afterward.

Figure 4 shows the path of non-stationary output and the shadow policy rate under the various policies. The estimated Taylor rule model matches the data where output rises until 2008, contracts during the Great-Recession, and rises afterward, without reversing back to the pre-Great-Recession trend. Under the nominal GDP target, there is a much smoother and longer lasting decline in output during the Great-Recession period.

Table 3: Inflation and Output Growth Volatility

	σ_Y	σ_π
Taylor Rule	0.61	0.92
Nominal GDP Target	0.43	1.6
Gold Standard	3.63	14.64

Notes: The table contains the standard deviation of inflation and output growth in the estimated Taylor model, nominal GDP target, and gold standard. Both measures are in terms of percent. The volatility of inflation is annualized.

When monetary policy follows a gold standard, output is significantly more volatile, and there is a much sharper decline during the Great Recession. At the end period, 2020 Q1, output under the gold standard is approximately 10 percent lower than output with a nominal GDP target and Taylor rule.

The shadow rate under the Taylor rule matches the data where it rises sharply prior to 2008, falls significantly during and after the Great-Recession, and begins rising as the Federal Reserve began to lift off from the zero lower bound and started to normalize its balance sheet. The shadow rate under a nominal GDP target mimics the Taylor rule behavior except with smaller downward and upward movements. During the Great-Recession, the shadow rate stays above the zero lower bound, a potentially attractive feature if the zero lower bound is especially costly. At 2020 Q1, the shadow rate is approximately 150 basis points (annualized) greater under a nominal GDP target than the Taylor rule. Under a gold standard, the shadow rate actually rises during the Great Recession period, a contributing factor to the significantly greater decline in output. Post-Great Recession, the gross shadow rate continues to stay around 1.05 (annualized) until the end of the sample. At 2020 Q1, the shadow rate is approximately 400 basis points (annualized) greater under a gold standard than the Taylor rule.

Table 3 quantifies the volatility of inflation and output growth under the three monetary policies. The Taylor rule matches the data, where in the last 20 years, the annual standard deviation of inflation was 0.92% and the quarterly standard deviation of output growth was 0.61%. The standard deviation of output growth with a nominal GDP target is 0.43%, which is smaller than the Taylor rule. However, the annual standard deviation of inflation is 1.6%, which is approximately twice as volatile as the Taylor rule. This can be attributed to the estimated sequence of non-stationary productivity shocks. Since nominal GDP under a nominal GDP target does not adjust for changes in trend growth,

Table 4: Consumption Equivalent Welfare Losses From Different Monetary Policies

	Policy	Compared to Flexible Prices	Compared to Taylor Rule
Gold Shocks			
	GS	3.6523	3.5401
	NGDP	0.3235	0.2149
	Taylor	0.1084	
No Gold Shocks			
	GS	0.4231	0.3143
	NGDP	0.3235	0.2149
	Taylor	0.1084	

Notes: The table contains the consumption equivalent welfare losses under the gold standard, nominal GDP target, and Taylor rule in the estimated model.

the price level is more responsive to these shocks.[13] Unsurprisingly given the dynamics shown in Figure 4, we find that inflation under the gold standard is approximately 9 times as volatile as inflation under a nominal GDP target and approximately 16 times as volatile as inflation under a Taylor rule. Similarly, output growth is roughly 8.4 times as volatile as a output growth under a nominal GDP target and 5.95 times as volatile as output growth under the Taylor rule.

The household's stationary welfare function is derived in Appendix B. We construct two unconditional welfare measures. In the first measure, we compute the percent of consumption each period that would make a household indifferent between the flexible price and wage economy and the sticky price and wage economy under the specific monetary policy. The second measure computes the percent of consumption each period that would make a household indifferent between the sticky price and wage economy with a Taylor rule and the economy under a nominal GDP target or gold standard. Formally, the measures can be expressed as:

$$\lambda = 100\left(\exp\left[(1-\beta)\left(\mathbb{E}\left(V^1\right) - \mathbb{E}\left(V^2\right)\right)\right] - 1\right) \tag{5.1}$$

where $\mathbb{E}\left(V^1\right)$ is the expected value of welfare, either for the corresponding flexible price world or the sticky wage and price economy with a Taylor rule and $\mathbb{E}\left(V^2\right)$ is

13. Note that Garín et al. (2016), who argue that nominal GDP targeting has desirable features, do not include permanent trend productivity shocks in their analysis.

the expected value of welfare for all three monetary policies, for the first measure, or the gold standard or nominal GDP target for the second measure. We can interpret λ as the percent of consumption in that households must be given on a quarterly basis in perpetuity such that they are indifferent between staying in the economy V_2 and switching to the alternative economy V_1. More desirable monetary policies correspond with lower values of λ.

