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▶ **To cite this version:**

Yann Algan, Xavier Ragot. Monetary policy with heterogenous agents and credit constraints. 2005. halshs-00590565

HAL Id: halshs-00590565
https://shs.hal.science/halshs-00590565

Preprint submitted on 3 May 2011

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WORKING PAPER N° 2005 - 45

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JEL Codes : E2, E5

Keywords : Monetary policy, credit constraints, incomplete markets, welfare.

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE – ÉCOLE DES HAUTES ÉTUDES EN SCIENCES SOCIALES
ÉCOLE NATIONALE DES PONTS ET CHAUSSÉES – ÉCOLE NORMALE SUPÉRIEURE

Monetary Policy with Heterogeneous Agents and Credit Constraints

Yann Algan (Université Marne la Vallée OEP, PSE)* and Xavier Ragot (PSE)†

Abstract

This paper analyzes the long-run effect of monetary policy when credit constraints are taken into account. This analysis is carried on in a heterogeneous agents framework in which infinitely lived agents can partially self-insure against income risks by using both financial assets and real balences.

First we show theoretically that financial borrowing constraints give rise to an heterogeneity in money demand, leading to a real effect of inflation. Secondly, we show that inflation has a quantitative positive impact on output and consumption in economies which closely match the wealth distribution of the United States. Thirdly, we find that the average welfare cost of inflation is much smaller compared to a complete market economy, and that inflation induces important redistributive effects across households.

JEL : E2, E5

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1 Introduction

The aim of most central banks is now to target a positive long run inflation rate which ranges between 1 percent and 3 percent (Bernanke and Mishkin, 1997). Yet the welfare gain of such a practice still lacks foundations in the literature since the question of the channels through which long run inflation affects economic activity is still under debate. The traditional result in the textbook macroeconomic literature with perfect capital markets, dynastic households and lump-sum taxes, is that inflation has no real effect in the long run and money is superneutral (Lucas, 2000). Recent research has explored this non neutrality result when the two main latter

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assumptions are not satisfied. Indeed, the effect of inflation has been studied when it induces some redistribution across generations in OLG models (Weiss 1980 ; Weil, 1991), or if distorting taxes are affected by inflation (Phelps, 1973 and Chari et al., 1996 among others).

This paper exhibits an alternative theoretical channel of the non-neutrality of inflation transiting through capital market imperfections. If households can use both fiat money and capital as partial private insurance designs against individual income risks, they can substitute money for financial assets when inflation increases and affects the return on real balances. Yet if asset market imperfections are such that some households are borrowing constrained, then these households can not undertake such a substitution and adjust in a different proportion their amount of money compared to unconstrained households. Thus credit constraints induce a heterogeneity in the response of money demand following a change in the inflation rate, which is at the core of the non-neutrality of money. Since the thigthness of credit constraints is a well-established empirical fact (Jappelli 1990; Gross and Souleles 2002; Grant 2003 among others), this channel is likely to have first order effect on the real economy and on the welfare of households.

To investigate this channel, we modelize capital market imperfections in a production economy following the approach of Aiyagari (1994). Heterogeneous agents receive idiosyncratic income shocks. They can accumulate financial assets in the form of capital to partially insure against these risks but they face a borrowing constraint. We embed in this framework money in the utility function. Money is praised both for its liquidity service and as a store of value which provides an additional insurance device against idiosyncratic labor market risks. Thus agents have multiple assets to self-insurance and the substitution between the two depend on relative prices and the tax system. The return on capital is endogenously determined by financial market equilibrium while the return on real balances depends on the exogenous inflation rate determined by monetary policy.

Firstly we provide theoretical evidence that inflation affects aggregate real variables in this incomplete markets framework with credit constraints. Inflation gives rise to heterogeneous substitution effects between financial asset and real balances across unconstrained households and constrained ones. This heterogeneity in the answer of money demand provides a real channel to monetary policy. We also show that the magnitude of the response of aggregate variables to inflation changes crucially depends on the structure of taxes and prices. Regarding the tax schedule, the redistribution of the inflation tax creates some (non distorting) redistribution between agents, which affects the savings rate of unconstrained households. Basically, if the revenue of the inflation tax is redistributed to constrained households, an increase in the inflation rate is a transfer toward these ones. It decreases the precautionary savings of savors because it decrease the incentives to self-insure. If the revenue of the inflation tax is redistributed to

savors, then it creates incentives to increase precautionary savings to smooth consumption. Furthermore, inflation tax changes might also affect, in general equilibrium other distorting taxes on capital and thus the incentives to save. Regarding price adjustments, the variation in the aggregate supply of capital induced by inflation might change the level of interest rates and wages and have a feed-back on the incentives to save. It is thus important to provide a quantitative evaluation of the effect of monetary policy in a general equilibrium model.

