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ABSTRACT

Which monetary regime is associated with the most stable price level? A commodity money regime such as the classical gold standard has long been associated with long-run price stability. But critics of the day argued that the regime was associated with too much short-run price variability and argued for reforms that look much like modern versions of price-level targeting. In this paper, we develop a dynamic stochastic general equilibrium model that we use to examine price dynamics under four alternative regimes. They are the gold standard, Irving Fisher's compensated dollar proposal, and two regimes with paper money in which the central bank uses an interest rate rule to run monetary policy. In the first, the central bank uses an interest rate rule to target the price of gold. In the second, there is no convertibility and the central bank targets uses an interest rate rule to target an inflation rate. We find that strict inflation targeting, even though it introduces a unit root into the price level, provides more short-run stability than the gold standard and as much long-term price stability as does the gold standard for horizons shorter than 30 years. We find that Fisher's compensated dollar reduces price level and inflation uncertainty by an order of magnitude at all horizons.

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I. Introduction

Which monetary regime is associated with the most stable price level? A commodity money regime such as the classical gold standard has long been associated with long-run price stability. Since the end of the gold standard, many economists have argued that a fiat money regime based on credible rules for low inflation could do better than commodity money (see, for example, Friedman 1951, 1960). In 1980 that promise was in doubt. High and variable inflation was the number one economic problem facing the major market-type economies. The U.S. gold commission was given a mandate to evaluate a future role for gold in the U.S. monetary system.¹ Since then, central banks appear to have learned how to maintain inflation at a low level. For many central banks, this new era has been characterized by central banks adopting implicit or explicit inflation targets.

In this paper we demonstrate that, in principle, inflation targeting may deliver as much price level stability as a commodity standard. We also show that the degree of instability in the price level under either regime is still an order of magnitude greater than is possible under a regime that stabilizes a path for the price level.

We use a dynamic general equilibrium model of a two-sector economy to evaluate the time series properties of the price level associated with alternative monetary regimes. Our model assumptions are based on the monetary business cycle model in Gavin and Kydland (1999) and the model of commodity money in Sargent and Wallace (1983) that addresses fundamental issues about welfare and the evolution of commodity money in a two-sector model. They showed conditions under which consumers are unambiguously

better off if convertible paper replaces gold coins as the circulating medium of exchange. And they showed that in a world with two capital goods, the one with the lower depreciation rate emerges as commodity money.

We first review in section 2 the behavior of the price level under the classical gold standard regime (1880-1913). We then examine the behavior of the price level under the recent fiat money regime (1968-2001). The main body of the paper (section 3) is a dynamic stochastic general equilibrium model of an economy with versions including either commodity money or a fiat currency. Next, we compare price dynamics under four alternative regimes—a pure commodity money standard, a commodity standard following Fisher’s compensated dollar proposal, and two regimes with paper money. In the first paper regime, the central bank uses an interest rate rule to stabilize the price of the commodity used as money. In the second, the central bank uses the interest rate instrument to target aggregate inflation in a pure fiat regime.

II. Historical Perspectives

The classical gold standard prevailed from 1880 to 1914. It provided a simple rule for domestic monetary authorities and for the international monetary system. The rule was to maintain the value of national currency in terms of a fixed weight of gold. Following this rule ensured long-run price stability through the automatic operation of a commodity-money standard.²

¹ See Report to the Congress of the Commission on the Role of Gold in the Domestic and International Monetary Systems, March 1982.

² See Barro (1979) and Bordo (1981) for an introduction to the operation of the gold standard in theory and in practice. Goodfriend (1988) and Fujiki (2003) discuss the role of Federal Reserve institutions in operation of the gold standard.

The degree of long-term price stability can be seen in Figure 1, which depicts annual values of the GDP deflator for 13 countries with the deflators indexed to 1 in 1880.³ Inflation averaged about 3 percent annually in Australia and Finland, about 2 percent annually in the Netherlands, and slightly less in the United States. For the other nine countries (Canada, Denmark, France, Germany, Italy, Norway Sweden, Switzerland and the United Kingdom), the average inflation rate was less than plus or minus 1 percent for the period.

We measure persistence in the price level using a median-unbiased estimate of the largest root in the characteristic equation of a univariate autoregressive model:

$$p_t = \alpha_0 + \gamma t + \sum_{i=1}^k \alpha_i p_{t-i} + \varepsilon_t, \quad (1)$$

where p is the log of the GDP deflator, t is a time trend, k is the number of lags of price level in the equation, and ε_t is a serially uncorrelated, homoskedastic random error term.

The largest autoregressive root, ρ , is defined as the largest root of the characteristic

equation $\lambda^k - \sum_{j=1}^k \alpha_j \lambda^{k-j} = 0$.

A median unbiased estimate of the largest root is calculated using the test statistic from the augmented Dickey-Fuller (1981) equation, which is a transformed version of equation (1):

$$p_t = \alpha_0 + \gamma t + \alpha_1 p_{t-1} + \sum_{i=1}^k \omega_i \Delta p_{t-i} + \varepsilon_t, \quad (1')$$

³ The GDP deflator was not available for Switzerland in the late 1800s, so we use the CPI. The data sources for the gold standard era for all countries except Australia are described in an appendix to Bordo and Jonung (2001). The price data for Australia come from private communication between Michael Bordo and David Pope at the Australian National University.

where $\omega_i = \alpha_i - \alpha_{i-1}$. A distribution for OLS estimates of the 't' statistic, denoted τ_τ , on α_1 is presented in Fuller (1976). We use the Akaike information criterion to choose the lag length, k . Using Table A1 from Stock (1991), information about τ_τ can be used to form a median-unbiased estimate of the largest root, ρ^{MU} , for each price series. We also present the 95th percentile value for this estimate, ρ^{95} , which is the upper limit of a 90 percent confidence interval.

Table 1 reports k , ρ^{MU} , ρ^{95} , and σ_ε . The first four columns report results for the gold standard era and the last four columns for the modern era. During the gold standard period we found that the average lag chosen was two years, although the mode was only one. The median unbiased estimates of the largest root ranged from 0.53 in the Netherlands to 1.08 in Canada. The average was 0.89. We never reject the null hypothesis of a unit root at the 5 percent critical level (a one-sided test; $\rho^{95} > 1$ in every case).

We have also included the standard error of the estimate (SEE) of the Dickey-Fuller equation as a measure of the short-run predictive uncertainty. Here the average standard error was 3.59 percent annually. It was partially the relatively high short-run uncertainty about the price level that led Irving Fisher and others to advocate reform of the gold standard.

The classical gold standard ended with World War I. After the war it was reinstated as a gold exchange standard whereby member countries could hold international reserves as gold or in the currencies of the key countries: Britain, France, and the United States. The gold exchange standard was short-lived. Eichengreen (1992) describes the collapse beginning in 1931 in the face of the Great Depression and

attributes it to fatal policy mistakes made by the U.S. and France. The Bretton Woods System established in 1944 was a weak variant of the gold standard. Under this system, the U.S. maintained gold convertibility at \$35.00 per ounce while the other members maintained current account convertibility in dollars. Most of the adjustment mechanism of the gold standard was thwarted and monetary policy was only in part constrained by gold. Gold cover for currency issue was eliminated in the United States in 1968 and the final link with gold was cut in August 1971 when President Nixon permanently closed the gold window. Gold has no monetary role anywhere in the world since the 1970s.

Today's economies use fiat money and base their nominal anchor on policy rules such as inflation targeting. It took some time following the collapse of Bretton Woods for central banks to learn how to maintain low inflation and relative price stability. Figure 2 shows the path for the GDP deflator in the same 13 countries that had been on the gold standard.⁴ The three most successful countries, Germany, the Netherlands, and Switzerland had 3 percent average annual inflation rates, comparable to Australia and Finland under the gold standard. The worst performance was in Italy where the price level rose by a factor 18 (8 percent average annual inflation rate). In the United Kingdom the price level rose by a factor of 11 (6.7 percent inflation average). For the other 8 countries, the price level rose between a factor of 4.2 in the United States (4.0 percent average inflation) and 7.9 in Sweden (6.1 percent average inflation).

The greater rise in price levels for the fiat money era is also matched by higher estimates of persistence. The last four columns of Table 1 report the summary statistics

⁴ The modern GDP deflator data are calculated from time series of real and nominal GDP provided by the OECD as of January 2003.

for the period from 1968 to 2001.⁵ The average lag length is 2.9 for the 13 countries. The median unbiased estimates of the largest root range from 0.53 in the United Kingdom to 1.09 in Australia, Canada, and Sweden. The average ρ^{MU} for the period was 1.00. Not surprisingly, we find that ρ^{95} is greater than unity for all the countries. Here the persistence is higher than for the gold standard era, but the SEE is also much smaller. The average is 1.78 percent, about half of the estimate for the gold standard era.

Although the average inflation rate was higher during the fiat standard, the short-run predictive uncertainty was lower. Klein (1975) noted that although the gold standard was associated with long-term price stability, there was more short-run price uncertainty than there was in the post-WWII era. If we define price stability by a measure of the short-run predictability of the price level, then the gold standard actually produced less short-run price stability than did the fiat regime in the high inflation era following the breakup of Bretton Woods. Of course, some of the difference may be due to measurement issues. Meltzer and Robinson (1989) discuss the importance of changes in the composition of GDP as well as in the data collection process. These changes probably would have made the price indexes less variable, even if we had kept the same monetary regime.