Table 4 presents the welfare measures, which are derived using a second order approximation. For the given estimated shock volatilities and model parameters, the most desirable monetary regime is the Taylor rule. The welfare loss of the Taylor rule compared to the flexible price economy is 0.1084% of consumption. Nominal GDP performs almost as well as the Taylor rule. The welfare loss of a nominal GDP target is 0.3235% of consumption compared to the flexible price economy and is 0.2149% of consumption compared to the Taylor rule. The gold standard performs very poorly relative to the Taylor rule and nominal GDP target. The welfare loss of the gold standard is 3.6523% of consumption compared to the flexible price economy and is 3.5401% of consumption compared to the Taylor rule.

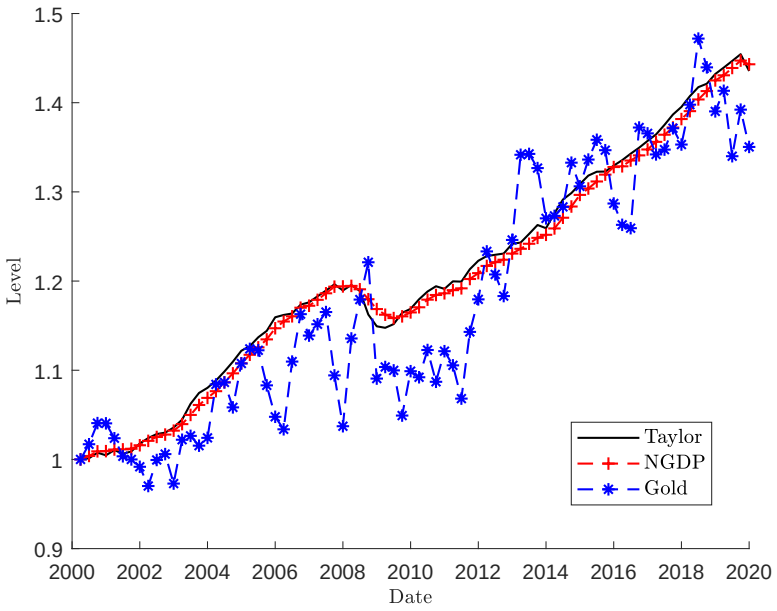
To emphasize the contribution of the gold shocks to the deterioration of welfare under the gold standard, we also include the consumption equivalent losses of all three monetary policies without the gold shocks present. Given that shocks to gold demand and supply do not affect output and inflation under the nominal GDP target or Taylor rule, there is no change in the welfare loss of either policy without the shocks present. However, there is a substantial improvement in the gold standard performance. Without gold shocks, the welfare loss of the gold standard is 0.4231% of consumption, which is 3.2292% better than when gold shocks are present. The gold standard does worse than the nominal income target even without gold-specific shocks because of intertemporal preference shocks, which affect the term η_t in the expressions above. As can be seen in Figure 7, the nominal GDP target completely stabilizes output and inflation conditional on these shocks, whereas the gold standard does not. If we were to compute welfare losses conditional only on permanent productivity shocks, the gold standard would actually outperform the nominal GDP target, consonant with the intuition laid out earlier.