Secondly, we thus quantify the long-run effect of inflation on aggregate variables by calibrating the model on the United States. Since the extent to which inflation affect real economy directly depends on the fraction of households who are borrowing constrained, we study an economy in which the wealth distribution over financial asset holdings closely resembles that in the United States. In this case, we find that credit constraints can give rise to quantitatively important departure from the traditional superneutrality of money. For example, in the benchmark general equilibrium economy with endogenous prices and endogenous distorting taxes, an increase in inflation from 2 percent to 3 percent leads to a rise of 0.39 percent in aggregate capital. Moreover, in a small open economy with exogenous interest rates, the same monetary policy experiment would lead to a 1.05 percent increase in aggregate capital. These outcomes are consistent with empirical results. Indeed, both savings (Loayza, et al., 2000), output (Bullard and Keating, 1995) and capital sotck (Kahn et al. 2001) increase with inflation reasonably low values of the inflation rate[1].

Thirdly and as a final step, we investigate the welfare effects of such a real impact of inflation. The first finding is that the average welfare costs of inflation are much lower in incomplete market economy compared to traditional complete market set-up *à la* Lucas (2000). If capital markets were perfect, the only impact of inflation would be to decrease the level of money holdings without any positive real effect on precautionary savings in capital. Thus a rise by one point in inflation would induce a 30 percent higher decrease in welfare in complete market economy compared to our benchmark incomplete market framework with endogenous prices and taxes. Importantly enough, this welfare effect is obtained in a the calibrated economy for which the capital stock is below its first best value. To that extent, inflation helps bridging the gap with the first best level of production.

Furthermore, the wealth heterogeneity stemming from incomplete markets leads to unequal welfare gains of inflation. In particular and paradoxically enough wealth-poor agents tend to benefit more from inflation compared to the wealthiest. This result is mainly driven by price effect: the income of the wealth-poor mainly comes from labor whose return rises as aggregate

[1] These results are usually reversed for higher level of the inflation rate (typically double digit inflation rates). In this case, inflation induces new distortions, such as an increase in volatility, which are detrimental to growth. These effects are beyond the scope of this article.

capital increases in response to a rise in inflation. Conversely, interest rates get lower, hurting the wealthiest whose income is mainly made up of financial assets.

Related literature

There are surprisingly few papers analyzing monetary policy with infinitely lived heterogenous agents facing financial credit constraints. To the best of our knowledge, our paper is this first to provide theoretical and quantitative evidence on the real effect of inflation stemming from credit constraints in a production economy (see also for more general theoretical investigation Ragot, 2005).

Some initial papers have studied monetary policy in endowment economy with credit constraints following the seminal articles of Bewley (1980, 1983). But as the goal of Bewley was partly to find some foundations for the theory of money, money is the only store of value in the economy. As a consequence, the heterogeneity in money demand and its induced real effect explained above cannot be found in this type of model, since households are not allowed to substitute money for other assets. For instance Kehoe, Levine and Woodford (1992) or Imrohoroglu (1992) study the welfare effect of inflation in such frameworks, but they only measure the redistributive effect of inflation, and not its real effect on production. Such an analysis is indeed impossible in an endowment economy.

More recently Erosa and Ventura (2002) analyzed the distributional impact of inflation in an incomplete markets economy but in which credit constraints do not bind in equilibrium. The real effect of inflation comes from a transaction technology which is assumed to exhibit economies of scale. This transaction technology gives rise to some heterogeneity in money demand due to the implied heterogeneity in consumption. They find that the fraction of wealth held in liquid assets decreases with income and wealth, which is empirically relevant. Yet we prove that this result can be obtained without this specific assumption about the transaction technology but only as an endogenous outcome of credit constraints.

