Inequality in the Welfare Costs of Disinflation*

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Abstract

We consider an economy where in the long run households prefer low and stable inflation to high inflation, but a disinflation requires a costly transition period. Although these costs are small with perfect insurance, when insurance markets are incomplete the welfare costs are borne unequally across households. We abstract from the aggregate real effects on output of a monetary tightening to study the distinct roles of redistribution, portfolio rebalancing and the incidence of an inflation tax in the heterogeneous effects of the disinflation across households. We quantify the welfare costs from these separate channels of the Volcker disinflation, which brought annual inflation from over 10 percent to nearly 3 percent over roughly 2 years. When calibrated to match the high inflation environment prior to the disinflation, including nominal mortgages on durable goods, a significant fraction of households are hurt by the redistribution. However, for all but the poorest households, these losses are offset by the benefit of a lower inflation tax. The size of this group depends on the tradeoff between the the redistribution costs and the benefits of portfolio rebalancing towards more liquid assets and general equilibrium effect on the real interest rate.

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1 Introduction

There is little controversy that if given the choice, the overwhelming majority, if not all, consumers would prefer to inhabit an economy with low and stable inflation over one with persistently high inflation.[1] Even putting aside costs from relative price dispersion or inflation uncertainty, high and stable inflation imposes resource costs as consumers alter their savings and consumption behavior in order to economize on nominal liquid assets subject to an inflation tax. In the late 1970s in the United States, consumers faced a substantial inflation tax. By almost all measures, consumers faced inflation in excess of 10 percent. It seems likely that most households in the late 1970s would have preferred the low and stable price inflation now routine in the U.S. But one cannot switch from one environment to another without some transition period with its own benefits and costs.

In this paper we characterize one aspect of a disinflation transition period, namely its unequal costs and benefits across households of varying types. The debate over the costs of disinflation typically center on the sacrifice ratio, or the short-run loss in aggregate output necessary to reduce the rate of price inflation. But the focus on aggregates necessarily abstracts from the diversity of responses underlying the aggregate effects. We fix our sights on quantifying in a precise way the redistributive costs of a large disinflation. These costs are potentially large. Households typically borrow in nominal contracts and hold a mix of real and nominal assets. A sudden change in inflation and inflation expectations increases the real burden of nominal borrowers. At the same time, it redistributes these resources towards those with assets paying a fixed nominal return.

To isolate the welfare costs from the endogenous redistribution imposed by a sudden disinflation, we abstract from the monetary non-neutralities embodied in a short-run sacrifice ratio. We consider an environment with perfectly flexible prices that should right away adjust to the new inflation rate without any short-run output costs. While highly stylized, our purpose is to study the welfare consequences of the endogenous redistribution. To the extent that the required monetary tightening induces real effects on output in practice through an upward sloping Phillips curve, we think of our results as conditioning out these aggregate effects.[2] An alternative interpretation is that we answer the question, what would the welfare costs be in a central banker's ideal world where the central bank could commit to a disinflation with perfect credibility, inflation expectations can adjust instantaneously, and firms and workers can reset their prices immediately? In practice, credibility is far from perfect, especially with such a potentially unpopular policy.

To do this we build a monetary economy with incomplete markets. To think about unequal effects of inflation and disinflation we need to shut down perfect insurance markets that would otherwise make all households effectively alike. We start with an Aiyagari (1994) framework, which we extend to include money and durable goods. Households may hold cash, valued for its liquidity services, and an interest bearing nominal asset. They face idiosyncratic earnings shocks as in the

[1] There is of course considerable debate about the magnitude of these costs and whether the benefits from reducing inflation (especially from low levels) justify the general equilibrium costs. See Aiyagari (1990) for an excellent summary. We discuss some of these results below.

[2] It is of course true, that the aggregate real effects may themselves be distributed unequally. This is a challenging question that we leave to future work.

standard Bewley (1977) income fluctuation problem but now also face a portfolio choice between money, interest-bearing nominal assets and durables. They have access to both limited unsecured borrowing and secured borrowing against their durable stock, both nominal contracts. As Doepke and Schneider (2006a) point out, it is households' net nominal wealth positions that will determine how they are effected by a change in steady state inflation. The use of secured borrowing against durables allows us to capture the main feature of many household balance sheets: a fixed-rate mortgage secured against a home or other durable goods such as vehicles.

From that starting point, we construct a disinflation equilibrium path as the economy's response to a sudden shift in the monetary policy stance. The central bank (consolidated in our case with the fiscal authority), announces a permanent shift to a lower inflation target of 3 percent from 10 percent as it was in the late 1970s. We calibrate the initial high inflation economy to match key features of the U.S. economy prior to the Volcker disinflation. We imagine the disinflation policy is perfectly credible so that inflation expectations immediately reflect the lower target. This of course differs significantly from the experience during the Volcker disinflation, which was initially plagued with credibility problems. In that sense, as we describe, this is a best-case scenario.

The unanticipated shift in policy endogenously redistributes resources away from borrowers and towards savers.Borrowers then deleverage in response to their unexpectedly large real debt burden while savers increase their asset holdings in order to consume their windfall over many periods. The redistribution channel puts downward pressure on the real interest rate. On the other hand, all households, expecting permanently lower inflation, rebalance their portfolios as a reduced inflation tax substantially lowers the cost of liquidity in the form of real balances. The rebalancing restricts the aggregate supply of non-cash savings putting upward pressure on the real interest rate, a version of the Tobin (1965) effect. For this reason we consider a production economy where an elastic demand for capital relieves some of the pressure on the real interest rate to adjust aggregate savings.

Throughout the paper we present the results from two experiments. In the first, we study a cashless limit where household portfolios consist solely of interest-bearing nominal assets and durable goods. Consistent with Doepke and Schneider (2006a) we find that almost all households with negative nominal wealth positions before the transition prefer to remain in the high inflation steady state rather than go through the disinflation. 58% of households have negative net nominal wealth positions and thus prefer to remain in the high inflation steady state.

In the second experiment, households hold money which they value for liquidity purposes. Since low wealth households hold a larger portion of their assets in money, the inflation tax hits them disproportionally hard. For most households, lowering the burden of the inflation tax is enough to reverse the welfare results from experiment one. Only 8.5% of households prefer to remain in the high inflation steady state though 58.5% of them have negative net nominal wealth positions before the transition.

When we average over the entire economy, the disinflation is equivalent to a roughly 1.2% increase in consumption in the model with money and a 0.6 percent decline in consumption in the

model without money. We decompose the overall welfare effect into an aggregate component and a redistribution component. In fact, the aggregate effects of the disinflation are positive almost immediately as aggregate real balances and consumption climb towards higher long run levels. The aggregate component is equivalent to a 2.0 percent gain in consumption. This is partly undone by the redistributive costs of the disinflation of roughly 1.0 percent of consumption. Overall, the results tell us that disinflation has substantial redistributive consequences, but for most households the benefit of the decrease in the inflation tax is enough to offset these costs.

After discussing the previous literature, in Section 2 we describe our model and in Section 3 we describe the data and model calibration. Section 4 describes the transition period for our baseline experiment, a surprise disinflation from 10 to 3 percent, evoking the Volcker disinflation. In Section 5 we discuss the welfare effects of the disinflation, and we use our model to consider recent calls for higher steady state inflation to avoid the zero lower bound. Section 6 concludes.

Contribution to the Literature

Our work builds on two streams of literature. First, it adds to the recent literature that examines the redistributive effects of monetary policy.Auclert (2015) decomposes the redistributive effects of monetary policy into two channels: unhedged interest rate exposure and revaluation of nominal assets (The Fisher Channel). Our work focuses on the Fisher Channel, a literature which was reinvigorated by Doepke and Schneider (2006a) who document the net nominal position of various cohorts and sectors in the U.S. economy, and conduct a reduced form experiment, computing the redistribution from a surprise inflation episode. Second, we contribute to an older literature which models inflation as a consumption tax.

Recently there have been several attempts to examine the effect of the Fisher Channel quantitatively in a heterogeneous agent model with incomplete markets. Doepke and Schneider (2006b) and Meh et al. (2010) do this by treating a surprise an inflation as an exogenous redistribution of wealth. They don't model inflation explicitly instead they start with a stationary distribution, revalue nominal assets and examine the transition path. In doing this they miss any important welfare results that come from endogenous portfolio rebalancing by the households in response to the change in inflation which changes the price of certain assets such as money.

Allais et al. (2016) is closer in spirit to our model. They include money as an asset which is valued for its liquidity services, but they miss nominal debt. Large nominal debt contracts secured against real assets are an important feature of U.S. households' balance sheets and, as shown by Doepke and Schneider (2006a) will be crucial in understanding the welfare costs of a sudden inflation. Allais et al. (2016) use their model to quantify the welfare costs of inflation *uncertainty* where monetary policy regimes follow a Markov chain. We quantify the realized welfare costs from a permanent switch.