In what follows we use the criteria shown in Figures 1 and 2 and in Table 1 to evaluate the relative stability of alternative monetary regimes. Our method is to develop a two-sector model in which the good from one of the sectors may be used as commodity money. We consider four different government policies—although we do not model the

⁵ We begin the modern era in 1968 because the fixed exchange rate regime based on a fixed dollar-gold price was beginning to unravel by this time. Beginning in 1968 also allows us to have the same number of years as we have for the gold standard era.

costs or uncertainty typically associated with government activity. We assume that policy is fully credible and can be implemented without using real resources. For each policy we conduct a large number of experiments and record the histories that are generated. From the generated data, we construct charts showing the distribution of price levels associated with the policy rules. We also use the data to generate measures of persistence and unit root tests, reporting the distribution of estimated parameters associated with each regime.

III. Commodity Money in a Two-Sector Model

We begin with a simple model in which there are two goods: gold and a composite good which includes everything but gold. The production sectors for these two goods are embedded in a neoclassical growth model. There are separate shocks to production technology in each sector, but no aggregate shock. Both goods are consumed and used as capital in both sectors. Gold is also used as money. Holding money balances reduces the time that is spent shopping. The government (central bank) in the first version of our model defines the numeraire by setting the mint ratio for gold coins and then, at zero cost, supplies minting and melting services at the end of the period.

The Economy. This model is modified from the one-sector model in Gavin and Kydland (1999). To simplify the discussion (and because none of our results depend on having an exogenous growth trend), we describe the model without growth. Many identical households inhabit the model economy. Each household maximizes expected lifetime utility

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t u(c_{1,t}, c_{2,t}, \ell_t) \right], \quad (2)$$

where c_1 is nonmonetary gold, c_2 is a composite good that includes everything else, $0 < \beta < 1$ is a discount factor, and ℓ_t is leisure time. The functional form of the current-period utility function is

$$u(c_{1,t}, c_{2,t}, \ell_t) = \frac{1}{1-\gamma} \left[c_{1,t}^{\mu_1} c_{2,t}^{\mu_2} \ell_t^{1-\mu_1-\mu_2} \right]^{1-\gamma}, \quad (3)$$

where $0 < \mu_1, \mu_2 < 1$, $0 < \mu_1 + \mu_2 < 1$, and $\gamma > 0$ but different from 1.

In each period the infinitely lived representative consumer decides how to allocate time between work, leisure, and time spent shopping for consumption goods. Larger money balances brought into the period decrease shopping time and increase the amount of time that can be allocated to work and leisure. At the end of the period, households decide how much money to carry into the next period. In the case of commodity money, they decide how much gold to convert into gold coins (or how many coins to melt). This conversion, which is assumed to be a reversible transformation, is done only at the end of the period.

Household time spent on transactions-related activities in period t is given by

$$f(\chi_t) = \omega_0 - \Omega \chi_t^\omega. \quad (4)$$

Real balances, χ_t , are defined per unit of consumption equal to $m_t / \sum_{i=1}^2 p_{i,t} c_{i,t}$,

where m_t is the nominal stock of money, $p_{i,t}$ is the price of good i , and Ω is the level of payments technology, which is assumed to be constant. The price of gold, $p_{1,t}$, is the numeraire, set equal to 1 in the first version of our model. By restricting Ω and ω to have the same sign and $\omega < 1$, the amount of time saved increases as a function of real money

holdings in relation to consumption expenditures, but at a decreasing rate. The budget constraint on time is given by

$$\ell_t + \sum_{i=1}^2 h_{i,t} + \omega_0 - \Omega \chi_t^\omega = 1, \quad (5)$$

where $h_{i,t}$ is time spent in production of good i .

Sector output, $Y_{i,t}$, is produced using labor and capital inputs:

$$Y_{i,t} = z_{i,t} H_{i,t}^{b_i} \prod_{j=1}^2 K_{i,j,t}^{a_{i,j}}, \quad (6)$$

where $z_{i,t}$ is the level of technology that is subject to transitory shocks, and $b_i + \sum_{j=1}^2 a_{i,j} = 1$.

Both goods are used as capital in both sectors. Competitive factor markets imply that in equilibrium each factor receives its marginal product. A law of motion analogous to that for individual capital describes the aggregate quantity of capital. The distinction between individual and aggregate variables is represented here by lowercase and uppercase letters, respectively. The technology changes over time according to

$$z_{i,t+1} = \rho_i z_{i,t} + \varepsilon_{i,t+1}^z, \quad (7)$$

where $0 < \rho_i < 1$ and the innovation $\varepsilon_{i,t+1}^z$ is distributed with a positive mean and with variance $\sigma_{z,i}^2$. The steady-state level of technology is chosen so as to normalize output in each sector to 1.

The budget constraint for the typical individual is

$$\begin{aligned} \sum_{i=1}^2 p_{i,t} c_{i,t} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} k_{j,i,t+1} + b_{t+1} + m_{t+1} = \\ \sum_{i=1}^2 p_{i,t} z_{i,t} h_{i,t}^{b_i} \prod_{j=1}^2 k_{i,j,t}^{a_{i,j}} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} (1 - \delta_{j,i}) k_{j,i,t} + (1 + R_t) b_t + m_t. \end{aligned} \quad (8)$$

On the left hand side, the total of household consumption in period t plus assets carried into period $t+1$ (capital, net bonds, and money balances) are equal to output produced in period t plus assets brought into period t (capital, net bonds, and money balances) minus depreciated capital plus interest on net bonds.

Competitive Equilibrium. A competitive equilibrium is achieved when the representative household and firm solves its optimization problem and all markets clear. The agent's decisions can be reduced to the choice of labor hours, $h_{i,t}$, next period's capital stock, $k_{i,j,t+1}$, next period's money balances, m_{t+1} , and net nominal borrowing, b_{t+1} . When these choices are subtracted from the agent's nominal income in the period, what is left will be split across consumption so as to satisfy the first-order conditions for consumption:

$$\frac{\frac{\partial u}{\partial c_j}(\bullet_t)}{\frac{\partial u}{\partial c_i}(\bullet_t)} = \frac{p_{j,t}}{p_{i,t}}. \quad (9)$$

The ratios of the marginal utilities of each type of consumption are equated to their relative prices in each period.

To simplify the agent's first-order conditions, we define

$$\kappa_{i,t} = \frac{1}{p_{i,t}} \frac{\partial u}{\partial c_i}(\bullet_t) + f_1(\chi_t) \frac{\chi_t^2}{m_t} \frac{\partial u}{\partial l}(\bullet_t), \quad (10)$$

This is in effect an augmented marginal utility of consumption that takes into account not only the direct impact of consumption on utility, but also the indirect effect that consumption has on leisure through its effect on shopping time. Equating these augmented marginal utilities across consumption goods gives us the intra-temporal first-

order condition discussed above. Since these are equal across all forms of consumption, we can more simply express first-order conditions in terms of $\kappa_t = \kappa_{1,t}$. We also note that, since individual output production functions have the form

$$y_{i,t} = z_{i,t} h_{i,t}^{b_i} \prod_{j=1}^2 k_{i,j,t}^{a_{i,j}}, \quad (11)$$

we can write the marginal product of the various types of capital as $a_{i,j} \frac{y_{i,t}}{k_{i,j,t}}$ and of

various types of labor as $b_i \frac{y_{i,t}}{h_{i,t}}$. These conventions allow us to write the agent's first-

order conditions taken with respect to labor as

$$\frac{\partial u}{\partial l}(\cdot_t) = p_{i,t} b_i \frac{y_{i,t}}{h_{i,t}}. \quad (12)$$

This is similar to the usual condition that sets the ratio of the marginal utility of leisure to the marginal utility of consumption equal to the wage rate. The first-order conditions taken with respect to the various kinds of capital take the form

$$E_t \left[\left(\frac{p_{i,t+1}}{p_{j,t}} a_{i,j} \frac{y_{i,t+1}}{k_{i,j,t+1}} + \frac{p_{j,t+1}}{p_{j,t}} (1 - \delta_{i,j}) \right) \frac{\kappa_{t+1}}{\kappa_t} \right] = \frac{1}{\beta}. \quad (13)$$

The term in parentheses above can be thought of as a nominal return to the various types of capital. Therefore this first-order condition can be thought of intuitively as the agent choosing capital levels so as to equate their expected nominal returns. The first-order condition for nominal lending or borrowing takes the form

$$E_t \left(\frac{(1 + R_{t+1}) \kappa_{t+1}}{\kappa_t} \right) = \frac{1}{\beta}. \quad (14)$$

The first-order condition for next period's money balances is not as intuitively meaningful as the conditions above due to the fact that the choice of money impacts the leisure choice in two ways. The amount of money held has not only a direct effect on shopping time, but an indirect one as well because it decreases the amount of consumption. One way of writing the first-order condition for money balances is

$$E_t \left(\frac{\kappa_{t+1} - f_1(\chi_{t+1}) \frac{\chi_{t+1}}{m_{t+1}} \frac{\partial u}{\partial l}(\bullet_{t+1})}{\kappa_t} \right) = \frac{1}{\beta}. \quad (15)$$

If the agent's choices don't affect his shopping time, i.e., $f_1(\chi) \equiv 0$, then the condition above reduces to the standard

$$E_t \left(\frac{p_{1,t} \frac{\partial u}{\partial c_1}(\bullet_{t+1})}{p_{1,t+1} \frac{\partial u}{\partial c_1}(\bullet_t)} \right) = \frac{1}{\beta}. \quad (16)$$

Money will only be held in equilibrium if its expected return matches the rate of time preference.