Akyol (2004) analyzes the welfare effect of inflation in an incomplete market set-up where credit constraints are binding in equilibrium, but in an endowment economy. Contrary to previous Bewley type models, he takes into account of the possibility to substitute money by other assets. But, this article assumes specific money demand implying that only the high income agents hold money in equilibrium. Furthermore, the analysis is carried on in an endowment economy rather than a production one, excluding any analysis on the long-run real effect of inflation on capital accumulation.

The analysis proceeds as follows. Since we exhibit a new channel for the non neutrality of monetary policy, section 2 first provides a simple model which derives analytically results on the basic mechanisms at stake. Section 3 lays out the full model. Section 4 presents the quantitative results on the real effect of inflation and its implied welfare gains in incomplete markets set-up.

2 A Simple Model

Although our aim is a quantitative evaluation of the effect of inflation, we first lay out a slightly simplified version of our general model to discuss the main channels through which inflation affects aggregate outcomes. For that purpose, we use a Bewley-style model in which infinitely lived agents face individual income risks and credit constraints. But we make the key assumption that households alternate *deterministically* between the different labor market states. This liquidity constrained model has been used, for instance, by Woodford (1990) to study the effect of public debt.

We extend this framework to monetary policy issues by taking into account the valuation of money in the utility function. We show analytically that the Sidrauski's neutrality result no longer holds when credit constraints are binding in this framework. Inflation affects the long run interest rate, even when the new money is distributed proportionally to money holdings.

Consider an economy made up of two types of infinitely lived households. Type H households have a high labor endowment e^H and type L household have a low labor endowment e^L. For the sake of simplicity let us assume that $e^H = 1$ and $e^L = 0$. Households alternate deterministically between state H and L in each period. The number of each type is normalized to one, yielding one unit of labor supply at each period. Eventually we assume that households cannot borrow. Both types ($i = H, L$) seek to maximize an infinitely horizon utility function over consumption c^{i} and real money balances m^i which provide liquidity services

$$\sum_{t=0}^{\infty} \beta^t u\left(c_t^i, m_{t+1}^i\right) = \sum_{t=0}^{\infty} \beta^t \ln\left[\left(c_t^i\right)^{\phi}\left(m_{t+1}^i\right)^{1-\phi}\right]$$

where β is the discount factor and $1 > \phi > 0$ scales the marginal utility of consumption and money. For the sake of simplicity we use a log-linear utility function in this section but the results hold for very general utility functions as in shown in Ragot (2005). We denote by r_t the real interest rate between period t and $t+1$, P_t the price of the final good, and $\Pi_{t+1} = \frac{P_{t+1}}{P_t}$ the gross inflation rate between period t and $t+1$.

The final good Y_t is produced with capital K_t and labor L_t. It is assumed that capital fully depreciates in production. Since the quantity of labor available for production is normalized to 1, the production is simply equal to $Y_t = K_t^{\alpha}$ where $0 < \alpha < 1$. The demand for capital K_t^d is such that $1 + r_t = \alpha(K_t^d)^{\alpha-1}$.

2.1 Households

We solve separately the programs of type H and type L households.

2.1.1 Agents in State H

Let denote by q_t^H the wealth made up of money and asset holdings that type H households hold at the beginning of period t. Households supply one unit of labor and receive a wage income $w_t e^H$ and a monetary transfer equals to τ_t^H in real terms. With their total income, they can buy a quantity of money denoted m_{t+1}^H in real terms, save on financial market, a_{t+1}^H, and buy final goods in quantity c_t^H. Due to the deterministic structure of productivity shocks, next period wealth of type H household becomes the beginning of period wealth of type L agents, denoted q_{t+1}^L. Next period wealth is made up of the return on financial savings $(1+r_{t+1})\, a_{t+1}^H$ and the level of real money balances $\frac{m_{t+1}^H}{\Pi_{t+1}}$ carried on between the two periods.