6 Conclusion

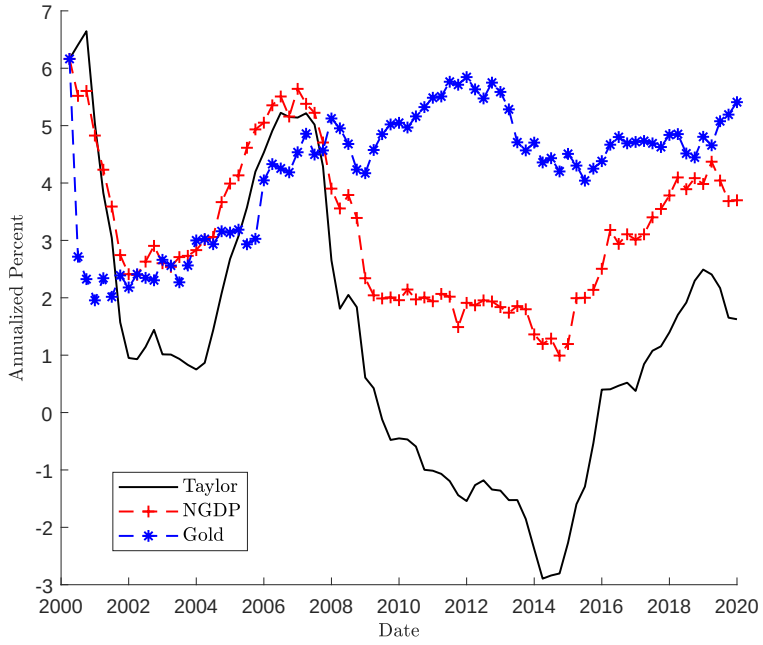
Moving the debate on the merits of the gold standard to a modern quantitative framework is important. It allows for a formal evaluation of trade-offs that cannot be estab-

Figure 4: Historical Counterfactuals

(a) Output



(b) Policy Rate



Notes: Black solid line represents current monetary policy with an assumed Taylor Rule. The red line is the historical counterfactual with a nominal GDP target. The blue line is the historical counterfactual under a gold standard. All three estimates start at the initial state, 2000 Q1.

lished in the confines of a discussion based on pure rhetoric. We determine that there are positive aspects associated with the implementation of the gold standard. For instance, in a world with only trend growth shocks to productivity and/or labor supply shocks, we find that the gold standard can outperform more conventional policies such as nominal GDP targeting. This is because nominal GDP targeting does not adjust for changes in the growth trend, leading to more volatile inflation. This is in contrast to the gold standard, which would internalize these trend growth shocks through the associated changes in the supply of gold.

However, once we incorporate gold-specific shocks, the performance of the gold standard severely deteriorates. In contrast to more conventional policies, the gold standard is forced to react to shocks in the supply and demand for gold. We show that these shocks tend to be much more volatile than typical macroeconomic variables, such as GDP growth. This excessive volatility leads to substantially higher output growth volatility and inflation volatility in our modeling framework.

We show that the welfare difference between policy under the gold standard and the Taylor rule would be equivalent to a 3.5401% difference in per period consumption. This is an economically significant disparity that translates into a permanent difference in real consumption per capita of approximately $1,500 per year.[14] Moreover, our historical counterfactual suggests that the level of output would be almost 10% lower in the year 2020 had a gold standard been in place since 2000.

The goal of this study was to help formalize evaluation of the strengths and weaknesses of the gold standard. It turns out our findings align with what many in the economics profession already suspect. We view this study as a starting point and look forward to the continuing discussion of the merits of the gold standard in a modern quantitative framework, in which assumptions can be challenged and model choices can be questioned. It is only under this construct that we can push the conversation forward and better establish some formal structure to the debate. Without it, the arguments will continue on indefinitely.