To approximate the dynamics of the model, we use the approach described in King and Watson (1998). In the simple commodity money model we can reduce the agent's decisions to the choice of $h_{I,t}$, $k_{Ij,t+1}$, and m_{t+1} . Consumption ratios are equal to price level ratios, and since net borrowing is zero in equilibrium the choice of b_{t+1} has no real effects on any of the model's variables in equilibrium. The equilibrium conditions that determine the price levels are goods market clearing and the government's choice for the mint price of gold.

Calibration

We assume that the gold sector uses only 5 percent of available labor, but that this sector is slightly more capital intensive than the other sector. The labor share is set to 65 percent in the gold sector and 70 percent in the non-gold sector. The share of gold capital is small relative to other capital. We assume the gold capital share is 0.05 in the gold sector and 0.03 in the goods sector. We use a quarterly depreciation rate of 0.005 for the gold capital and 0.025 for other capital.

There are two independent shocks to production technology, one in the gold sector and one in the goods sector. Historically, shocks to the gold sector took many forms. There were new gold mines discovered, new veins of gold in existing mines, and permanent improvements in the technology for extracting gold. In this paper, we consider only a temporary shock to the gold sector. Consider our shock to gold production to be the discovery of a new vein of gold in an existing mine. The newly discovered veins have layers of gold that are increasingly more costly to extract so that the increase in productivity is persistent, but not permanent. We assume the standard deviations of the goods and gold shocks are 1 and 2 percent per quarter, respectively. Because we had no reason to assume the gold shocks were more or less persistent than shocks to the goods sector, we set the autocorrelation parameters, ρ_i , to 0.95 for both sectors.

Turning to the household sector, the quarterly discount factor, β , is approximately 0.99. The risk-aversion parameter, γ , is set equal to 2, which means more curvature on

the utility function than that corresponding to logarithmic utility. This value is consistent with the empirical findings of Neely, Roy, and Whiteman (2001).

In addition to normalizing steady-state output to unity in each sector, we can normalize the price of gold to unity as well. These choices, coupled with an assumption about the income velocity of money, determine the steady state money stock. We use the value in Friedman and Schwartz (1963) who report that M2 velocity was about 4 when the United States went on the gold standard in 1879. The parameter Ω can then be derived from the household's first-order condition for the choice of money holding. The implied value of Ω is -0.0037. We calibrate the money-time tradeoff so that the implied steady-state money demand function has an interest rate elasticity of $-1/3$ and a consumption elasticity of $2/3$.

Without loss of generality, we choose time units so that $\sum_{i=1}^2 h_{i,t} + \ell = 1$. We assume that the workweek was somewhat longer a century ago. Atack and Bateman (1992) report that the standard manufacturing workweek was 10 hours per day, six days per week in 1880. This is much higher than today, but there were fewer second workers in each household then. We set n to 0.33 for the gold standard, slightly higher than we would for today. This may be a conservative adjustment, but our results for price dynamics are not sensitive to the assumption. The μ_i , the share of gold and non-gold consumption in the utility function, typically are determined from an intra-temporal substitution condition such as $MU_g/MU_c = w$. In the case of a one-sector model, the share of consumption would typically turn out to be close to total time spent working. Here the majority of working time is spent in the non-gold sector, so μ_2 here is quite

close to total labor time. Since the intra-temporal trade-off between labor and consumption is complicated in our model by the presence of shopping time, the ratio of marginal utilities depends on both wage rates and shopping time. The first-order condition taken with respect to labor is used to calculate the values of μ_i implied by the model calibration; these are $\mu_1 = .015$ and $\mu_2 = .341$. These calibrations are the same for all four versions of the model that are considered below.

IV. Dynamics of Adjustment with Commodity Money

Gold Standard. The government sets the mint ratio for gold at the desired level. Figures 3 and 4 show the response of our gold standard economy to technology shocks. In the top panel of Figure 3 we show the sector responses to a gold technology shock. Resources move to the gold sector to take advantage of the higher marginal products for capital and labor. By the end of the second period, gold output rises almost 13 percent above the steady state. The output of other goods declines slightly in the second period as labor and capital of both types move to the gold sector. The price of other goods jumps about 1 percent in the first period and then gradually falls back over the next three years as the economy adjusts most of the way back to the steady state.

The lower panel in Figure 3 shows how the economy responds to a shock to production technology for goods. The economic responses to a goods shock are much larger than to a gold shock because the goods sector uses 95 percent of market labor time (in the steady state) and represents about 93 percent of expenditures on output. Following this goods technology shock, gold output falls 8 percent below the steady state as resources now move to the goods sector. Goods output peaks about 2 percent above

the steady state in the second quarter following the shock. The price of goods declines by about 1 percent in the first period and returns close to the steady state in the second.

This result that output in the two sectors move counter to one another in response to sector shocks is common in multi-sector models without adjustment costs. Murphy, Shleifer, and Vishny (1989) showed that market-clearing multisector models without some frictions could not explain the positive co-movement of output and hours across sectors that is typically found in business cycle data. They showed that immobile labor or credit imperfections could be used to generate co-movement among sectors. Huffman and Wynn (1999) show that adding intratemporal adjustment costs to a multisector model also tends to make the model data mimic modern economies where all sectors move together. While this rapid transfer of capital and labor across sectors is not typical of modern business cycles, it is consistent with stories from the period. Certainly, the discovery of gold at Sutter's mill in California in 1848 led to a rapid deployment of labor and capital to the area. Since our empirical work and experimental calculations are reported for annual averages and economy aggregates, this high-frequency negative co-movement does not have an important impact on our results.

In Figure 4, we show the responses of the money stock as well as aggregate indexes for output and prices. We use the steady-state values as fixed weights in the aggregation. The steady-state output levels are normalized to unity, so the aggregate price level is just the sum of the sector prices. We use the steady-state prices (unity for gold and 17.6 for goods) as relative weights in the output index. The top panel of Figure 4 shows the aggregate response to a 2 percent gold shock. The price level jumps about 1 percent above the steady state and then returns very slowly to the steady state. Total

output rises very slightly in the first period, about 0.2 percent, then falls slightly below the steady-state level in the second period. A shock to the gold sector lowers the money stock in the second period (established at the end of period one) as some gold coins are melted and used as capital in the next period's gold production. Over time, the increase in the gold supply causes the money supply to rise to a peak of about 1-1/2 percent above the steady state after four years. It then begins a very gradual return to the steady state.

The bottom panel shows the aggregate response to a goods shock. A 1 percent shock to the goods technology leads to a peak in output in the second period about 1.6 percent above the steady state. The price level falls by 0.7 percent in the first period, stays at that level for about 2 years, and then begins a slow return to the steady state. Notice that although the gold sector is much smaller and a gold shock has only a small effect on real output, it has about the same order of magnitude impact on the aggregate price level as does the goods sector shock. Following a shock to goods technology the money supply moves slightly higher in the first period. The relative price of gold has risen, so the money supply falls for 2 to 3 years, to about 0.8 percent below the steady state before beginning a very gradual return back to the steady-state level.

We measure the persistence in the price level implied by our model by computing the largest autoregressive root in repeated experiments. We draw 1000 samples each 34 years long. We aggregate to annual data and estimate the augmented Dickey-Fuller equation (1') as we did for the actual data. The only differences are that we do not have any growth trends in the model so we do not include a time trend in the estimation and we assumed that the lag, k , was 2 years. In the top row of Table 3, we report results for our model under the gold standard. Here the price level is persistent because the output

shocks are persistent. The period, 34 years, is not enough to reject a unit root in this model economy. In the bottom panel we show that with 125 years, ρ^{95} is less than unity for this regime.

Fisher's compensated dollar. The next regime we consider is based on an early proposal to have the central bank target a price index. Although the price level was relatively stationary during the gold standard era, there were large price fluctuations and, at the time, many economists felt that they were destabilizing and argued that a central bank could do better by stabilizing a broad price index. Fisher (1920) proposed the compensated dollar scheme. Fisher (1934) also traces the evolution of the idea of a monetary standard based on a price index and describes 28 19th century proposals made by legislators and prominent economists.⁶

Under Fisher's compensated dollar plan the government would systematically adjust the mint ratio to keep the aggregate price level stable. While this plan was never implemented, it is interesting because it is a forerunner of modern proposals to target the price level and actual inflation-targeting regimes. In this simple case with only gold coins circulating as money, the model is the same as the gold standard except that the government manages the mint ratio so that the price of goods is stabilized at its steady-state level. We assume that the government's policy is fully credible. As we did with the gold standard, we have abstracted from the resource costs that would occur if the government actually implemented the policy scheme. Our interest is in understanding how the economy adjusts to shocks when the government varies the gold price to stabilize the price level.

The output responses are nearly identical under the two regimes and are not shown here. The significant differences between the performance of the economy under the alternative regimes are at the sector level. The compensated dollar standard requires the mint ratio to be adjusted in a way that causes a larger change in the relative price of gold in response to all shocks. Figure 5 shows the relative price response to both shocks under both regimes. Under the gold standard, the gold price is fixed and the price level rises about 1 percent in response to a 2 percent gold shock. To prevent the price of the non-gold goods from rising 1 percent, the government must lower the mint ratio by more than 1.5 percent.