The dynamic problem solved by H agents is

$$v(q_t^H, e^H) = \max_{c_t^H, m_{t+1}^H, a_{t+1}^H} u\left(c_t^H, m_{t+1}^H\right) + \beta v(q_{t+1}^L, e^L)$$

$$\begin{aligned} \text{s.t} \quad c_t^H + a_{t+1}^H + m_{t+1}^H &= w_t e^H + \tau_t^H + q_t^H \\ q_{t+1}^L &= (1+r_{t+1})\, a_{t+1}^H + \frac{m_{t+1}^H}{\Pi_{t+1}} \end{aligned}$$

Since type H households are in the high productivity state, they save to smooth their consumption and are never borrowing constrained. By using the two constraints to substitute for c_t^H and q_{t+1}^L, the program boils down to maximize utility over m_{t+1}^H and a_{t+1}^H. The maximization over a_{t+1}^H yields

$$u_c'\left(c_t^H, m_{t+1}^H\right) = \beta\,(1+r_{t+1})\, v_q'(q_{t+1}^L, e^L) \text{ and } a_{t+1}^H > 0 \tag{1}$$

The maximization with respect to m_{t+1}^H yields

$$u_c'\left(c_t^H, m_{t+1}^H\right) - u_m'\left(c_t^H, m_{t+1}^H\right) = \frac{\beta}{\Pi_{t+1}} v_q'\left(q_{t+1}^L, e^L\right)$$

By using the log-linear expression of the utility function, the two previous equalities yield the following ratio of money holdings over consumption

$$\frac{m_{t+1}^H}{c_t^H} = \frac{1-\phi}{\phi} \frac{1}{1 - \frac{1}{\Pi_{t+1}} \frac{1}{1+r_{t+1}}} \tag{2}$$

The right hand side is the opportunity cost of holding money. If the net inflation rate π_{t+1} and the interest rate r_{t+1} are small enough, then one gets $1 - \frac{1}{\Pi_{t+1}} \frac{1}{1+r_{t+1}} \simeq r_{t+1} + \pi_{t+1}$, which is precisely the expression of the nominal interest rate. Since consumption and money are both positive, equation (2) implies the following inequality between the inflation rate and the interest rate

$$\frac{1}{\Pi_{t+1}} < 1 + r_{t+1}$$

The inflation rate can not be too small, otherwise the return on money would be higher than the return on the financial markets and these markets would collapse. Moreover, the previous expression cannot hold with equality in this model since no satiation point for money demand has been assumed for the sake of simplicity. Finally, the envelop theorem yields

$$v'\left(q_t^H, e^H\right) = u'_c\left(c_t^H, m_{t+1}^H\right) \tag{3}$$

2.1.2 Agents in State L

The program of type L households closely mirrors that of type H households. By denoting q_t^L the wealth of agents L at the beginning of period t, the recursive program simply reads

$$v\left(q_t^L, e^L\right) = \max_{c_t^L, m_{t+1}^L, a_{t+1}^L} u\left(c_t^L, m_{t+1}^L\right) + \beta v\left(q_{t+1}^H, e^H\right)$$

$$\begin{aligned} c_t^L + a_{t+1}^L + m_{t+1}^L &= w_t e^L + \tau_t^L + q_t^L \\ q_{t+1}^H &= \left(1 + r_{t+1}\right) a_{t+1}^L + \frac{m_{t+1}^L}{\Pi_{t+1}} \end{aligned}$$

The maximization over real balances m_{t+1}^L yields

$$u'_c\left(c_t^L, m_{t+1}^L\right) - u'_m\left(c_t^L, m_{t+1}^L\right) = \frac{\beta}{\Pi_{t+1}} v'_q\left(q_{t+1}^H, e^H\right) \tag{4}$$

The maximization over asset holdings a_{t+1}^L yields

$$\begin{cases} u'_c\left(c_t^L, m_t^L\right) = \beta\left(1 + r_{t+1}\right) v'_q\left(q_{t+1}^H, e^H\right) \text{ if } a_{t+1}^L > 0 \\ u'_c\left(c_t^L, m_t^L\right) = \beta\left(1 + r_{t+1}\right) v'_q\left(q_{t+1}^H, e^H\right) \text{ if } a_{t+1}^L = 0 \end{cases}$$

In case of *non binding* credit constraints, the ratio of real balances over consumption is equal to

$$\frac{m_{t+1}^L}{c_t^L} = \frac{1-\phi}{\phi} \frac{1}{1 - \frac{1}{\Pi_{t+1}} \frac{1}{1+r_{t+1}}} \tag{5}$$

But in case of *binding* credit constraints, the previous equality no longer holds, and the first order condition is simply given by equation (4).