14. Dollar value calculation based on real consumption per capita in 2012 dollars of $40,566 in 2019Q4.

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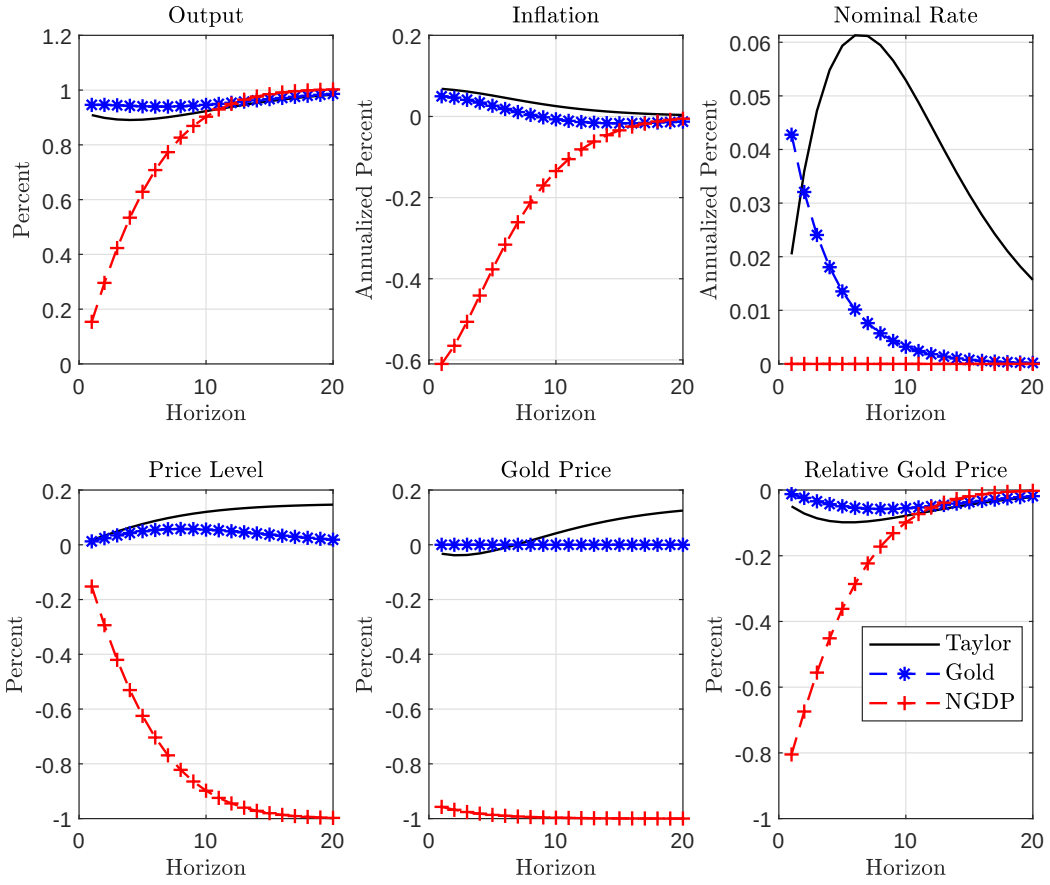
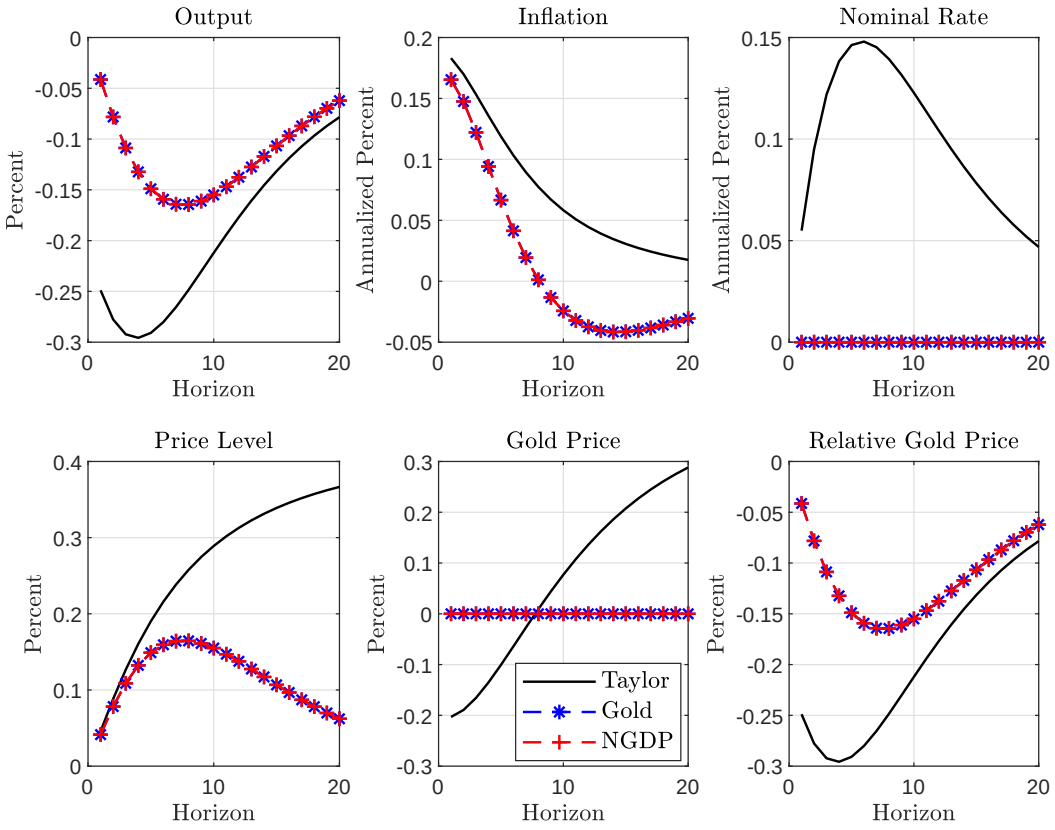
A Model Dynamics