An older literature thinks about inflation as a consumption tax. Lucas (2000) revisits early empirical work from Bailey (1956) who found small welfare costs from integrating under an estimated money demand curve and finds these small estimates are consistent with welfare costs arising from

a microfounded monetary model. Dotsey and Ireland (1996) and Aiyagari et al. (1998) introduce a channel where inflation draws resources away from production and into credit services to avoid an inflation tax. In the case of Dotsey and Ireland (1996) the reallocation can affect long run growth rates and amplify the welfare costs.

Chatterjee and Corbae (1992) and Imrohoroglu (1992) find that incomplete market arrangements can further amplify welfare costs over the standard complete markets estimates. Attanasio et al. (2002) use actual detailed household transaction data and show that while welfare losses due to transaction costs from inflation vary considerably across households, they are small in magnitude. Erosa and Ventura (2002) focus on the non convexities in the transaction costs to credit purchases so that inflation mimics a non linear consumption tax that is largest for the poor who make most purchases with cash.

2 Monetary economy with heterogeneity

We start by extending an Aiyagari (1994) economy to examine a monetary equilibrium. As before, households cannot perfectly insure idiosyncratic shocks to their labor productivity, but now may trade in cash, a nominal interest-bearing asset and durable goods, of which the latter also serves as collateral. We first consider a stationary environment where there is no aggregate uncertainty.[3] To study the welfare effects of a disinflation, we quantify the response of this stationary economy with high inflation to an unanticipated and credible change in the monetary policy stance of the government. Inflation adjusts to a new constant and lower level, and the economy converges in finite time to a new stationary distribution with low inflation. We measure both the short-run and long-run benefits and costs of inflation across the evolving distribution of households along the exact equilibrium path. We abstract from the output effects of the disinflation and consider only the welfare effects of the redistribution and portfolio adjustment.

2.1 Preliminaries

Time is discrete and the period length is one year. The economy consists of a large number of dynastic households indexed by i and represented by a unit measure $i \in [0, 1]$ who supply labor inelastically to a single production sector; a government implements fiscal and monetary policy.

This is a monetary economy where money $\tilde{m}$ is together a numeraire, a store of value and a source of liquidity services to the households. As numeraire we define the money price of period t output as P_t and denote the real value of money balances as $m \equiv \tilde{m}/P$. Throughout we use the $\tilde{\cdot}$ notation to indicate a nominal variable. We capture the liquidity value of money by including real balances m directly in the household's preferences as in the original Sidrauski (1967) model, although the economy would be little changed if demands for real balances were instead determined by shopping time or cash-in-advance constraints.[4]

[3] Algan and Ragot (2010) consider a similar stationary environment to ours absent durable goods. Additionally, we build on their work to analyze the transitional dynamics of a disinflation policy.

[4] With some small alterations to the timing assumptions our model would be equivalent to cash-credit or shopping

Preferences and endowments Households have identical preferences over sequences of non durable consumption c_t, the service flow from its stock of durables d_{t-1} and real balances m_t ordered by

$$E_0\left[\sum_{t=0}^{\infty}\beta^t u\left(c_t, m_t, d_{t-1}\right)\right], \tag{1}$$

with discount factor β and standard assumptions on u. The expectation is over the household's idiosyncratic labor efficiency. Each household has one unit of raw labor that is supplied inelastically to a production sector. Its efficiency $z_t \in \{z_1, \ldots, z_{N_e}\}$ is a Markov chain with constant transition matrix $P = [p_{lk}]$ initialized from its stationary distribution $\bar{p} \in \mathbb{R}^{N_z}$. Since draws are independent across households a law of large numbers implies that the aggregate quantity of efficiency units of labor N is constant and equal to $E\left[z_t\right]$.

Production The production sector consists of a representative firm that uses the installed capital stock K_{t-1} and efficiency units of labor N to produce output with a stationary constant returns to scale technology[5]

$$Y_t = F\left(K_{t-1}, N\right).$$

Aggregate output Y_t may consumed by households C_t, invested, either in the capital stock I_t^K or durables I_t^D, or used by the government G_t

$$Y_t = C_t + I_t^K + I_t^D + G_t.$$

Given aggregate investment I_t^K the capital stock depreciates at rate δ^K and follows the law of motion

$$K_t = \left(1 - \delta^K\right) K_{t-1} + I_t^K.$$

Durable investment may vary across households, who each accumulate durables according to

$$d_t = \left(1 - \delta^D\right) d_{t-1} + x_t + \Psi\left(d_{t-1}, d_t\right), \tag{2}$$

where x_t is durable investment and Ψ is an adjustment cost. Aggregate durable investment is I_t^D is simply the sum of x_t across households; the aggregate adjustment cost will depend on the underlying distribution of durable investment across households.

2.2 Market arrangements

There are competitive labor and capital markets. The representative firm hires labor at wage $P_t W_t$ per efficiency unit from households and rents capital from a competitive banking sector at rate $P_t V_t$. Banks are funded by household savings, which they use to purchase capital to rent to firms

time microfoundations of money demand. We would expect similar results in any model where inflation generates utility or resources costs to economizing on liquid assets.

[5] Throughout, we use capital letters to denote aggregate quantities.

and to make loans to borrower households and the government.

Bank funding Banks are funded by equity rather than deposits. The distinction makes no difference in the stationary equilibrium, but will later become important when an unexpected shift in inflation would otherwise leave banks insolvent. Since the banking market is competitive, we consider a representative bank, that is funded by equity E_t from saver households. With its equity, the bank purchases capital K_t at price P_t to be rented (in the following period) to firms, and also makes loans $\tilde{L}_t$ to borrower households at nominal interest rate i_t. We let ϕ_t denote the share of the bank's assets invested loans

$$\phi_t = \frac{\tilde{L}_t}{\tilde{L}_t + P_t K_t} = \frac{\tilde{L}_t}{E_t},$$

which is also the nominal share of the bank's assets. The gross nominal return on bank equity is

$$R_{t+1} = \phi_t (1 + i_t) + (1 - \phi_t) \Pi_{t+1} (1 + V_{t+1} - \delta), \tag{3}$$

where $\Pi_{t+1} = P_{t+1}/P_t$ is the gross inflation rate. We consider an equilibrium where banks lend to both firms and households $\phi_t \in (0, 1)$, so the expected return on bank equity must equal to the return on loans and the expected return on capital

$$E_t [R_{t+1}] = 1 + i_t = E_t [\Pi_{t+1}] (1 + V_{t+1} - \delta). \tag{4}$$

With no fluctuations in aggregate productivity and a constant labor supply, the future rental rate V_{t+1} is already determined in t. Although prices are deterministic so $\Pi_{t+1} = E_t [\Pi_{t+1}]$, the nominal return $1+i_t$ is determined before inflation Π_{t+1} is realized. If, ex post, Π_{t+1} differs from its expected value because of a completely unanticipated disinflation, the ex post return on bank equity in (3) simply adjusts to reflect the share of the bank's assets invested in nominal assets. If the bank were instead funded by deposits that paid a nominal return $1 + i_t$, the ex post nominal return from their capital assets would have been insufficient to fully cover the interest on their deposits.

Household borrowing and saving There are no state-contingent securities so the household can only borrow or save through the banking sector by adjusting its nominal assets or, less directly, by adjusting its holdings of money or durable goods. Since ex ante the borrowing and saving rates are identical, we only consider the households net nominal asset position $\tilde{a}_t$, which trades at discount $\frac{1}{1+i_t}$. For saver households, $\tilde{a}_t \geq 0$, nominal assets are invested in bank equity. For borrower households, $\tilde{a}_t < 0$, banks limit their borrowing so that

$$-\tilde{a}_t \leq bP_{t+1} + \mu \left(1 - \delta^D\right) d_t P_{t+1}. \tag{5}$$

The payment $-\tilde{a}_t$ due in the following period cannot exceed an unsecured limit bP_{t+1} and an additional amount secured by fraction μ of the future resale value of the household's durables. The

unsecured borrowing limit $b \geq 0$ is tighter than the household's natural borrowing limit.[6]

Given these arrangements, the timing is as follows. In each period t, a household begins with its nominal savings $\tilde{m}_{t-1} + \tilde{a}_{t-1}$ and its remaining durables $\left(1 - \delta^D\right) d_{t-1}$. The current price level P_t is realized. Households earn a nominal wage $P_t W_t$ per efficiency unit of labor. They may purchase consumption c_t and invest in durable goods x_t both at price P_t. They can also adjust their money holdings $\tilde{m}_t$ and trade in new nominal claims $\tilde{a}_t$ sold at discount $\frac{1}{1+i_t}$ subject to borrowing constraint (5). Using (2) to substitute for x_t and dividing by P_t to express in terms of output, the household is subject to a sequence of budget constraints

$$c_t + m_t + \frac{a_t}{1+i_t} + d_t + \Psi\left(d_t, d_{t-1}\right) = z_t W_t + \frac{a_{t-1} + m_{t-1}}{\Pi_t} + (1 - \delta^D) d_{t-1}. \tag{6}$$