Eventually, the envelop theorem yields

$$v'\left(q_t^L, e^L\right) = u'_c\left(c_t^L, m_{t+1}^L\right) \tag{6}$$

2.2 Market equilibria

The sequence of market opening is the following. First, the labor market opens, production takes place and wages are paid and loans repaid. Second, the financial market opens and borrowing takes place. Its equilibrium is given by the equality between the supply and the demand for capital $a_{t+1}^L + a_{t+1}^H = K_{t+1}^d$. Third, the new money is given to households and the money market opens. The money market equilibrium is $m_{t+1}^H + m_{t+1}^L = \Omega_t$, where Ω_t is the real quantity of money in circulation at the end of period t. Finally, the good market opens. Its equilibrium simply reads $Y_t = c_t^H + c_t^L + K_{t+1}$. Firms buy and instal their capital to produce the next period, households consume and use money for liquidity services.

We assume that monetary policy follows a simple rule, which is to increase the nominal stock of money by a given amount π at each period, $\pi P_{t-1}\Omega_{t-1}$. The whole newly created money is given to households by lump sum transfers denoted by τ_t^H and τ_t^L in real terms. As a consequence, $P_t\left(\tau_t^H + \tau_t^L\right) = \pi P_{t-1}\Omega_{t-1}$ and hence,

$$\tau_t^H + \tau_t^L = \frac{\pi}{\Pi_t}\Omega_{t-1}$$

In this simple model, we focus on stationary equilibrium where the inflation rate Π and all the real variables $a^H, a^L, q^H, q^L, m^L, m^H, c^L, c^H, K,\ \Omega$ and r are constant. As a consequence, we drop the time subscript except for nominal variables, which grow at a rate π, with $\Pi = 1+\pi$.

To prove that inflation has a real effect which truly transits through credit constraints and not through distorting taxes or redistributive mechanism as previously identified in the literature, we assume henceforth a extreme case of completely neutral distribution of money. The inflation tax is redistributed as a lump sum transfer proportional to the beginning of period level of real balances, implying $\tau^H = \frac{\pi}{1+\pi}m^L$ and $\tau^L = \frac{\pi}{1+\pi}m^H$. As a consequence, the inflation tax paid by private agents on their money balances is exactly redistributed as lump sum transfers. This assumption cancels out any redistribution effect of the inflation between types H and L households. Indeed, the two budget constraints can be written as

$$c^H + m^H + a^H = m^L + w \tag{7}$$

$$c^L + m^L + a^L = (1+r)\,a^H + m^H \tag{8}$$

and inflation does not appear in the budget constraints.

2.3 Impact of monetary policy

The long-run effect of monetary policy crucially depends on the thigthness of credit constraints. We thus need to exhibit the conditions under which credit constraints are binding. Firstly, if no one is borrowing constrained in the economy, then by using the first order conditions and the

envelop conditions in a stationary equilibrium, one finds the standard Euler equations:

$$\begin{aligned} u'_c\left(c^L, m^L\right) &= \beta\left(1+r\right)u'_c\left(c^H, m^H\right) \\ u'_c\left(c^H, m^H\right) &= \beta\left(1+r\right)u'_c\left(c^L, m^L\right) \end{aligned}$$

what immediately yields $1+r=\frac{1}{\beta}$. Secondly, credit constraints are binding if - and only if - : $u'_c\left(c^L, m^L\right) > \beta\left(1+r\right)v'_q\left(q^H, e^H\right)$. Using the equality (3) to substitute for $v'_q\left(q^H, e^H\right)$, and equalities (1) and (3) in a stationary state, one finds $1+r<\frac{1}{\beta}$. The result is that credit constraints are binding when the equilibrium interest rate is lower than the inverse of the discount factor, which is standard in this type of model (Woodford, 1990; Kehoe and Levine 2001, among others). This result is summarized in the following proposition.

Proposition 1 *Credit constraints of agents L are binding in a stationary equilibrium if and only if* $1+r<\frac{1}{\beta}$. *If credit constraints never bind then* $1+r=\frac{1}{\beta}$.

This proposition implies that the real interest rate is constant and is not affected by the inflation rate when credit constraints do not bind. But this neutrality result no longer holds when credit constraints are binding as discussed below.