Figure 5: Permanent Productivity Shock



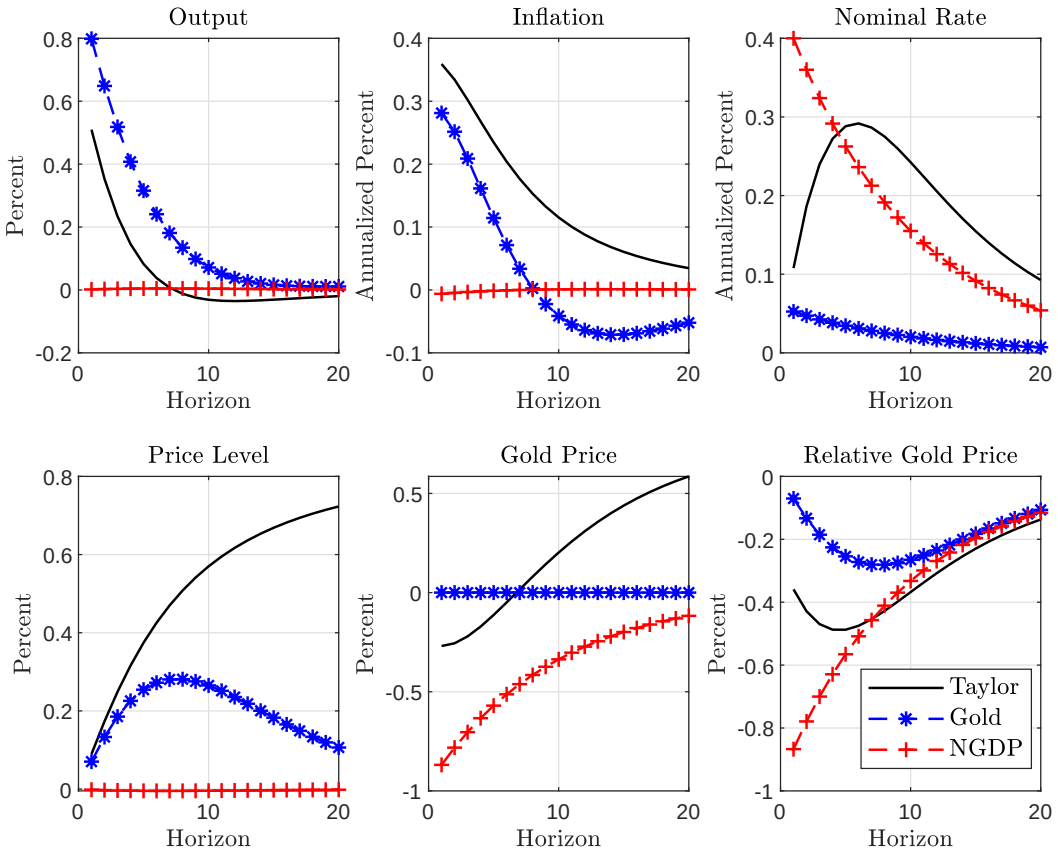
Notes: Black solid line: policy rate follows a Taylor rule; blue dashed lines: central bank follows a gold standard; red dashed lines: central bank follows a nominal GDP target. Impulse responses are to a 1 standard deviation shock to non-stationary productivity.