2.3 Household behavior

Given initial real savings $a_{-1} + m_{-1}$ and durable stock d_{-1}, each household maximizes (1) subject to sequences of borrowing (5) and budget (6) constraints for $t \geq 0$. To characterize household behavior, it is helpful to re-express its sequence problem recursively. We first define the household's real net worth in period t

$$q_t = \frac{m_{t-1} + a_{t-1}}{\Pi_t} + \left(1 - \delta^D\right) d_{t-1}, \tag{7}$$

which is measured after inflation is Π_t realized. For all $t \geq 0$, given real net worth q_t, accumulated durables d_{t-1}, and labor efficiency z_t we let $V_t\left(q_t, d_{t-1}, z_t\right)$ denote the value of a household in period t. Then for all $t \geq 0$ V_t satisfies a Bellman equation

$$V_t\left(q_t, d_{t-1}, z_{it}\right) = \max_{c_t, \tilde{m}_t, d_t, \tilde{a}_t} \left\{U\left(c_t, m_t, d_{t-1}\right) + \beta E\left[V_{t+1}\left(q_{t+1}, d_t, z_{t+1}\right) | z_t\right]\right\}, \tag{8}$$

subject to a real budget constraint

$$c_t + \frac{a_t}{1+i_t} + d_t + \Psi\left(d_t, d_{t-1}\right) + m_t = q_t + z_t\left(1 - \tau_t\right) W_t,$$

real borrowing constraint

$$a_t \leq \Pi_{t+1}\left(b + \mu\left(1 - \delta^D\right) d_t\right),$$

and with q_{t+1} determined according to (7). The value functions depend on t through interest rates i_t, wages W_t and fiscal and monetary policy, which may vary over time. We abuse notation slightly and label the policy functions that satisfy the Bellman equation as $c_t\left(q_t, d_{t-1}, z_t\right)$, $m_t\left(q_t, d_{t-1}, z_t\right)$, $a_t\left(q_t, d_{t-1}, z_t\right)$ and $d_t\left(q_t, d_{t-1}, z_t\right)$.

[6] Since the borrowing constraint (5) depends on future prices, an unexpected disinflation pushes constrained households beyond their borrowing limit ex post.

2.4 Firm behavior

The production sector is straightforward: a representative firm rents capital and efficiency units of labor in a competitive market at real prices V_t and W_t respectively.[7] Imposing market clearing in the labor market, profit maximization requires

$$F_k\left(K_{t-1}, N\right) = V_t \quad F_n\left(K_{t-1}, N\right) = W_t. \tag{9}$$

2.5 Government

For simplicity, the government is a consolidated fiscal and monetary authority. It adjusts the nominal money stock to achieve an inflation target and it uses seignorage revenue to finance government expenditures determined by a balanced budget constraint. Specifically, given an an inflation target Π^*, and initial nominal liabilities $\tilde{M}_{-1}$, *a fiscal and monetary policy* is a sequence of money stocks $\tilde{M}_t$ and government expenditures G_t that implement the inflation target $P_t/P_{t-1} = \Pi^*$ and satisfy

$$P_t G_t = \tilde{M}_t - \tilde{M}_{t-1}. \tag{10}$$

the government balanced budget constraint (10) in each period $t \geq 0$.[8]

With incomplete markets, passive fiscal policy, even with lump sum transfers, is non-ricardian, and the welfare costs depend on the details of the fiscal backing of the monetary policy regime. This dependence is both because aggregate savings depends non linearly on savings and because lump sum transfer provide some insurance by reducing the variance of household income. We have the government directly adjust spending instead of transfers to avoid capturing these effects on welfare from changes in the proceeds of the inflation tax.

2.6 Aggregating over heterogeneous households

Before characterizing an equilibrium, we first define a measure to keep track of the distribution of households who each differ by their beginning of period characteristics. Let $\psi_t\left(q, d, z\right)$ be the measure of households that *begin* period t with $q_t \leq q$, $d_{t-1} \leq d$ and efficiency $z_t = z$. Given the sequence of household policy rules a_t, m_t and d_t, this measure must satisfy the law of motion

$$\psi_t\left(q', d', z\right) = \sum_{k=1}^{N_z}\left[\iint \mathbf{1}\left\{\left(\frac{a_{t-1}\left(q, d, z_k\right) + m_{t-1}\left(q, d, z_k\right)}{\Pi_t} + (1-\delta_D) d_{t-1}(q, d, z_k)\right) \leq q' \right.\right.$$
$$\left.\left. \bigcap d_{t-1}\left(q, d, z_k\right) \leq d'\right\} \psi_{t-1}\left(\partial q, \partial d, e_k\right)\right] p_{kj}, \tag{11}$$

[7] The production sector's primary purpose is to generate an elastic demand for savings that attenuates fluctuations in the real interest rate from shifts in the aggregate supply of savings.

[8] We think of government expenditures as completely separable from household preferences over consumption and real balances.

capturing the evolution of real net worth and durables given each household's choices. The measure depends on t through household decisions, which are themselves functions of equilibrium prices.

Using ψ_t we can define aggregate quantities for consumption

$$C_t \equiv \sum_{k=1}^{N_z} \left[\iint c_t\left(q, d, z_k\right) \psi_t\left(\partial q, \partial d, z_k\right) \right] \bar{p}_k,$$

demand for real balances

$$M_t^d \equiv \sum_{k=1}^{N_z} \left[\iint m_t\left(q, d, z_k\right) \psi_t\left(\partial q, \partial d, z_k\right) \right] \bar{p}_k, \tag{12}$$

durables

$$D_t \equiv \sum_{k=1}^{N_z} \left[\iint d_t\left(q, d, z_k\right) \psi_t\left(\partial q, \partial d, z_k\right) \right] \bar{p}_k,$$

and aggregate savings

$$S_t \equiv \frac{1}{1+i_t} \sum_{k=1}^{N_z} \left[\iint a_t\left(q, d, z_k\right) \psi_t\left(\partial q, \partial d, z_k\right) \right] \bar{p}_k. \tag{13}$$

The outer sum in each definition is over the distribution of z, which is stationary.[9]

2.7 Stationary high inflation equilibrium

We define the *stationary high inflation equilibrium* as follows. Given a fiscal and monetary policy with inflation target Π^H, a stationary high inflation equilibrium is

1. Constant prices i, W, V and inflation $\Pi = \Pi^H$ that satisfy the no arbitrage condition (4) and profit maximization (9).

2. A stationary value function $V\left(q, d, z\right)$ that solves the Bellman equation (8) with decision rules $c\left(q, d, z\right)$, $m\left(q, d, z\right)$, $d\left(q, d, z\right)$ and $a\left(q, d, z\right)$.

3. A stationary measure ψ^H that satisfies (11) given household decision rules.

4. Aggregate capital demand from (9) equaling aggregate savings from (13)

$$K = S. \tag{14}$$

5. The government budget constraint (10) holds with $M = M^d$ given aggregate demand for real balances (12).

[9] Recall that the transition matrix of the Markov chain for labor efficiency z is defined $P = [p_{lj}]$ and the chain is initialized from its unique ergodic distribution $\bar{p} \in \mathbb{R}^{N_e}$.

2.8 A disinflation equilibrium path

We use the stationary high inflation equilibrium as the starting point for the following experiment. What if, in a high inflation stationary equilibrium at $t = 0$, in the following period $t = 1$, the government abruptly changes its monetary policy stance? We consider a scenario where it abandons its original inflation target Π^H and makes a credible commitment to a lower inflation target $\Pi^L < \Pi^H$ for $t \geq 1$. The announcement takes households by surprise as they have already made their portfolio choices in period $t = 0$ in the high inflation equilibrium. Now, in period $t \geq 1$, the government does whatever it takes to reach the lower inflation rate by accommodating the initial shock to aggregate real money demand as households rebalance their portfolios under the new lower inflation environment.

Redistribution The change in the realized level of inflation $\Pi_1 = \Pi^L$ from its anticipated value $E_0[\Pi_1] = \Pi^H$ alters the real value of household net worth across the distribution of households. With the aggregate real value of assets unchanged, this change is a pure redistribution, sometimes known as the "Fisher" effect. The redistribution sets each household's real net worth according to

$$q_1 = \begin{cases} \frac{m_0+a_0}{\Pi^L} + \left(1-\delta^D\right) d_0 & \text{if} \quad a_0 \leq 0 \\ \frac{m_0+\left(\Pi^L+\phi_0\left(\Pi^H-\Pi^L\right)\right)a_0}{\Pi^L} + \left(1-\delta^D\right) d_0 & \text{if} \quad a_0 > 0 \end{cases}. \tag{15}$$

For households with nominal debt $a_0 \leq 0$, the redistribution increases the real value of their nominal liabilities (relative to a_0/Π^H). For household's with nominal savings $a_0 > 0$, the redistribution increases the real value of their bank equity, but only for the nominal share ϕ_0 of bank assets. The surprise disinflation has no effect on the real value of the fraction $1-\phi$ of the bank's assets invested in the capital stock. If the bank were funded by nominal debt rather than equity, the increase in the real value of its liabilities would exceed the increase in the real value of its assets, leaving it insolvent. The expression $\Pi^L + \phi_0\left(\Pi^H - \Pi^L\right)$ adjusts the face value of the household's claim on bank equity to reflect the gain in the real value of the bank's nominal assets. Rather than the expected real return $\frac{1+i_0}{\Pi^H} = 1 + V_1 - \delta$ on bank equity, the household instead earns actual real return $\phi\frac{1+i_0}{\Pi^L} + (1-\phi)(1+V_1-\delta)$.