2.3.1 Non-Binding Credit Constraints

To illustrate the neutrality of money when constraints are not binding, one can first rewrite equations (2) and (5) at the stationary equilibrium, which yields for $i=\{H,L\}$

$$\frac{m^i}{c^i}=\frac{1-\phi}{\phi}\frac{1}{1-\frac{1}{\Pi}\frac{1}{1+r}}$$

Thus all agents are affected to the same extent by an increase in inflation irrespective of the labor endowment

$$\frac{\partial\frac{m^H}{c^H}}{\partial\Pi}=\frac{\partial\frac{m^L}{c^L}}{\partial\Pi}<0 \tag{9}$$

When inflation increases, type H households prefer to buy less money. But, they already reduced their level of real balances by using more capital and less money in the previous period. Thus they transferred less resources toward state H. The key point is thus that the decrease in their level of real balances is exactly equal to the decrease in their total resources. As a matter of fact inflation has no effect on real variables since it affects exactly in the same way each agent. We are back to the standard Sidrauski result according to which inflation has no real impact but decreases the demand for money and the utility of households.

2.3.2 Binding Credit Constraints

The neutrality of inflation breaks down when credit constraints bind since inflation affects differently constrained and unconstrained agents. Note first that when credit constraints are binding, real balances held by type L households are the only store of value which allows for consumption smoothing. Using equations (1), (3) and (4) one finds in this case

$$\frac{m^L}{c^L} = \frac{1-\phi}{\phi} \frac{1}{1-\frac{\beta^2}{\Pi}(1+r)} \tag{10}$$

But since $1+r < \frac{1}{\beta}$ when credit constraints are binding, the expression above is different from that of households of type H given by equation (2). Indeed, the equilibrium ratio for L agents is no more determined by the opportunity cost to hold money, but by the difference between consumption the current period and the return on money holdings two periods ahead. Indeed, the ratio $\frac{\beta^2(1+r)}{\Pi}$ is the discounted value of one unit of money held in state L, transferred in state H, and then saved on financial market to the next period, where the household is in state L again.

As a matter of fact, the reaction of the two types of agents differ when they face a change in inflation. Comparing equations (2) and (10), one gets that

$$0 > \frac{\partial \frac{m^L}{c^L}}{\partial \Pi} > \frac{\partial \frac{m^H}{c^H}}{\partial \Pi} \tag{11}$$

The following proposition summarizes the non-neutrality of inflation, the proof of which is left in appendix.

Proposition 2 *If credit constraints are binding in the stationary equilibrium, the real interest rate decreases when inflation increases.*

The rationale for this result lies in the fact that $\frac{m^H}{c^H}$ decreases more rapidly than $\frac{m^L}{c^L}$ as the inflation rate increases. Actually for a given interest rate, type H households, who are the only net savers in this economy, increase their level of asset holdings at the expense of real balances. This is the first effect of inflation well-known as the *Tobin effect*: inflation induces a shift away from money whose return decreases. The heterogeneity of this Tobin effects across agents is precisely at the core of the non-neutrality of money.

The magnitude of the non-neutrality of money might depend on the way the inflation tax is redistributed to households and on the adjustment of prices of factors in general equilibrium. First inflation might induce a *redistributive effect*. So far we have assumed that the inflation tax was redistributed to all agents. But any transfer from high income agents to low income agents affects the incentive to save. For instance, if the additional money is redistributed to low agents such that $\tau^L = \frac{\pi}{1+\pi}\Omega$ and $\tau^H = 0$, then inflation provides some extra revenue to the constrained

agents, which decrease the incentives to save in the high state. Conversely if the additional money is given to agents H, such that $\tau^L = 0$ and $\tau^H = \frac{\pi}{1+\pi}\Omega$, then inflation is a transfer from constrained to unconstrained agents which will favor savings. This effect can be called the *redistributive effect* of inflation, and it only arises from the existence of credit constraints. Second, the change in saving behavior affects the real interest rate and real wages, which brings about an additional effect on money demand. This is a standard *price effect* which appears in general equilibrium.

3 The General Model

We describe a fully-fledged model encompassing more general assumptions about income risks, which is studied quantitatively in Section 4. The economy we consider builds on the traditional heterogeneous agents framework *à la* Aiyagari (1994). This is an incomplete markets economy with stochastic individual risks and borrowing constraints. The key new feature is the introduction of money in the utility function and monetary policy in this framework.