FIGURE 6: LABOR SUPPLY PREFERENCE SHOCK



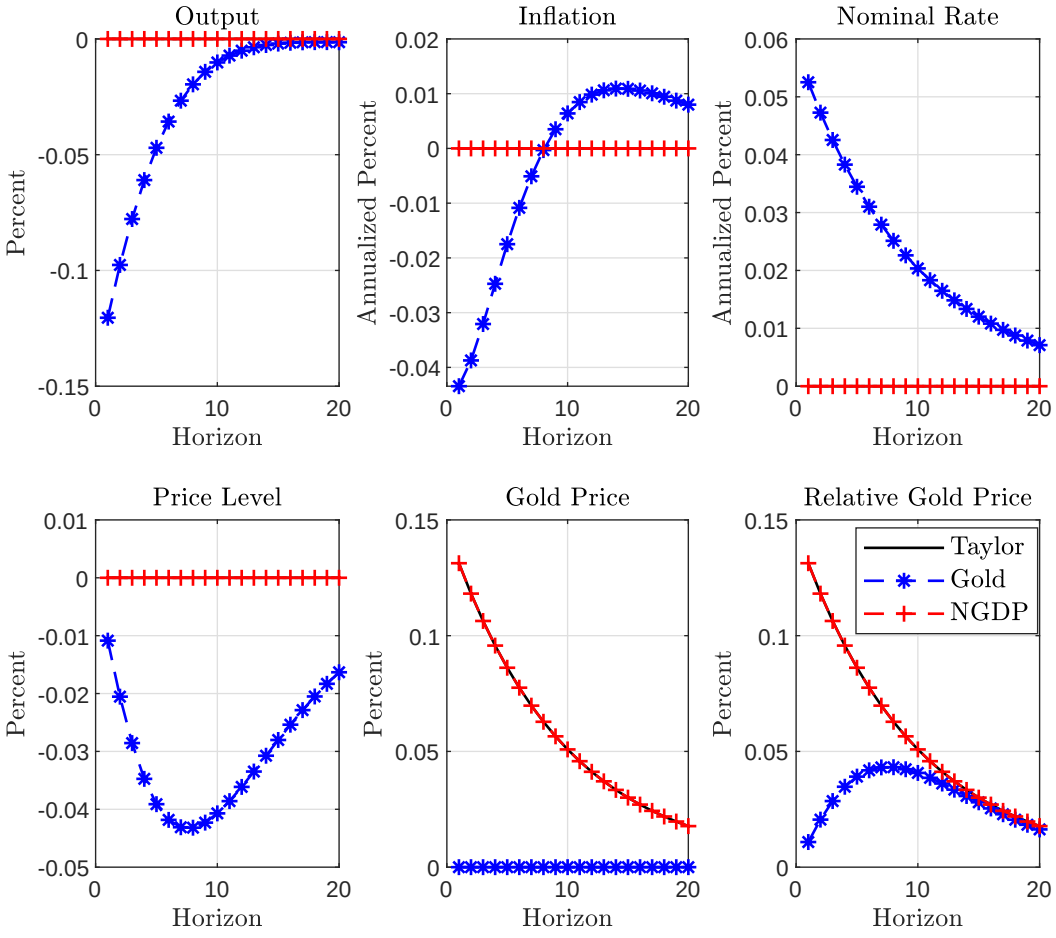
Notes: Black solid line: policy rate follows a Taylor rule; blue dashed lines: central bank follows a gold standard; red dashed lines: central bank follows a nominal GDP target. Since the dynamics under the nominal GDP target and gold standard are identical, the red dashed lines overlay the blue dashed lines. Impulse responses are to a 1 standard deviation shock to labor supply preference.