Transition path Given this immediate redistribution, we consider the welfare effects along the exact equilibrium path that converges in finite time to a low inflation stationary equilibrium. The experiment is similar in spirit to Domeij and Heathcote (2004) who popularized this methodology to consider the welfare costs of a one time change in the capital gains tax rate under imperfect insurance.

Given an initial high inflation stationary equilibrium as described in Section 2.7 and its stationary measure ψ^H we characterize the disinflation transition equilibrium as follows. Let $\psi_1 = \psi^H$, then for $t \geq 1$ given a sequence of government expenditures $G_t = G$, an inflation path Π_t^L, and real balances M_t that satisfy the government budget constraint (10) and aggregate demand for real

balances given by (12), *a disinflation transition equilibrium* is for $t \geq 1$

1. An initial redistribution described by equation (15).
2. A sequence of measures ψ_{t+1} that satisfy (11).
3. A sequences of prices i_t, W_t, V_t, inflation $\Pi_t = \Pi_t^L$ that satisfy the no-arbitrage condition (4).
4. Decision rules $c_t(q, d, z)$, $m_t(q, d, z)$, $a_t(q, d, z)$ and $d_t(q, d, z)$ that solve the sequence of Bellman equations (8).
5. Firms maximize profits (9) with aggregate capital demand equal to aggregate savings

$$K_t = S_t. \tag{16}$$

6. The government budget constraint (10) holds with $M_t = M_t^d$ given aggregate demand for real balances given by (12).

2.9 Model solution

For the stationary economy, we use an extended version of the endogenous grid method developed by Hintermaier and Koeniger (2010) to solve for the household decision rules under constant prices and compute the prices in which aggregate demand for nominal bonds over the implied stationary distribution of households is equal to demand from government borrowing and the capital stock.[10]

Computing the non-stationary solution for the disinflation equilibrium path is by now relatively standard. We use an approach similar to Domeij and Heathcote (2004). We look for a stationary low inflation equilibrium using the method just described. The disinflation equilibrium will converge to the low inflation equilibrium in finite time. For our calibration this is well under 150 periods. We consider 200 period sequences of prices that would characterize the transition path. For a given sequence we can solve backwards from the low inflation equilibrium along the conjectured sequence of prices, again using the endogenous grid method to find the sequences of optimal decision rules. Then starting from the distribution of households in the initial high inflation economy, we solve the distribution forwards using the law of motion (11) and the disinflation sequences of policy rules. We look for a sequence of prices where the capital market (16) and the government budget constraint (10) clear in each period. The disinflation equilibrium solution delivers the sequence of policy rules and distributions characterizing household heterogeneity during the disinflation period.

3 Initial high inflation equilibrium

The starting point for our experiment is the high inflation period from the mid 1970s to 1981 that preceded the Volcker disinflation. We calibrate our model economy to mimic this environment, and

[10] We discuss the model solution for the stationary and non-stationary economies in some detail in our online appendix.

we use microdata on household finances during that period to compare the heterogeneity in the data against the heterogeneity we have induced in our artificial economy.

3.1 Household finance data

To measure the pre-Volcker high inflation period, our primary source of data is the 1983 Survey of Consumer Finances (SCF) from the Federal Reserve Board. The survey consists of a representative sample of the U.S. population plus a supplemental sample of high income households drawn from a sampling frame of 5000 high-income tax payers estimated to have substantial wealth by the Internal Revenue Service's (IRS) Statistics of Income Division (SOI). The oversampling of high income households allows for a more accurate representation of the tail of the wealth distribution than comparable surveys.[11] Ideally we would have household finance data measured during the exact high inflation period. Unfortunately, we are not aware of any data for this time period.[12] Interviews for the 1983 SCF were conducted in person from February to August of 1983, and respondents in many cases were answering questions about their household finances in 1982. Our view is the 1983 SCF is a reasonable approximation to the wealth and income distributions in the high inflation period. Although in the model the disinflation is completely credible, in practice inflation expectations even during the Volcker disinflation remained stubbornly high. So household finances in 1982 to 1983, especially portfolio positions, reflected in part the high inflation period from the late 1970s.

Using the 1983 SCF we measure components of household wealth. Participants are asked about a variety of asset and debt classes including financial assets, paper assets, liquid assets, the cash value of durable goods, consumer debt and real estate debt. We classify the debt and assets into nominal and real positions and calculate the net nominal, the net real and the liquid wealth distribution.[13]

With one exception, this measurement is similar to Doepke and Schneider (2006a) for a different time period. We differ by only identifying direct nominal positions at the household level. Doepke and Schneider (2006a) use the Flow of Funds data from the Federal Reserve Board to correct for the indirect nominal positions of households, where indirect nominal wealth includes the nominal positions of the businesses on which the household has claims. They determine the indirect position using the nominal leverage ratio of the U.S. business sector which they define as the nominal debt position per dollar of equity. This correction is well suited to their goal of characterizing the nominal position of the household sector and cohorts of the household sector, but will be substantially less accurate for characterizing the distribution of the nominal wealth among households. We believe that the bias created by not correcting for indirect nominal positions will be small. In the 1983

[11] See Avery et al. (1988) for a complete description of the 1983 SCF survey and methodology.

[12] The predecessor to the SCF was conducted in 1970 and again in 1977. In 1976 and 1977 inflation had also abated somewhat, so it is not ideal. Also, the 1983 survey design was the first to include the high income oversample needed to precisely estimate the distribution of wealth. We thank Kyle Herkenhoff for making us aware of the 1970 and 1977 years of the Survey of Consumer Finances at the University of Michigan's ICPSR data archive.

[13] Appendix A describes in detail our grouping of the household assets and liabilities in the 1983 SCF.

SCF only 34.9% of households have any claims to public or private equity, and of those, the median equity share of net worth was only 16.6%.

3.2 Calibration

Period length and high inflation We choose the period length to be one year rather than a more common choice of one quarter. The longer time period is a compromise between studying short-run effects of the disinflation and providing a long enough duration for nominal borrowing and saving contracts. Unsecured credit is typically at variable rates that would adjust within a year given a shift in expected inflation. Although fixed rate mortgages in the U.S. are 15- or 30-year contracts, they include a prepayment option. So in practice, a surprise disinflation that increased the real burden of the nominal debt would create strong incentives to refinance. In fact in the early 1980s there was a boom in mortgage refinancing for exactly that reason. In the model the surprise disinflation increases the carrying cost of the debt for one period, but then it is "refinanced" at the lower rates that prevail under the disinflation regime. For the initial high inflation equilibrium we consider a gross inflation rate target of $\Pi^* = 1.10$. This is roughly in line with price inflation at the beginning of Volcker's term as Chairman of the Federal Reserve Board.

Preferences We specify household preferences with relative risk aversion σ over a CES aggregate of consumption, real balances and durables so that

$$u\left(c_t, m_t, d_{t-1}\right) \equiv \frac{1}{1-\sigma}\left(\left(\omega c_t^{\frac{\eta-1}{\eta}} + (1-\omega)\, m_t^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}\theta} d_{t-1}^{1-\theta}\right)^{(1-\sigma)}$$

With these preferences the elasticity of substitution between consumption and real balances η will turn out to be the interest elasticity of money demand. When unconstrained, households will choose

$$m = \left(\frac{1+i_t}{i_t}\frac{1-\omega}{\omega}\right)^{\eta} c\ . \tag{17}$$

The parameter $\omega \in [0,1]$ scales the liquidity value of real balances with $\omega = 1$ implying no liquidity value of money. The interest elasticity of money demand is not precisely estimated in the data. Lucas (2000) finds $\eta = 0.5$ to be a reasonable approximation for the aggregate interest elasticity of demand for M1, and he uses this value when computing the welfare costs of inflation. Other estimates put the elasticity closer or equal to 1.[14] We choose $\eta = 0.5$ and examine the sensitivity of our results to alternative elasticities. With η fixed, we set $\omega = 0.988$ to target the ratio of real balances to output in the high inflation stationary distribution with money and $\omega \to 1$ in the cashless limit. We choose the discount factor $\beta = 0.9391$ to generate a steady state capital to output ratio of approximately 3.3 in equilibrium. In the high inflation environment, this implies a nominal interest rate of $i = 14.54$ percent for the model with money and $i = 14.47$ for the model without money and a real return of $r = 4.13$ percent and $r = 4.07$ percent, respectively.