There are important differences between the gold standard and the compensated dollar in the behavior of price level and the money supply. The aggregate price level moves about 1 percent in response to both shocks under the gold standard and hardly at all under the compensated dollar regime. Figure 6 shows how the money supply differs under the two regimes. Under the gold standard a gold shock causes a large rise in nominal consumption expenditures that leads to a rise in the demand for money balances. This effect dominates the relative price effect that induces an increased use of gold capital in the gold sector. Under the compensated dollar, nominal consumption spending is relatively unchanged. The lower relative price of gold causes it to be used more intensely in gold production with a small negative effect on the level of money balances.

⁶ Included among them were Stanley Jevons in 1876, Robert Giffen in 1879, Leon Walras in 1885, Alexander Del Mar in 1885, Alfred Marshal in 1887, F.Y. Edgeworth in 1889, and Knut Wicksell in 1898.

After a shock to technology in the goods sector, the government raises the mint ratio by more than 1 percent. Under both standards, the rise in the relative price of gold tends to make money balances fall. Under the gold standard, the aggregate price level and nominal consumption fall, lowering money balances. In the case of the compensated dollar, the increase in consumption with a relatively fixed aggregate price level raises the desired amount of money balances. The result is that a goods shock induces a persistent rise in money balances above the steady state.

Fisher advocated the compensated dollar standard because he felt that the goods price fluctuations under the gold standard (caused by shocks to the market for gold) were a source of harmful output fluctuations. This is not the case in our model because there is no nominal price stickiness. However, we think that price flexibility is probably an acceptable assumption for that era. First, we note that a much larger share of the economy was related to agriculture where, even today, prices are more flexible. Second, Calomiris and Hubbard (1989) and other researchers cited by them report evidence of rapid price adjustment to monetary developments for this gold standard era.

The price stability statistics for the compensated dollar regime are shown in the second row of Table 3. The results for ρ^{MU} and ρ^{95} are nearly identical to those found under the gold standard, but the standard error of the price level is more than an order of magnitude smaller. Clearly, Fisher's proposal induces short-run price stability. Again, there is no unit root here, but 34 years does not produce enough data to reject the null hypothesis that there is one. However, when we extend the experiment to 125 years we reject a unit root.

V. Dynamics of Adjustment with Fiat Money

The demise of the gold standard is attributed to many factors. Conceptually, one of the important ideas was that gold is a real resource with uses other than money. If the government's monetary program is credible, replacing costly gold with paper money should release real gold resources and result in higher welfare (See Friedman 1960 and Sargent and Wallace 1983). We model that idea in this section. Imagine a country (such as Sweden) where the government and the banking system operated with convertible paper money and low gold reserves.⁷ Actual reserves were very low because the policy was credible. As long as people were willing to hold the paper as if it were gold coins, there was little need to hold large gold reserves.

In this section we add government-supplied fiat money to the model and consider the limiting case where no gold is used as money. The budget constraint, equation (8), is modified by adding transfers at time t to the RHS.

$$\begin{aligned} \sum_{i=1}^2 p_{i,t} c_{i,t} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} k_{j,i,t+1} + b_{t+1} + m_{t+1} = \\ \sum_{i=1}^2 p_{i,t} z_{i,t} h_{i,t}^{b_i} \prod_{j=1}^2 k_{i,j,t}^{a_{i,j}} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} (1 - \delta_{j,i}) k_{j,i,t} + (1 + R_t) b_t + m_t + v_t. \end{aligned} \quad (8')$$

Transfers at time t , v_t , can be used to reduce shopping time in period $t+1$.⁸ The paper money drives out all the gold and the government uses an interest rate rule to manage the quantity of money. The central bank manipulates transfers to implement a backward-looking interest rate rule of the type:

$$R_{t+1} = \bar{R} + v_\pi (\pi_t - \bar{\pi}) + v_p (p_{1t} - \bar{p}_1), \quad (17)$$

⁷ See Jonung (1984).

⁸ This follows the timing convention in Kydland (1989).

where R_{t+1} is the period $t+1$ nominal interest rate target chosen by the central bank at the end of period t (or, equivalently, at the beginning of period $t+1$); $\pi_t = \ln P_t - \ln P_{t-1}$ is the aggregate inflation rate; p_{1t} is the log of the price of gold, and the bar over a symbol refers to the steady-state value.

We examine two alternative policy rules, the first with $\nu_\pi = 0$ and $\nu_p = 0.333$ and the second with $\nu_\pi = 1.5$ and $\nu_p = 0$. The first is a target for the gold price. This policy is meant to mimic a gold standard, but with an elastic currency that absorbs shocks to the market for money.⁹ The second is a target for inflation in the aggregate price level. The response of the price level to shocks under these regimes (and the gold standard) is summarized in Figure 7.

Gold Price Target. In this regime the central bank sets the nominal interest rate equal to the steady state plus 0.333 times the deviation of the gold price from the steady state. We chose this value because it results in gold price fluctuations of plus and minus 1/2 percent from par, close to actual experience during the late 19th century. In this regime, all gold is consumed or used as capital, so output, consumption, and the capital stock are all slightly larger than they are when gold coins are used as money.

Price level dynamics under this regime are almost identical to those under the gold standard. Following a gold technology shock, the price of other goods rises and the price of gold falls slightly. The real rate rises with the increase in the marginal return to capital. The policy rule requires the nominal rate to fall below the steady-state rate. The equilibrium path for the price level requires a long period with enough deflation to yield

the spread between the real rate and the nominal rate implied by the rule. This is achieved by the unexpected rise in the price level associated with the shock and the subsequent gradual return to the steady state. The size of the government's reaction determines how much the price level will jump. A more aggressive response--a larger parameter--causes a larger initial jump in the price of other goods and a higher average deflation during the transition back to the steady state.

Following a shock to goods technology, the price of gold tends to rise and the price of other goods falls. As in the case of the gold shock, the real rate rises. Now, the nominal rate must also rise to prevent the gold price from rising. An equilibrium response with the gold price policy rule requires the price level to fall enough in the initial period so that the subsequent inflation is consistent with the paths for nominal and real interest rates.

The third row of Table 3 shows that the short-run variability of prices (as measured by the SEE in estimates of the augmented Dickey-Fuller equation) is about 50 percent higher than under the gold standard. The amount of persistence in the price level, as measured by the largest root in an autoregressive model of the price level, is about the same. Again, we find that it takes almost 125 years of data to reject a unit root in the log of the price level.

Inflation Targeting. In our final regime, the central bank sets the nominal interest rate to stabilize inflation in the aggregate price index. Here, again, we assume complete

⁹ See Goodfriend (1988) for an analysis of asset prices in a model where the central bank uses the gold reserve ratio in a convertible fiat system to achieve temporary monetary policy objectives while keeping the mint price of gold fixed.

credibility for the policy.¹⁰ The central bank sets the interest rate target equal to its steady-state value plus 1.5 times the deviation of aggregate price inflation from the steady state. We chose the value reported by Taylor (1993) as "working well" in the post-1980 U.S. economy.¹¹ A gold technology shock causes the real rate and the aggregate price level to rise. Here, however, gold is just another commodity. The inflation rule eliminates the need for a jump in the price level and, thus, the inflation response remains small. Thus, as we found for the compensated dollar, inflation targeting will eliminate the price fluctuations induced by shocks to the gold sector. However, an inflation target does not help much when there are shocks to the goods sector. The price response is damped slightly in the short-run, but the price effects go on much longer because there is no direct mechanism for correcting for the deviation of the price level from the steady state.

Row four of Table 3 reports the estimates of the largest root and the 95th percentile of the distribution. Again, we cannot reject that there is a unit root. But here there is a unit root in the price level and the results look distressingly like those in cases where there is none. The median unbiased estimate is correct but ρ^{95} is almost identical to the cases with no unit root. When we increase the experimental histories to 125 years, as we should expect, we cannot reject the null hypothesis of a unit root.

Inflation Targeting and Price Level Uncertainty. In Figure 8 we report the 95 percent envelopes for the price level that are generated in 1000 runs from three of our policy regimes. The results for the gold price target are nearly identical to those for the

¹⁰ See Erceg and Levin (2003) for an analysis with imperfect credibility.

gold standard, so they are not reported. With our calibration, 95 percent confidence intervals for the price level under the gold standard increase rapidly as the forecast horizon rises to five years and then stabilize around plus and minus 12 percent at a 10-year horizon.

A strict inflation target does better than the gold standard if your horizon is not too long. At a 30-year horizon, the 95 percent confidence intervals begin to grow beyond those associated with the gold standard. Here also there is a relatively rapid increase in uncertainty in the first 5 years, but then the level of uncertainty continues to grow with the horizon. As McCallum (1999) argued, a strict inflation target does not involve much price level uncertainty even over horizons as long as 20 or 30 years.¹²

Under Fisher's compensated dollar regime, the price level stays within plus and minus 1 percent of the target value. Not only is the price level anchored in the long run, but, in the short-run, uncertainty is an order of magnitude smaller than with an inflation target.¹³

VI. Conclusion

The advantage of adhering to the gold standard is that it provides a market-driven mechanism to ensure long-run price stability. The disadvantage is that it involves

¹¹ Note that this inflation regime results in a unique equilibrium as long as the coefficient on lagged inflation is greater than 0.5, half the value found for the one sector model. See Dittmar and Gavin (2003) for details.