Figure 7: Intertemporal Preference Shock



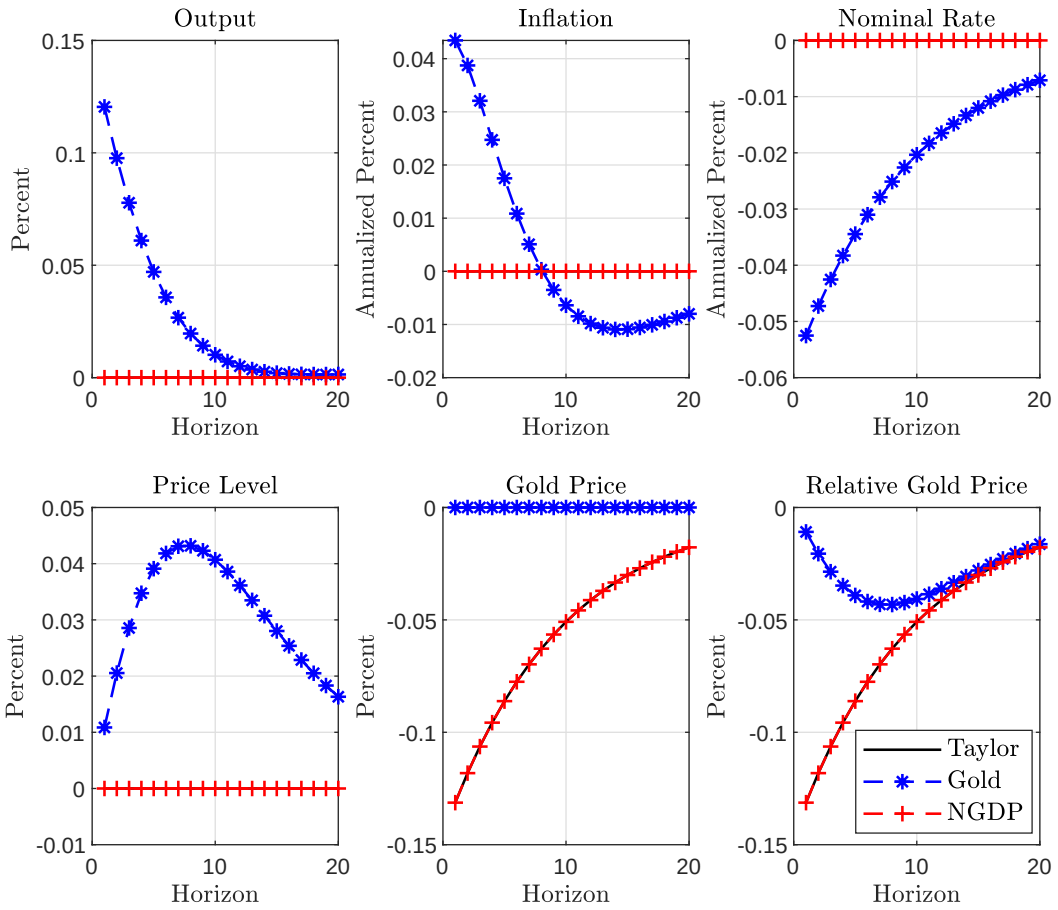
Notes: Black solid line: policy rate follows a Taylor rule; blue dashed lines: central bank follows a gold standard; red dashed lines: central bank follows a nominal GDP target. Impulse responses are to a 1 standard deviation shock to the household's discount factor

FIGURE 8: GOLD DEMAND SHOCK



Notes: Black solid line: policy rate follows a Taylor rule; blue dashed lines: central bank follows a gold standard; red dashed lines: central bank follows a nominal GDP target. Impulse responses are to a 1 standard deviation shock to household preference over gold holdings.

FIGURE 9: GOLD SUPPLY SHOCK



Notes: Black solid line: policy rate follows a Taylor rule; blue dashed lines: central bank follows a gold standard; red dashed lines: central bank follows a nominal GDP target. Impulse responses are to a 1 standard deviation shock to supply of gold.

B Welfare

Household welfare in recursive form can be written as:

$$V_t = \nu_t \left(\ln C_t - \psi_t \frac{N_t^{1+\chi}}{1+\chi} + \theta_t \ln G_t \right) + \beta \mathbb{E}_t V_{t+1} \tag{B.1}$$

After detrending the value function, we obtain:

$$V_t = \nu_t \left((1+\theta_t) \ln A_t + \ln \hat{C}_t - \psi_t \frac{N_t^{1+\chi}}{1+\chi} + \theta_t \ln \hat{G}_t \right) + + \beta \mathbb{E}_t V_{t+1} \tag{B.2}$$

Breaking up stationarized welfare into components:

$$V_t = \hat{V}_t^C + \hat{V}_t^N + \hat{V}_t^G + \Psi_t \tag{B.3}$$

where:

$$\hat{V}_t^C = \nu_t \ln \hat{C}_t + \beta \mathbb{E}_t \hat{V}_{t+1}^C \tag{B.4}$$

$$\hat{V}_t^N = -\nu_t \psi_t \frac{N_t^{1+\chi}}{1+\chi} + \beta \mathbb{E}_t \hat{V}_{t+1}^N \tag{B.5}$$

$$\hat{V}_t^G = \nu_t \theta_t \ln \hat{G}_t + \beta \mathbb{E}_t \hat{V}_t^G \tag{B.6}$$

$$\Psi_t = \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \nu_{t+j} \left(1 + \theta_{t+j}\right) \ln A_{t+j} \tag{B.7}$$

If A_t is normalized to 1, then Ψ_t can be written recursively as:

$$\Psi_t = \frac{\beta}{1-\beta} \nu_{t+1} \left(1 + \theta_{t+1}\right) \ln Z_{t+1} + \beta \mathbb{E}_t \Psi_{t+1} \tag{B.8}$$