[14] See Hoffman et al. (1995), Holman (1998), Lucas (2000) and citations therein.

Durable goods We follow Hintermaier and Koeniger (2010) and set the functional form of adjustment costs for durables to

$$\Psi\left(d_t, d_{t-1}\right) = \frac{\rho}{2}\left(\frac{d_t - (1-\delta_d)d_{t-1}}{d_{t-1}}\right)^2 d_{t-1}$$

where $\rho = .05$. The parameter ρ represents the cost of adjusting durable holdings. Hintermaier and Koeniger (2010) set ρ to .05 to represent the typical transaction costs for buying or selling a home.

Production For production we use a Cobb-Douglas production function

$$F\left(K, N\right) = K^{\alpha} N^{1-\alpha}$$

with capital share $\alpha = 0.33$, which is roughly in line with long run average of capital income to output. We choose an annual depreciation rate of $\delta = 0.06$ to generate a investment to output ratio of roughly 0.2 given the capital to output ratio.

Remaining parameters In the model with money we force government spending, G, to adjust with the change in seignorage revenue as discussed in Section 2.5. Government spending will be zero in the model without money.

The only parameters remaining are the real borrowing limit and the parameters of the Markov chain governing idiosyncratic labor efficiency, which we calibrate to approximately match the distribution of net worth. We follow Domeij and Heathcote (2004) and choose a 3 state Markov chain with a relatively high productivity state with less persistence. We summarize all of the calibration parameters in Table 1.

3.3 High inflation period in data and model

In Table 2 we compare the wealth distribution of households in the 1983 SCF with our calibrated high inflation economy. Instead of expressing the distribution in dollars, we instead describe points along the Lorenz curve. For example, in the 1983 SCF, the top 10 percent of households ordered by their net worth, owned 66.7 percent of total net worth, and the bottom 50 percent of households owned only 3.8 percent of total net worth. We hold the ordering by net worth fixed across all of the variables. We also report the Gini statistic for each of our variables. The Gini measures the area between a 45 degree line and the Lorenz curve for each variable. When all shares are non negative, it will be between zero and one, with zero indicating perfect equality and one indicating perfect inequality. In our case some households will be net borrowers so the Gini coefficient could in principle be above one.

In 1983, as in other years, the distribution of net worth is skewed, with the top one percent of households owning 31 percent of total net worth. The precautionary savings motive in our model

Table 1: Calibration parameters

Parameter		Calibrated value	Target
	A. Preferences		
Discount factor	β	0.9391	$K/Y = 3.3$
Risk aversion	σ	2	
Money demand elasticity	η	0.5	Lucas (2000)
Nondurable share	θ	.8092	
	B. Durables		
Adjustment cost	ρ	.05	
Depreciation	δ^D	.03	$I/Y = 0.2$
	C. Production		
Capital share	α	.33	$VK/Y = 0.33$
Depreciation	δ^K	.06	
	D. Other parameters		
Income risk	z_i, P	See Domeij and Heathcote (2004)	
Secured borrowing	μ	.97	
Unsecured borrowing	b	$.95Wz_1$	

is able to replicate the inequality in the wealth distribution, but fails to generate the substantial wealth accumulation in the very far tail. This is typical in this class of model where precautionary motives alone cannot account for the extreme wealth accumulation of the very rich. Models with an additional savings motives from a rare and transient superstar state, entrepreneurship with financial constraints, or bequest motives are better able to replicate this behavior. This shortcoming has consequences for our welfare results since the extreme wealth accumulation will imply higher debt levels for other households in the distribution. Our model misses some of the debt accumulation for the poorest 10% of the households whose share of net worth in the data is negative.

In our model, in the high inflation equilibrium 58.0 percent of households are net (nominal) borrowers. In the data, net nominal positions are negative for half of the population. This of course reflects secured borrowing in the form of mortgages, which is captured in our model by secured borrowing against durables. This is important when thinking about welfare since households with nominal debt contracts stand to lose in a sudden disinflation. In a model that incorporates secured nominal borrowing against durable real assets, this means welfare losses occur across the distribution, not just among the poor.

4 The Volcker disinflation

Starting from the high inflation equilibrium just described in Section 3, we implement the disinflation policy as an unanticipated but credible change in the inflation rate with all other parameters

Table 2: Distribution of Wealth: Data and Model

	Lowest, ordered by net worth			Highest, ordered by net worth			
Percent of total	10%	25%	50%	10%	5%	1%	Gini
			A. 1983 SCF				
Net worth	-0.14	0.12	3.82	66.65	54.56	31.22	0.78
Liquid assets	.31	1.07	6.58	50.18	34.80	13.97	0.81
Nominal wealth	-4.83	-9.22	-34.8	121.40	95.44	43.06	—
Real wealth	.15	.70	5.71	65.11	53.93	31.97	0.76
			B. Model with money				
Net worth	.26	2.82	7.80	50.46	30.12	7.33	.67
Liquid assets	2.24	10.57	25.93	31.47	18.23	4.3	.40
Nominal wealth	-17.83	-41.78	-73.20	100.38	59.80	14.53	—
Real wealth	.87	4.38	10.64	48.76	29.11	7.09	.64
			C. Cashless limit				
Net worth	.22	.27	7.6	51.1	30.5	7.41	.70
Nominal wealth[1]	$.25e^5$	$.63e^5$	$1.14e^5$	$-.79e^5$	$-.48e^5$	$-12.e^5$	—
Real wealth	.85	4.36	10.63	49.05	29.28	7.11	.64

Note: 1983 Survey of Consumer Finances. Adjusted net worth is total net worth less the value of any durable assets or secured borrowing against these assets. See appendix for detailed descriptions. We omit the Gini coefficient for nominal net worth because it is negative for almost 75 percent of households.

[1]The total nominal wealth in the model without money is negative. Thus, a positive wealth share reflects a negative stock of nominal wealth for that group.

held fixed. The economy eventually converges to the low inflation stationary equilibrium. Along this equilibrium path, we compute the exact transition path of the aggregate variables and their underlying distributions. These form the basis for our welfare calculations.

4.1 Disinflation policy

In November of 1980 to very early 1981 the Volcker disinflation began in earnest. Lasting roughly two years, inflation declined from over 10 percent to a little less than 4 percent.[15] We consider this disinflation policy in the model as an unexpected and immediate shift in the monetary policy stance. The government announces a 3 percent inflation target and commits to *whatever it takes* to achieve this new lower inflation rate, i.e., at the beginning of period $t = 1$, $\Pi^* = 1.03 < \Pi^H$. To implement this policy the government accommodates the change in demand for real balances induced by the new inflation target and chooses government spending G_t to balance it's budget.

[15]Goodfriend and King (2005) recount the course of events and policy commitments leading up to and through the "incredible Volcker disinflation." See also Lindsey et al. (2005)

Table 3: High Inflation and Low Inflation Steady State Comparison

	Model with money		Cashless limit	
	High inflation	Low inflation	High inflation	Low inflation
	A. Interest rates			
i	14.54	7.29	14.47	7.19
r	4.13	4.16	4.07	4.07
	B. Aggregates			
Y	0.508	0.507	0.510	0.510
C/Y	0.713	0.724	.732	0.732
K/Y	3.26	3.25	3.28	3.28
Y/M	4.54	3.27	—	—
D/Y	2.39	2.39	2.38	2.38
G/Y	0.0200	.00887	—	—

4.2 Long-run low inflation equilibrium

Before we measure the disinflation period in the model, we see where it will eventually lead the economy. In Table 3 we compare the high inflation and low inflation long-run economies that represent the beginning and ultimate ending of the disinflation. The first thing we notice is that in the model with money, monetary policy is not super-neutral. Even in the long run, higher inflation slightly raises the real rate and thus lowers the capital stock. As the inflation tax decreases, households shift their portfolios away from other assets and towards money. Aggregate real balances increase approximately 38% in the low inflation steady state. This puts upwards pressure on the real interest in order to encourage households to save in assets and fund the capital stock, a version of the Tobin (1965) effect.[16] Moreover, our specification of the borrowing constraint relaxes with higher inflation also weakening the precautionary savings motive. For both reasons inflation policy is not super-neutral in this environment. In the model without money however, the change in inflation is super-neutral and the aggregates do not change between the low and high inflation steady states. Thus, the change in steady state inflation can be interpreted as pure wealth redistribution.

4.3 Volcker disinflation period

Now we mimic the Volcker disinflation by computing the transition equilibrium path to the new low inflation long-run equilibrium. As we describe in Section 2.8, the first period of the transition imposes a one time wealth redistribution. Those with net nominal liabilities find the real burden of their liabilities unexpectedly higher. Those with net nominal savings find the opposite and receive an unexpected windfall. In the model with money, everyone benefits from a lower inflation tax.