¹² However, Dittmar, Gavin, and Kydland (1999) show that this result does not hold if the central bank has objectives in addition to an inflation target. They show that putting just a small amount of weight on output in the interest rate rule can increase both the short- and long-run variability of prices by an order of magnitude.

significant resource costs and is subject to shocks to the gold market. Nevertheless, the gold standard has long been viewed as superior to an inconvertible fiat regime in providing for price stability. But a fiat regime based on a credible nominal anchor provides the price stability benefits of the gold standard without both the resource costs and the short-run variability associated with the gold standard.

Our computational experiments with a dynamic stochastic general equilibrium model for alternative variants of the gold standard and fiat money regimes corroborate much of the accepted wisdom about the gold standard and provides insights about modern inflation targeting. As Irving Fisher argued, we find that if a central bank wants price stability for the short-term, then stabilizing a broad price index clearly dominates the classic gold standard. We find that his idea as represented by his compensated dollar proposal also dominates the short-term stability offered by modern inflation targeting.

¹³ Although not reported here, we did experiment with fiat money and a target for the price of goods. The results are similar to the compensated dollar. However the SEE of the Dickey-Fuller equation was larger, 0.34 percent versus 0.12 percent reported in Table 3.

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Table 1: Persistence Estimates for the Price Level

(The price level is defined as the logarithm of the GDP deflator)

	1880 to 1913				1968 to 2001			
	k	$\hat{\rho}^{MU}$	$\hat{\rho}^{95}$	SEE	k	$\hat{\rho}^{MU}$	$\hat{\rho}^{95}$	SEE
Australia	3	1.07	1.14	5.27	4	1.09	1.15	1.79
Canada	1	1.08	1.15	3.78	4	1.09	1.16	1.41
Denmark	2	0.99	1.12	2.71	2	1.05	1.13	2.41
Finland	3	0.75	1.10	2.49	3	1.08	1.14	1.91
France	1	1.00	1.12	4.51	3	1.08	1.14	1.28
Germany	1	1.06	1.12	3.05	2	1.06	1.13	2.08
Italy	1	1.07	1.14	3.05	2	1.07	1.14	2.17
Netherlands	4	0.53	1.07	3.5	4	0.67	1.09	1.00
Norway	2	1.06	1.13	2.51	2	1.07	1.14	3.50
Sweden	2	0.57	1.08	2.47	2	1.09	1.16	1.69
Switzerland	3	0.55	1.07	4.68	4	1.07	1.14	1.48
UK	1	0.71	1.09	2.86	2	0.53	1.07	1.47
USA	2	1.07	1.14	5.85	4	1.08	1.14	1.01
Average	2.0	0.89		3.59	2.9	1.00		1.78

Notes to Table 1.

 $\hat{\rho}^{MU}$ is the median unbiased estimator. $\hat{\rho}^{95}$ is the upper end of a 90 percent confidence interval.

SEE is the standard error of the equation in estimates of equation (1').

 $\hat{\rho}^{MU}$ and $\hat{\rho}^{95}$ are based Stock (1991) using estimates of equation (1').

Shaded Cells indicate that the Dickey-Fuller test rejects the hypothesis that there is a unit root in the logarithm of the price level at the 5 percent critical level.

Table 2: Baseline Calibration

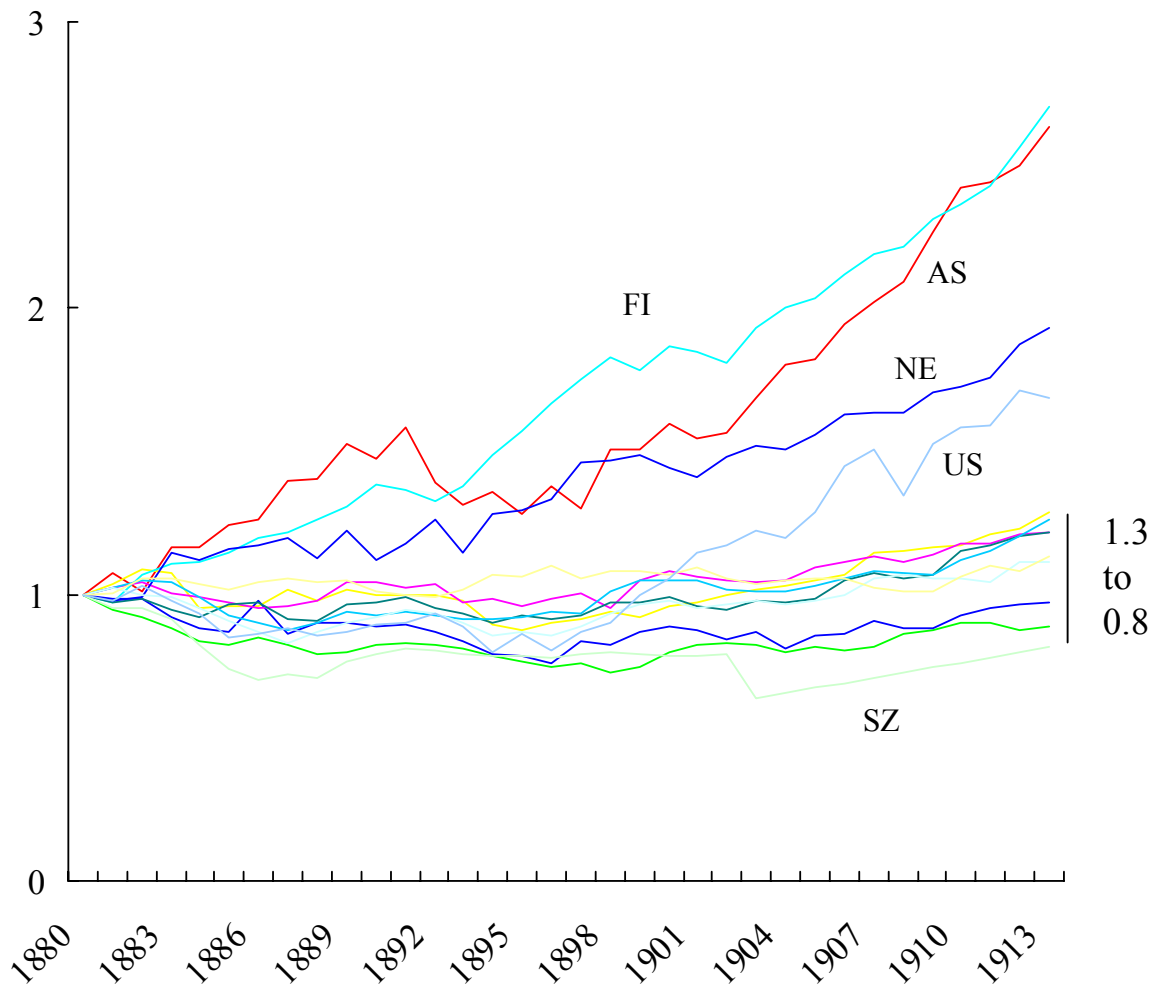
Parameter	<i>Symbol</i>		
Discount factor	β		0.99
Relative risk aversion	γ		2
Shopping time parameters	Ω		.0037
	ω		-2
		Good 1	Good 2
Consumption share in utility	μ_i	.0146	.3407
Depreciation rates in all uses	$\delta_{i,j}$	0.005	0.025
Steady-state share of time supplying labor services	h_i	0.0165	0.3135
Labor share in production	b_i	0.65	0.70
Capital shares used in sector 1	a_{i1}	.05	.30
Capital shares used in sector 2	a_{i2}	.03	.27

Table 3: Persistence Estimates for the Price Level under Alternative Regimes

34 years	k	$\hat{\rho}^{MU}$	$\hat{\rho}^{95}$	SEE
Gold standard	2	0.91	1.09	1.86
Compensated dollar	2	0.88	1.09	0.12
Fiat price gold	2	0.87	1.08	2.68
Fiat inflation	2	1.00	1.10	1.44
125 years				
Gold standard	2	0.87	0.97	1.97
Compensated dollar	2	0.85	0.95	0.13
Fiat price gold	2	0.84	0.94	2.83
Fiat inflation	2	0.99	1.02	1.54

See notes to Table 1.