3.1 Agents

3.1.1 Households

The economy consists of a unit mass of ex ante identical and infinitely-lived households. Individuals are subject to idiosyncratic shocks on their labor productivity e_t. We assume that e_t follows a three state Markov process over time with $e_t \in \left\{e^h, e^m, e^l\right\}$ where e^h stands for high productivity, e^m for medium productivity, e^l for low productivity, and with a 3×3 transition matrix[2] Q. The probability distribution across productivity is represented by a vector $n_t = \{n_t^h, n_t^m, n_t^l\}$: $n_t \geq 0$ and $n_t^h + n_t^m + n_t^l = 1$. Under technical conditions, that we assume to be fulfilled, the transition matrix has a unique vector $n^* = \{n^h, n^m, n^l\}$ such that $n^* = n^*Q$. Hence, the n_t converges toward n^* in the long run. n^* is distribution of the population in each state. For instance, n^h is the proportion of the population who has a high productivity.

Markets are incomplete and no borrowing is allowed. In lines with Aiyagari (1994), they can self-insure against employment risks by accumulating a riskless asset a which yields a return r. But they can also accumulate real money assets m, which introduces a new channel compared to the previous heterogeneous agent literature.

[2] This assumption is based on Domeij and Heatchcote (2003) who found that one needs at least three employment states to match crucial empirical features of the employment process and wealth distribution. See the section devoted to the calibration of the model.

For the sake of generality, we follow the literature which introduces directly money in the utility function of private agents to summarize the liquidity services it offers. If the price level of the final good at period t is denoted P_t, the gross inflation rate between period $t-1$ and period t is $\Pi_t = \frac{P_t}{P_{t-1}}$. If an household holds a real amount m_t of money at the end of period $t-1$, the real value of her money balances at period t is $\frac{m_t}{\Pi_t}$. As long as $\Pi_t > \frac{1}{1+r_t}$, money is a strictly dominated assets, but which will be demanded for its liquidity services. Households are not allowed to borrow and can not issue some money. As a consequence, the demand for final goods, the demand for financial assets and for money satisfies at each period t, $c_t \geq 0, a_t \geq 0, m_t \geq 0$

The preferences over the streams of consumption of final goods and of money is given by

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, m_{t+1}\right)$$

It will be assumed that the utility function has a simple form used by Chari, Kehoe and McGrattan (2000), among others

$$u\left(c,m\right) = \frac{1}{1-\sigma}\left[\left(\omega c^{\frac{\eta-1}{\eta}} + \left(1-\omega\right) m^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}\right]^{1-\sigma} \tag{12}$$

where $\eta > 0$ stands for the elasticity of substitution between consumption and money, ω $(1-\omega)$ refers to the relative weight of consumption (money) and σ is the standard intertemporal elasticity of substitution.

The budget constraint of households at each period is,

$$c_t + a_{t+1} + m_{t+1} = \left(1+r_t\right) a_t + w_t e_t + \frac{m_t}{\Pi_t}$$

The value r_t is the after-tax return on financial assets, e_t is the productivity level of the worker at period t, and w_t is the after-tax revenue on labor.

For the sake of realism, we assume that there is a linear tax on private government income. The tax rate on capital at period t is denoted χ_t^a and the tax rate on labor is denoted χ_t^w. As a consequence, if $\tilde{r}_t$ and $\tilde{w}_t$ are the revenue of capital and labor paid by the firms, the returns for households satisfy the following relationship

$$\begin{aligned} r_t &= \tilde{r}_t(1-\chi_t^a) \\ w_t &= \tilde{w}_t(1-\chi_t^w) \end{aligned}$$

The solution of the problem of households is given by a sequence of function m_t, a_t, c_t which maximizes expected utility given the sequence of budget constraints, and the after tax wages w_t, the real interest rate r_t and the gross inflation rate Π_t. There is no aggregate uncertainty and r and Π are thus constant.