In Figure 1 we compute the response of the aggregate variables along this transition path, which is plotted as the solid line. The star represents the levels in period 0's high inflation equilibrium and

[16] See Algan and Ragot (2010) who discuss this property in more detail.

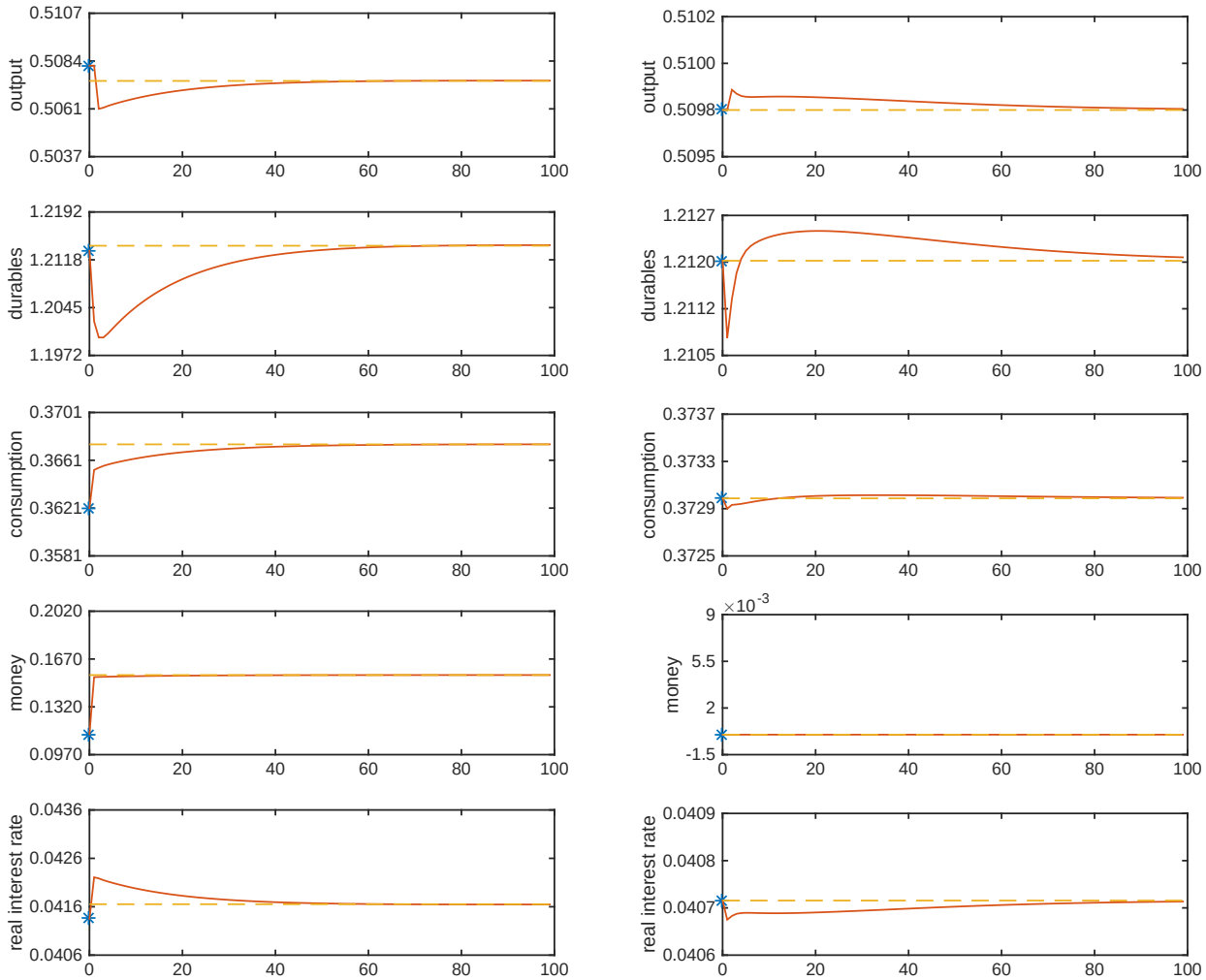
the broken line indicates the new low inflation long-run values. The reduction in inflation induces an economy wide portfolio rebalancing. In the model with money the portfolio rebalancing also creates a one time jump in the level of real balances as the central bank responds to households new additional demand for liquid assets. Although this outcome may be surprising, we see a similar movement in 1983 when empirically household expectations of lower inflation seemed to first stick.

The path of the aggregate variables changes significantly between the models with and without money. In the model with money, plotted in panel (a), indebted households find themselves with more debt than anticipated and wish to deleverage. At the same time, all households wish to rebalance their assets away from equity and durables and towards money and consumption which has become cheaper with the lower inflation tax. This causes an initial decrease in aggregate investment and output while aggregate real balances and consumption rise to their new steady state level. As households reach their optimal portfolios, investment and output begin to recover to their new steady state levels.

In the model without money, plotted in panel (b), the change in inflation is a pure redistribution of wealth. The path of the aggregate variables reflects the balance between the response of the winners and losers from the redistribution which are largely offsetting. Thus, on impact, aggregate consumption declines, but it will increase above it's long run level before returning to steady state. This is because the nominal borrowers who lose from the redistribution have a much higher marginal propensity to consume out of additional wealth. They deleverage quickly and increase their consumption back to it's equilibrium level. Initial savers, on the other hand, have a lower marginal propensity to consume. In response to the windfall they receive from the redistribution, they increase their consumption slightly but maintain the higher level for a longer period of time. Auclert (2015) emphasizes the ability of the central bank to stimulate aggregate consumption by an inflation which redistributes wealth from savers to borrowers. This channel holds in the model without money, but is reversed by the decline in the inflation tax. As the inflation tax declines, consumption goods become cheaper for all households which is enough to reverse the losses from the redistribution for most households.

Figure 1 also plots the paths of the real interest rate in the models with and without money. When money is valued for liquidity services, the real interest rate jumps in response the to the change in steady state inflation. The price of holding money, and therefore of consumption, is lower in the low inflation steady state. As a result, households decrease their saving in order to consume and hold more cash. In response, the real interest rate jumps in order to encourage households to save more which is necessary for markets to clear. After the initial jump, as households reach their optimal portfolio, the real interest rate slowly decreases to it's new steady state level. However, in this model, money is not super-neutral. The real interest rate in the low inflation steady state is higher than the high inflation steady state since households have decreased their savings in favor of money and consumption.

In the model with no money, the shock to steady state inflation causes the real interest rate to decrease on impact. The inflation shock results in a redistribution of wealth from borrowers to



(a) Model with money

(b) Cashless limit

Figure 1: Aggregate effects of Volcker disinflation

savers. As savers find themselves wealthier than their ideal they increase their supply of savings. Borrowers, on the other hand, become more indebted than they intended. Over time they deleverage decreasing their consumption and increasing their savings. The overall result is a small drop in the real interest rate as demand for nominal debt goes down which then slowly returns to it's steady state level. Without money, the change in the inflation rate is super neutral so the real interest eventually returns to it's previous level.

5 Measuring inequality in the welfare costs of disinflation

To quantify the welfare impact of the disinflation period, we offer several different measures. First we define a simple conditional welfare measure that asks on the eve of the inflation reform what consumption equivalent each household would require to be indifferent between the economy with the disinflation and a counterfactual economy where the economy remains in the high inflation equilibrium permanently. Next we consider a utilitarian measure of the consumption equivalence for a social planner that can distribute aggregate consumption as it sees fit. We decompose this measure as in Domeij and Heathcote (2004) to decompose this welfare change into a component resulting from the change in aggregate variables and a redistribution component. Finally we consider the same measures over the long run.

5.1 Short-run conditional welfare

We consider an unanticipated disinflation in period $t = 1$. We define $V_1^L(q_1, d_0, z_1)$ as the value of a household in period $t = 1$ with its resources q_1 having been determined in the high inflation period, but already reflecting redistribution because of the unexpected change in Π_1

$$V_1^L(q_1, d_0, z_1) = E\left[\sum_{k=0}^{\infty} \beta^k u\left(c_{t+k}^L, m_{t+k}^L, d_{t+k-1}^L\right) | t = 1, z_1\right],$$

where c_t^L and m_t^L for $t \geq 1$ are the sequences of consumption and real money balances determined along the disinflation equilibrium path. Note that q_1 reflects the unexpected change in inflation Π_1, in period $t = 1$ there is a one-time windfall gain to those with positive net worth and a loss to borrowers. Next, we define for the same household with q_1', d_0 and z_1 the counterfactual value $V_1^H(q_1', d_0, z_1)$ of remaining in the high inflation environment forever where q_1' is the real net worth with the high inflation that was expected .

$$V_1^H\left(q_1', d_0, e_1\right) = E\left[\sum_{k=0}^{\infty} \beta^k u\left(c_{t+k}^H, m_{t+k}^H, d_{t+k-1}^H\right) | t = 1, z_1\right].$$

Since the initial high inflation environment is stationary of course $V_0^H = V_1^H$.