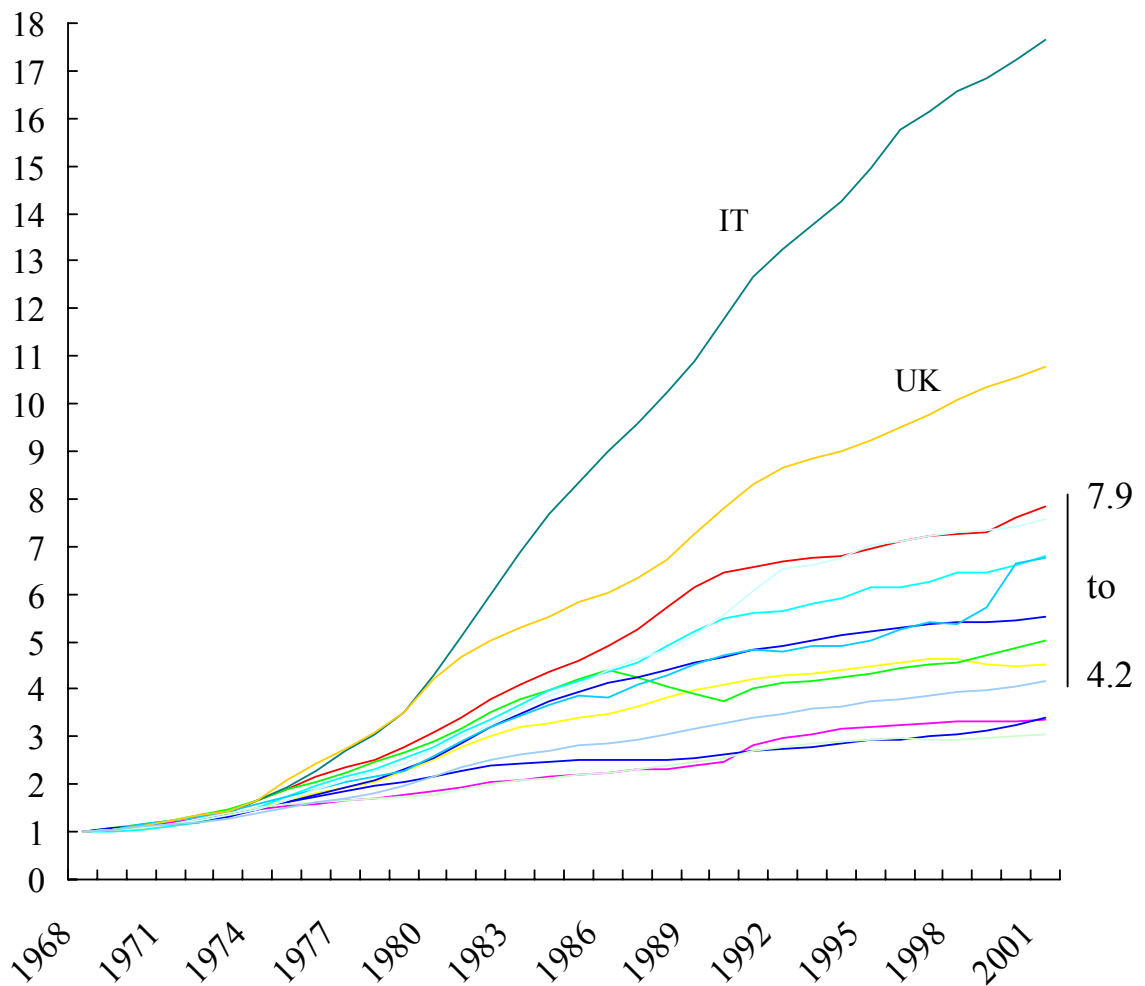
Figure 1 GDP Price Levels During the Gold Standard (1880 to 1913)



13 countries on the gold standard:

Australia, Canada, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, Sweden (SW), Switzerland (SZ), United Kingdom, and the USA.

Figure 2: GDP Price Levels During the Post-WWII Era (1968 to 2001)



Italy and the UK had the biggest increases in price levels. Germany, the Netherlands, and Switzerland had the lowest. The other eight countries, Australia, Canada, Denmark, Finland, France, Norway, Sweden, and the USA, had price levels that rose by factors between 4.2 and 7.9 over these 34 years.

Figure 3: Sector responses to technology shocks under the gold standard

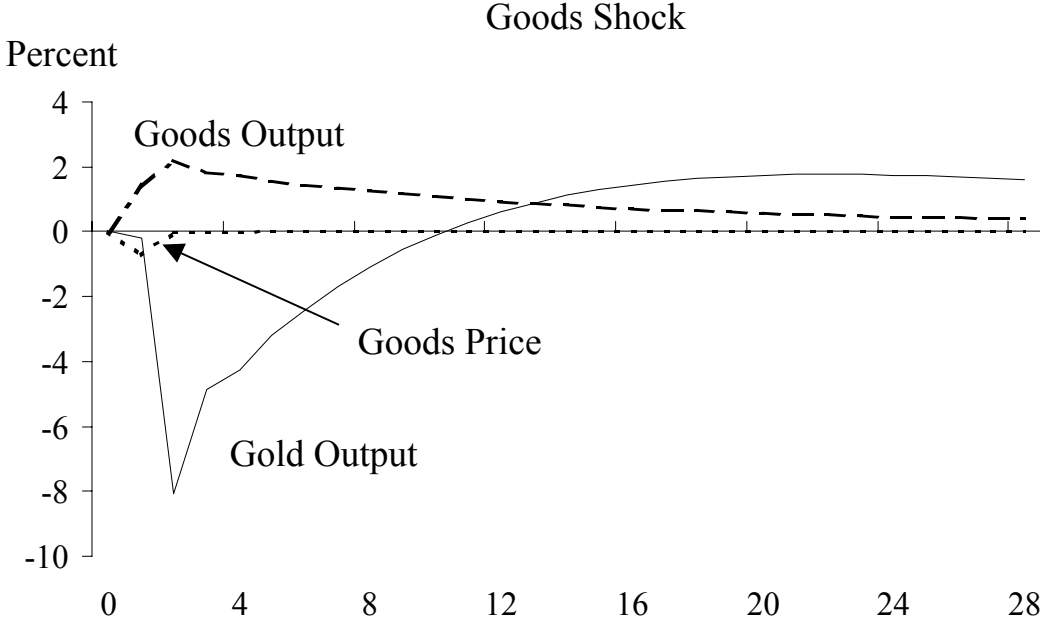
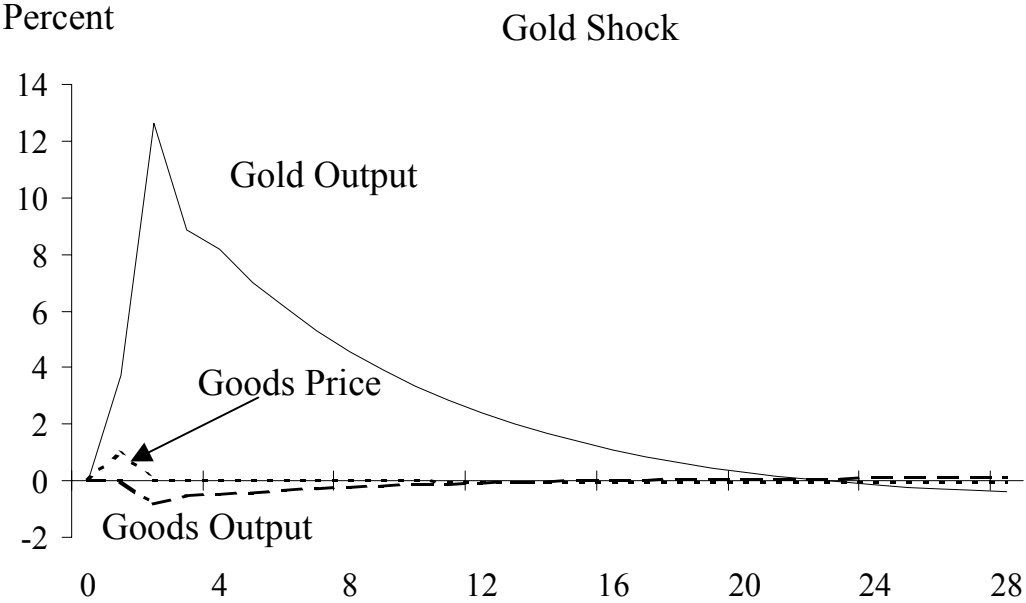


Figure 4: Aggregate responses to technology shocks under the gold standard

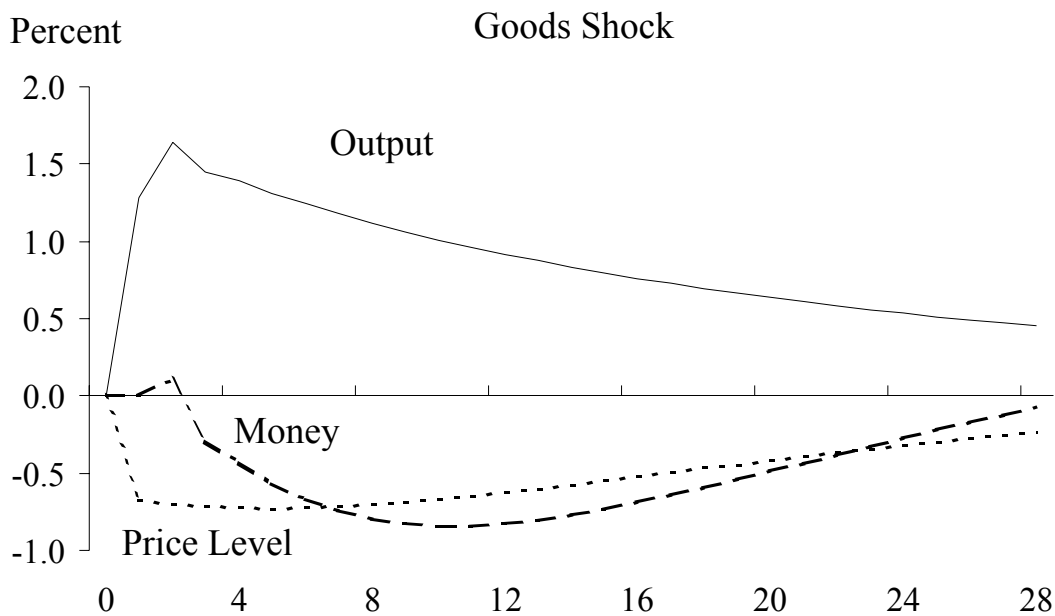
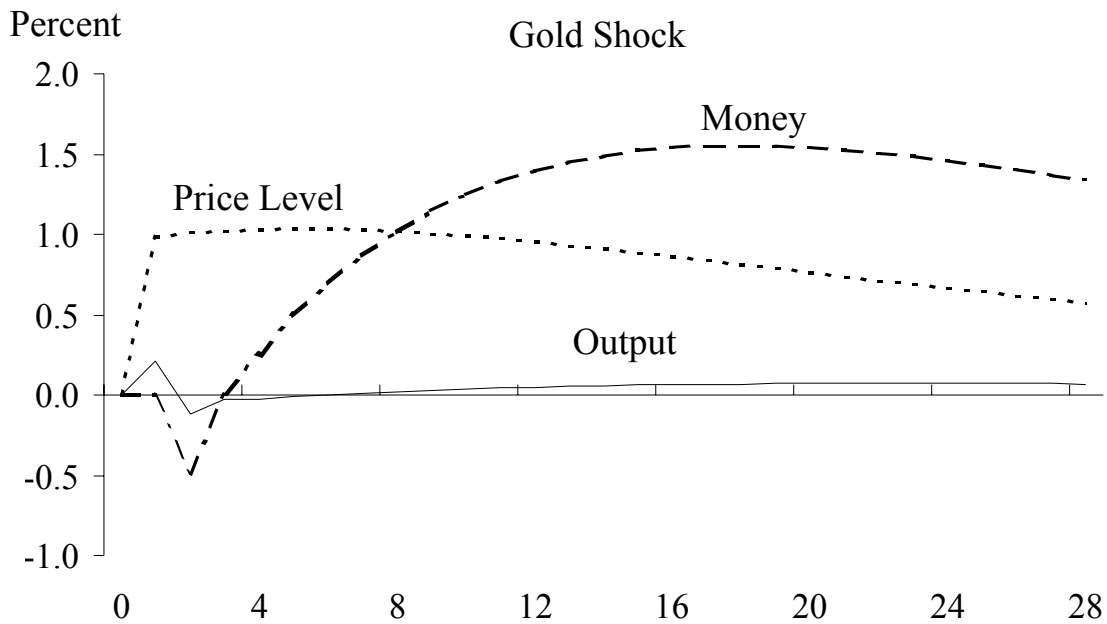