We define the consumption equivalent conditional welfare change $\Delta_{SR}(q_1, d_0, z) \times 100$ as the percentage adjustment to counterfactual consumption needed to make the counterfactual environment

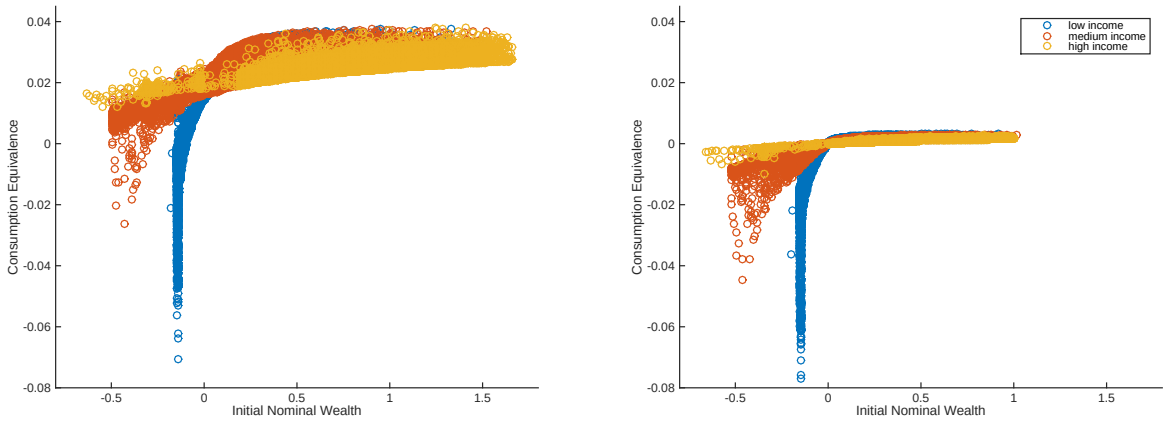


Figure 2: Permanent consumption equivalent of Volcker disinflation

equivalent to a transition to a new low inflation steady state

$$E\left[\sum_{k=0}^{\infty}\beta^k u\left((1+\Delta_{SR})c_{t+k}^H, m_{t+k}^H, d_{t+k-1}^H\right)|t=1,z_1\right] = V_1^L\left(q_1, d_0, z_1\right) \ . \tag{18}$$

When $\Delta_{SR} < 0$, this implies that they would be willing to sacrifice $\Delta_{SR} * 100\%$ of their consumption in order to avoid going through the transition while $\Delta_{SR} > 0$ means they need to be compensated with an additional $\Delta_{SR} * 100\%$ of their consumption to stay in the high inflation steady state. We plot in Figure 2 the consumption equivalent for each household versus the initial nominal wealth position of the household.

Despite the disinflation raising output and consumption in the medium and long run, the gains are not spread equally across the distribution. It is apparent from Figure 2 that nominal borrowers bear the cost from the one time redistribution from the surprise disinflation with low income nominal borrowers bearing the worst costs - up to 7% of their consumption for the poorest households in the model without money. Comparing the figures for the models with and without money shows that while the decrease in the inflation tax reverses the welfare costs of the redistribution for most medium and high income households, many low income households still lose (49% of them) facing welfare costs of up to 5% of their consumption.

In Table 4 we tally a simple vote. Who would vote for the Volcker disinflation? The difference between the two models is stark. In the model without money, the decrease in steady state inflation is a pure redistribution of wealth from borrowers to savers. Since 58% of households are borrowers, most stand to lose from the redistribution. We see that 99 percent of the borrower households, at least according to these preferences, would prefer to remain in the high inflation equilibrium than start a disinflation period. These voters are concentrated among the low and middle earners, specifically among the segment of those groups that are borrowers or have little net worth.

However, in the model with money, despite the fact that most households are borrowers, only 8% of households prefer to undergo the transition to the low inflation steady state. This suggests

Table 4: Preference for Disinflation Policy

A. Model with money				
	Percent that prefer high inflation		Percent borrowers	Percent of population
	Short run	Long run		
Total economy	8.48	4.36	58.46	100
Low income	48.69	35.43	56.99	11.69
Middle income	3.63	0.29	66.93	76.92
High income	0	0	5.43	11.38
B. Cashless limit				
	Percent that prefer high inflation		Percent borrowers	Percent population
	Short run	Long run[1]		
Total economy	57.85	-	58.45	100
Low income	57.39	-	58.02	11.69
Middle income	65.76	-	66.46	76.92
High income	4.85	-	4.85	11.38

Note:[1]Without money, households are indifferent between the low and high inflation environment.

that for most households, the gains from the decrease in the inflation tax outweigh the losses from the redistribution.

5.2 Short-run economy-wide welfare losses

To get an ex ante economy-wide measure we find $\bar{\Delta}_{SR}$

$$\sum_{i=1}^{N_z} \iint E\left[\sum_{k=0}^{\infty} \beta^k u\left(\bar{\Delta}_{SR} c_{t+k}^H, m_{t+k}^H, d_{t+k-1}^H\right) | t=1, z_i\right] \psi^H\left(\partial q_1, \partial d_0, z_i\right) \bar{p}_i$$

$$... = \sum_{i=1}^{N_z} \iint V_1^L\left(q_1, d_0, z_1\right) \psi^H\left(\partial q_0, \partial d_0, z_i\right) \bar{p}_i.$$

The overall welfare gains include both the overall increase in output and consumption and money, which are positive in the model with money, but also the redistribution that is most costly for the poorest segment of the population. To separate the two effects we follow the decomposition of Domeij and Heathcote (2004). The idea is to isolate the aggregate effects by holding households shares of aggregate consumption fixed through the transition.

We define

$$C_t^L = \sum_{i=1}^{N_z} \iint c^L(q,d,z)\,\psi_t^L(\partial q, \partial d, z_i)\,\bar{p}_i$$

$$M_t^L = \sum_{i=1}^{N_z} \iint m_t^L(q,d,z)\,\psi_t^L(\partial q, \partial d, z_i)\,\bar{p}_i$$

$$D_t^L = \sum_{i=1}^{N_z} \iint d_t^L(q,d,z)\,\psi_t^L(\partial q, \partial d, z_i)\,\bar{p}_i$$

as the aggregate (average) consumption and real balances in each period t in the transition. Then we define shares $\theta^c(q,d,z)$, $\theta^m(q,d,z)$, and $\theta^d(q,d,z)$ as the household i's share of aggregate consumption, money and durables, respectively in the high inflation environment. Finally, we define that aggregate component as the value of Δ_{SR}^a that satisfies

$$\sum_{i=1}^{N_e} \iint E\left[\sum_{k=0}^{\infty} \beta^k U\left(\Delta_{SR}^a c_{t+k}^H, m_{t+k}^H, d_{t+k-1}^H\right) | t=1, e_i\right] \psi^H(dq_0, dd_0, e_i)\,\bar{p}_i$$

$$... = \sum_{i=1}^{N_e} \iint E\left[\sum_{k=0}^{\infty} \beta^k U\left(\theta^c C_{t+k}^L, \theta^m M_{t+k}^L, \theta^d D_{t+k-1}^L\right) | t=1, e_i\right] \psi^H(dq_0, dd_0, e_i)\,\bar{p}_i.$$

This component reflects the change in overall welfare from changes in aggregate consumption. It measures the average welfare cost of the transition for individual i if their share of consumption, money and durables remained at its high inflation steady state level. Other changes in overall welfare reflect an updating of each household's share of aggregate consumption, or the welfare results from the redistribution, and we define

$$\Delta_{SR}^R \equiv \frac{1+\bar{\Delta}_{SR}}{1+\Delta_{SR}^a} - 1.$$

Table 5: Aggregate welfare losses

	Model with money	Cashless limit
	Percent welfare change	Percent welfare change
Total economy	+1.19	-.64
Aggregate component	+2.13	-.006
Redistribution component	-.92	-.63

In Table 5 we see that in the model with money the overall welfare change is positive. This reflects the welfare gains from the decrease in the inflation tax and the resulting increase in real balances and consumption outweigh the welfare costs of the redistribution for most. In the model without money, the aggregate variables do not change significantly so the aggregate component

is close to zero and the overall measure is approximately equal to the redistribution component. The overall measure is negative which reflects that some suffer large losses from the redistribution outweighing the welfare gains experienced by others.

5.3 Long-run measures

We ask whether they would choose differently if they could immediately reach the low inflation equilibrium. To do this we examine the same individuals in the counterfactual and disinflation economies long after the disinflation equilibrium has reached its permanent state. In Table 4 we report the same vote far into the future, and see that about 95 percent of households now prefer the low inflation equilibrium in the model with money. We note that our experiment *does* include the one-time initial redistribution, but many years have passed and households have sufficient time to readjust their savings. That most prefer the low inflation economy should not be surprising, given the lower liquidity in the high inflation economy. What may be surprising is the 5 percent of households that would still prefer to remain in the high inflation economy. These are only the poorest households who suffer from the slight rise in the real interest rate.