Figure 5: Relative gold price responses to shocks

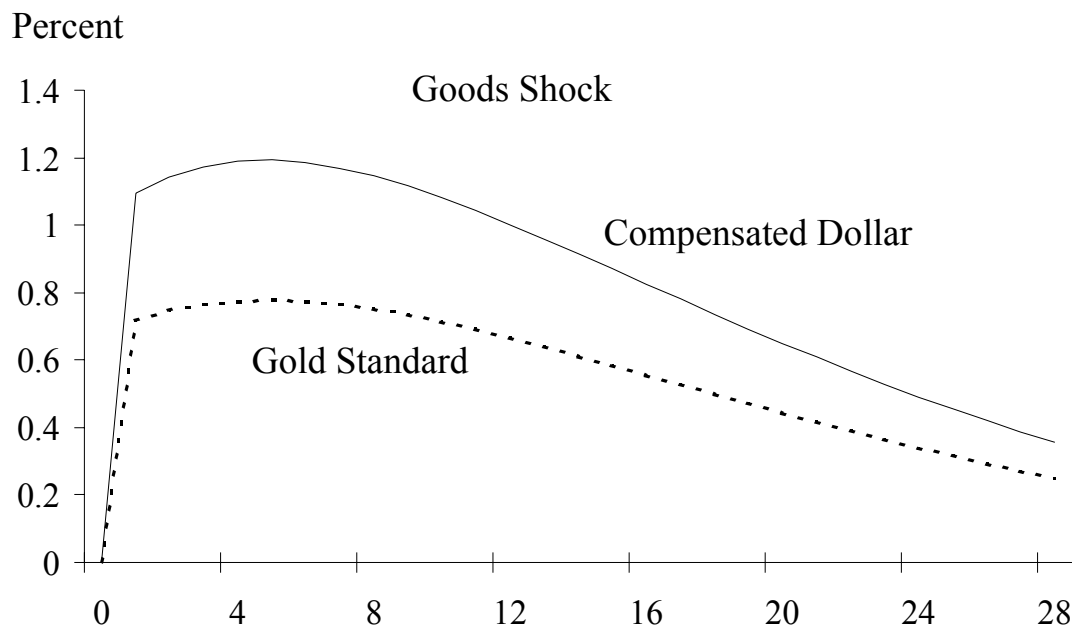
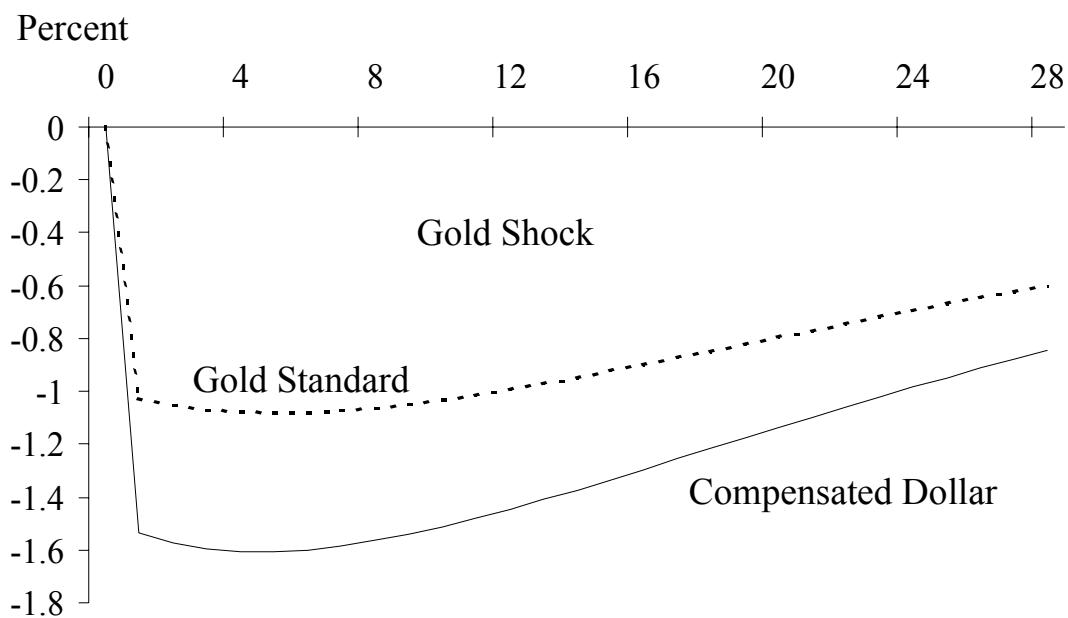


Figure 6: Money stock responses

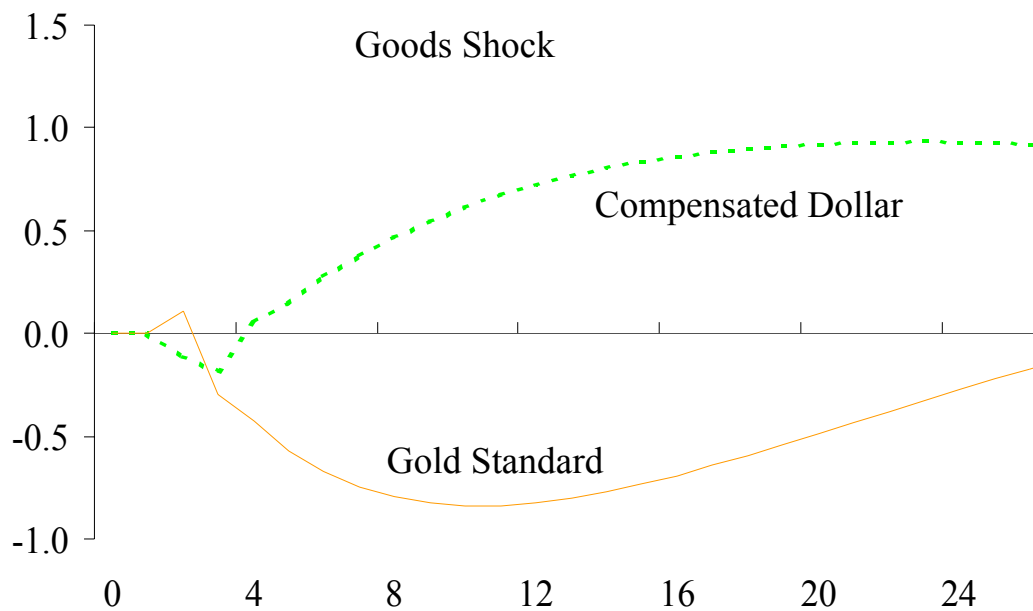
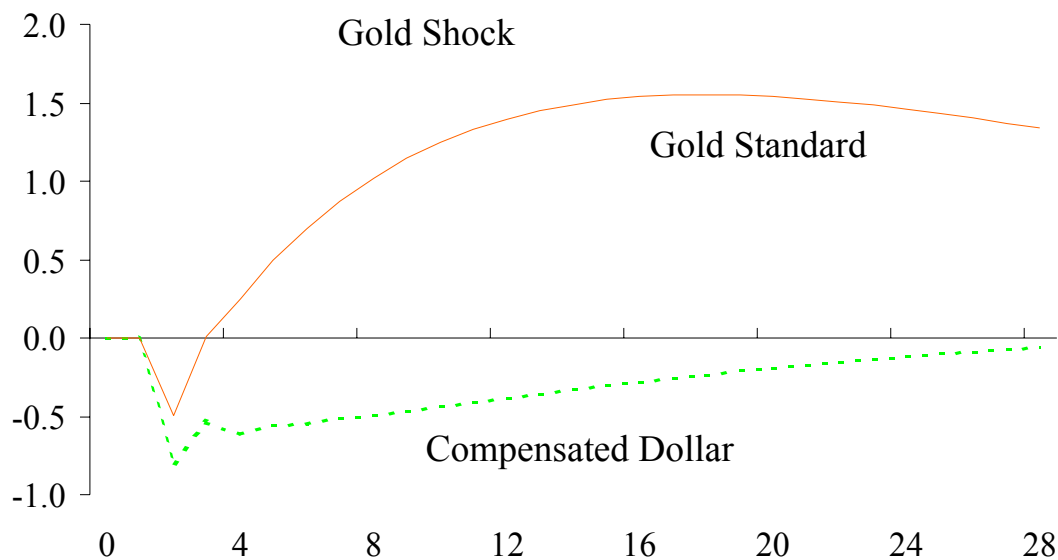