In the model without money, all households are indifferent between the low and high inflation environments in the long run. This follows from the super-neutrality of the change in steady state inflation which has no long run effect on the real interest rate or aggregate variables.

5.4 Interpreting the welfare losses

Currently in our model, we do not address the welfare effects of the permanent decrease in government spending implied by the decrease in seignorage revenue. One possible implication of the low seigniorage in the low inflation economy is a reduction in transfers to maintain fiscal budget balance. These transfers provide additional insurance against being a low earner with little or negative net worth. The result would be additional and substantial welfare costs for the low income households who rely most on the transfers for insurance.

With an alternative means to keep budget balance some of these effects can be reversed. For example, if the government adjusts the money supply through open market operations, all seigniorage revenues are rebated to the treasury, which uses them to pay interest on the government debt. Assuming that households do not adjust their consumption in response to the increase in government debt[17], the welfare effects from the loss of seigniorage income will be reversed. This policy is closer to the operation of the Federal Reserve in practice. In a steady state comparison, long run low inflation dominates long run high inflation for most of the distribution, as we would expect. We have not yet been able to successfully solve for the transition path between these steady states. In fact, there will not be a unique path of interest rates and government debt that will solve this economy. The change in seignorage revenue will require an adjustment to the net present value of government debt, but this adjustment could occur anywhere along the transition path. The

[17]This is not an extreme assumption as the increase in government debt from the loss of seignorage revenue will be small.

adjustment of debt, however, will then affect market clearing interest rate. The result is that this problem is underdetermined without additional assumptions.

We should also remark that the model provides equal unsecured access to credit for all households. In practice some low income households are unbanked, conducting their expenditures almost exclusively in cash. These households would stand to benefit from the disinflation since it would permanently reduce the inflation tax on their consumption.

5.5 Raising the inflation target

Briefly, we use our model to consider one alternative experiment. In light of recent concerns about low inflation leaving monetary policy close to the zero lower bound on interest rates, we consider an increase in the inflation rate from 2 to 5 percent. An inflationary period has also been considered as a way to decrease the real debt burden of borrowers and stimulate aggregate demand.

In a straight up vote on whether or not to go from 2 to 5 percent inflation, 91.6 percent of households prefer to remain at 2 percent inflation rather than go through the inflation period to 5 percent. As in our baseline experiment, the welfare costs are distributed unequally across the distribution, 51.6 percent of poor households would prefer to go through the inflation as the benefits from decreasing their real debt burden offset the increase in the inflation tax. Figure 3 presents a scatter plot of the short-run consumption equivalence measure from equation (18) using a simulation of the inflationary experiment. Low income households, represented by the blue dots, gain the most from the inflation, up to 2% of their consumption.

We also present the path of aggregate variables. Importantly, even though the poorest households with a high marginal propensity to consume gain from the redistribution, the increase in the inflation tax increases the price of consumption goods and makes aggregate consumption decline. The effects on output however are positive as households rebalance their portfolios away from money and towards assets causing the real interest rate to decline.

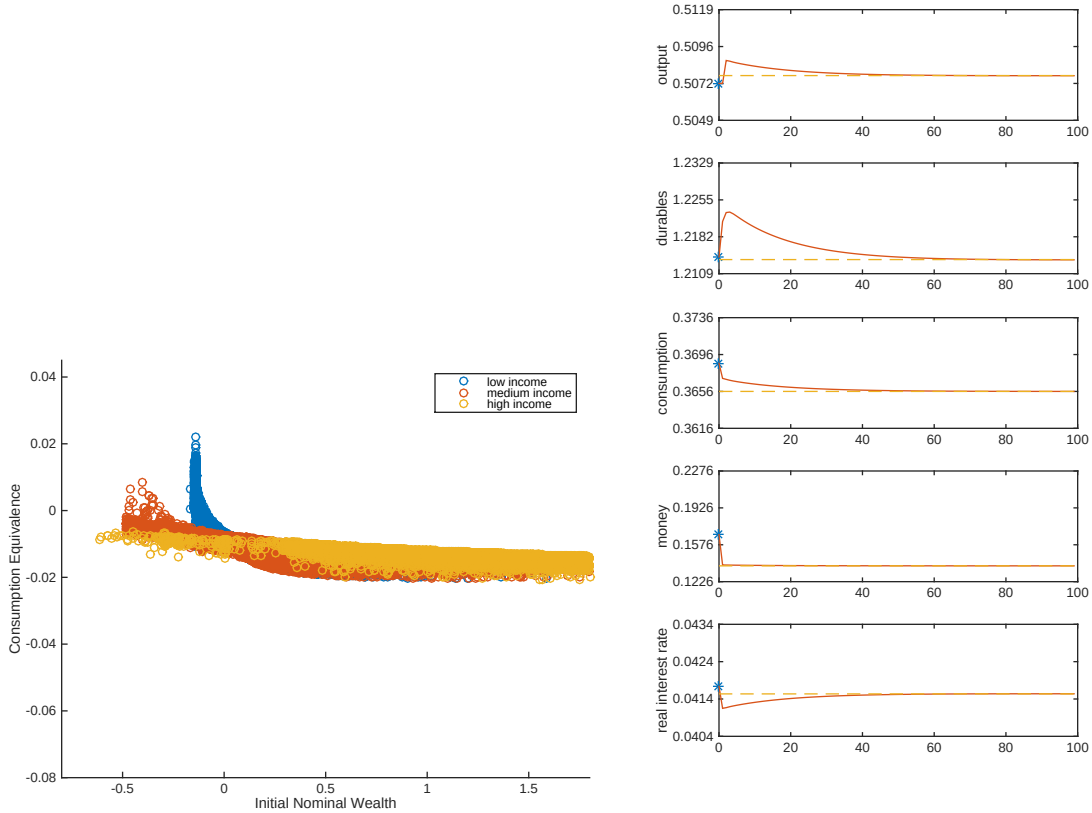


Figure 3: An Inflationary period from 2 to 5 percent Inflation

6 Conclusion

We examine the welfare effects of a permanent and unexpected change in the inflation target of the central bank. An unexpected change decline in the inflation rate redistributes wealth from nominal borrowers towards savers, but it also lowers the burden of the inflation tax for all households. We focus on the welfare effects stemming from the resulting redistribution of wealth and the change in the inflation tax and abstract from the consequences on output from the Phillips Curve.

We build an Aiyagari (1994) model modified with a consumer portfolio choice between a one period nominal bond, real durable goods, and money which we use to analyze the welfare effects of an unexpected change in the steady state inflation rate. Beyond a limited amount of unsecured borrowing, borrowing must be secured against real durable goods meaning that even wealthy households can have negative nominal wealth positions, as is often the case for U.S. households with a nominal, fixed interest mortgage secured against their home. The change in the inflation rate redistributes wealth from households with nominal liabilities towards those with positive nominal assets.

We use the model to consider a disinflation from 10 to 3 percent, roughly the disinflation

experienced during the "Great Volcker Disinflation" in the early 80s. We compare the welfare results from two experiments. In the first, households do not value money and therefore do not benefit from the lower inflation tax. The disinflation is a pure redistribution of wealth from borrowers to savers. In this case, only 57.8 percent of households would prefer to remain in the high inflation steady state rather than undergo the disinflation, roughly the same number of households that start with negative nominal wealth.

In the model with money, the disinflation benefits all households through a lower inflation tax. For most, this is enough to offset the welfare losses from the redistribution. Only 8.48 percent of households would vote to remain in the high inflation steady state. With or without money, both models show that the welfare costs of the disinflation are unevenly borne across the income distribution with low income households facing a welfare loss of up to 7 percent of their consumption.

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A Data appendix

Table A.1: Categorization of SCF household assets and liabilities

Assets	Liabilities
A. Nominal assets and liabilities	
Liquid:	**Secured borrowing:**
Cash in checking accounts	Home mortgages
Cash in savings or share accounts	Amount owed against land contract notes
Money market and call accounts	Amount outstanding on other property mortgages
IRA or Keogh accounts	
Certificates of Desposit	
U.S. Savings Bonds	
Non liquid:	**Unsecured borrowing:**
Face value of bonds	Amount outstanding on loans other than mortgages[1]
Loans owed to household and gas leases	Credit card debt
Aggregate gross value of land contracts and notes	Amount owed on lines of credit
Thrift type pension account assets	
B. Real assets	
Durables:	
Home	
Other properties	
Vehicles	
Financial:	
Stocks and mutual funds	
Trust accounts	
Business:	
Net value of business with management interests	

Note: classification of assets and liabilities variables in 1983 Federal Reserve Board Survey of Consumer Finances.
[1]Also substracts loans against life insurance policies.