Figure 7: Aggregate Price Responses

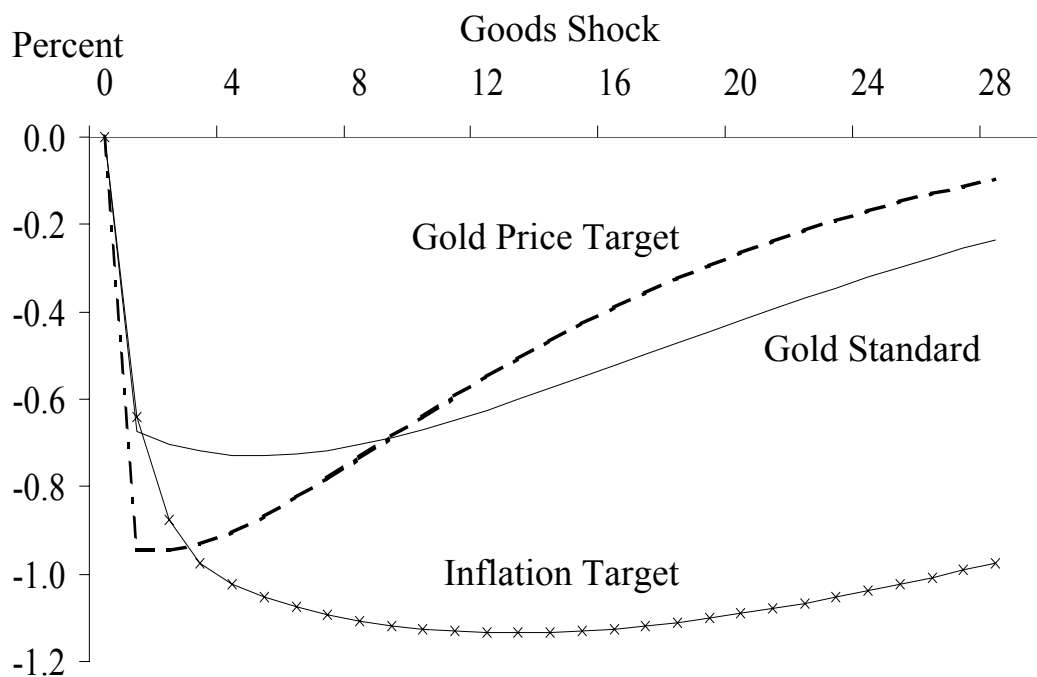
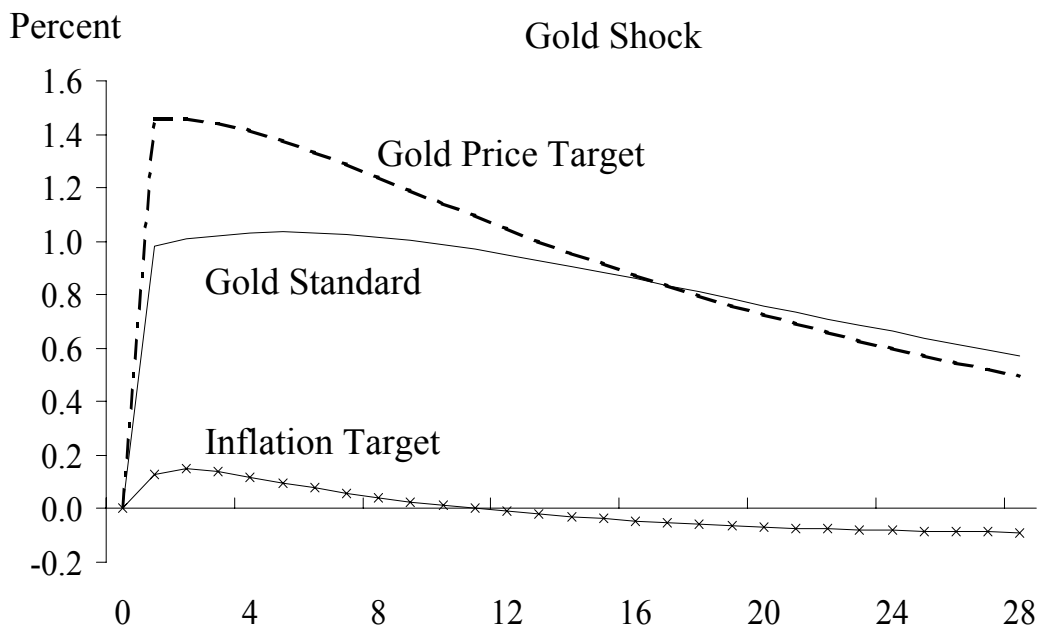
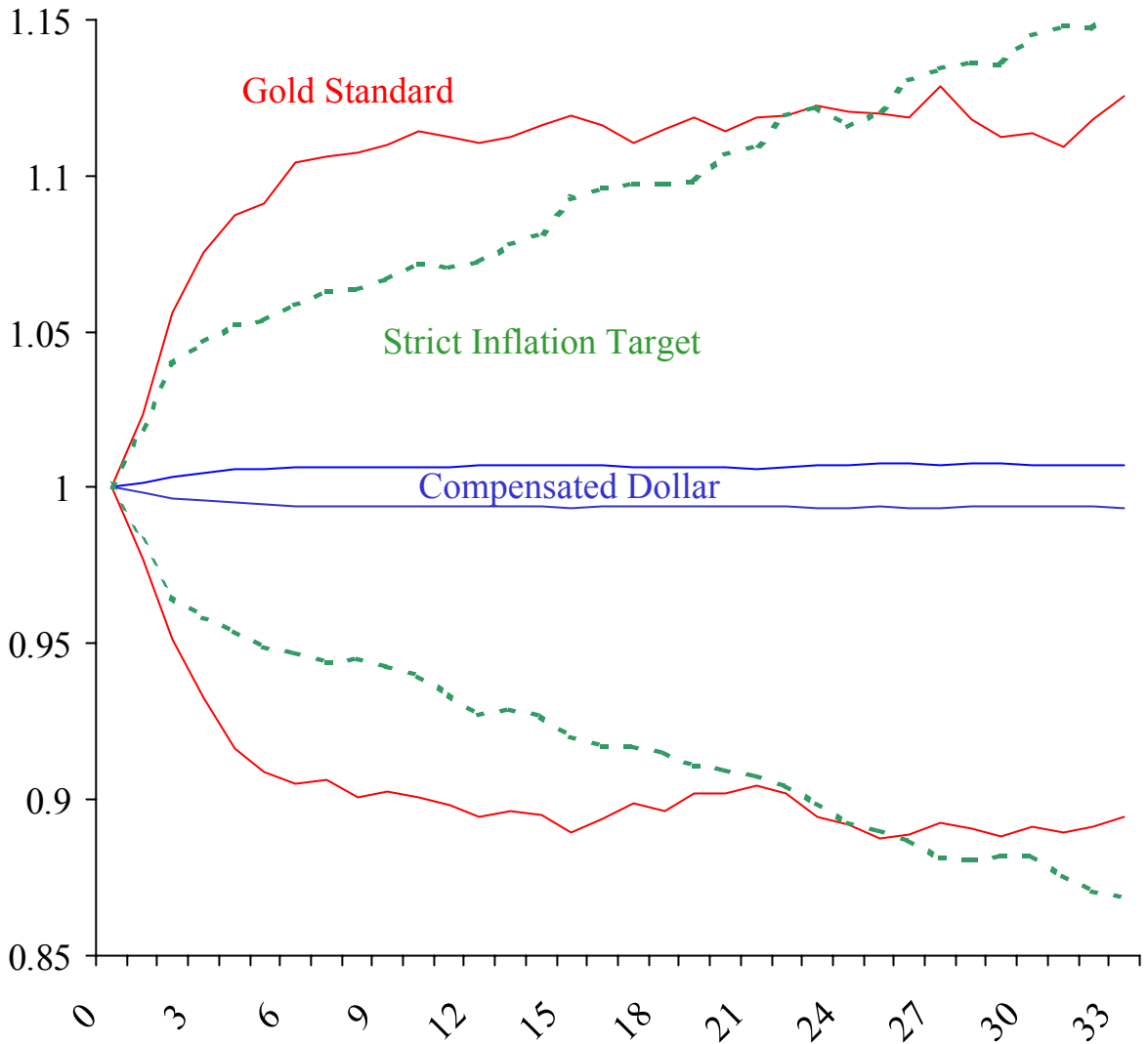


Figure 8: 95% Bounds for Paths of the Aggregate Price Level



These envelopes (bounds) are created from 100 histories for each policy rule using the baseline calibrations for the model and shock processes.