Let total wealth in period t be q_t. Then

$$q_t = (1 + r_t) a_t + \frac{m_t}{\Pi_t}$$

With this changes, the dynamic programming problem solved by agents is

$$v(q_t, e_t) = \max_{\{c_t, a_{t+1}, m_{t+1}\}} u(c_t, m_{t+1}) + \beta E[v(q_{t+1}, e_{t+1})]$$

$$\begin{aligned} \text{s.t} \quad c_t + a_{t+1} + m_{t+1} &= q_t + w_t e_t \\ q_{t+1} &= (1 + r_{t+1}) a_{t+1} + \frac{m_{t+1}}{\Pi_{t+1}} \\ a_{t+1} &\geq 0,\ c_t \geq 0,\ m_{t+1} \geq 0 \end{aligned}$$

and with the transition probability for labor productivity given by the matrix Q. Since the effect of inflation on individual behavior heavily depends on whether the credit constraints are binding, we distinguish two cases.

- *Binding credit constraints*

When the household problem yields a value for financial savings which is negative, credits constraints are binding and the first order condition yields the inequality

$$u'_c(c_t, m_{t+1}) > \beta (1 + r_{t+1}) E\left[v'_1(q_{t+1}, e_{t+1})\right]$$

In this case, the problem of the household can be simplified as

$$\begin{aligned} v(q_t, e_t) &= \max_{\{c_t, , m_{t+1}\}} u(c_t, m_{t+1}) + \beta E[v(q_{t+1}, e_{t+1})] && (13) \\ c_t + m_{t+1} &= q_t + w_t e_t && (14) \\ q_{t+1} &= \frac{m_{t+1}}{\Pi_{t+1}} \end{aligned}$$

which yields the following expression for the value function:

$$v(q_t, e_t) = \max_{m_{t+1}} u(q_t + w_t e_t - m_{t+1}, m_{t+1}) + \beta E\left[v\left(\frac{m_{t+1}}{\Pi_{t+1}}, e^i_{t+1}\right)\right]$$

The first order condition is

$$u'_c(c_t, m_{t+1}) - u'_m(c_t, m_{t+1}) = \frac{1}{\Pi_{t+1}} \beta E\left[v'\left(\frac{m_{t+1}}{\Pi_{t+1}}, e^i_{t+1}\right)\right] \quad (15)$$

Money demand has no simple expression in case of binding-constraints. The static trade-off between demand for money and demand for consumption appears at the left hand side. If money was not a store of value, this expression would be equal to 0. But, as money allows to transfer revenue to the next period, it creates an additional motive to demand it.

Importantly enough, inflation turns out to have two contrasting effect on the demand for money of borrowing constrained households, what can be seen at the right hand side. On the one hand, inflation induces a substitution effect which contributes to decrease the demand for money when inflation increases (represented by the term $\frac{1}{\Pi_{t+1}}$). On the other hand, the inflation rate entering into the value function through a revenue effect, it might induce an increase in demand for money when inflation increases. The core reason for this result is that money is the only store of value for borrowing constrained households. If the function v is very concave, and for realistic values of the parameters, this second effect can dominate, and *the demand for money can increase with inflation.* We will show in the quantitative analysis that this result holds for the poorest agents.

As a consequence, this case proves that the change in money demand because of inflation, what we call the *Tobin effect*, can be decomposed into a revenue effect and a substitution effect for the constrained households.

- *Non Binding credit constraints*

In this case, the first order condition reads as follows

$$\begin{aligned} u'_c(c_t, m_{t+1}) &= \beta(1+r_{t+1})\, E\left[v'_1(q_{t+1}, e_{t+1})\right] \\ u'_m(c_t, m_{t+1}) &= \beta\left(1+r_{t+1}-\frac{1}{\Pi_{t+1}}\right) E\left[v'_1(q_{t+1}, e_{t+1})\right] \end{aligned}$$

Let define the real cost of money holdings γ_{t+1} by

$$\gamma_{t+1} \equiv 1 - \frac{1}{\Pi_{t+1}} \frac{1}{(1+r_{t+1})}$$

This indicator measures the opportunity cost to hold money. When the after-tax nominal interest rate r^n_{t+1}, defined by $1 + r^n_{t+1} = \Pi_{t+1}(1+r_{t+1})$ is small, then one can check that $\gamma_{t+1} \simeq r^n_{t+1}$. With this notation and the expression of the utility function given above, the first order conditions yield

$$m_{t+1} = \left(\frac{1-\omega}{\omega}\frac{1}{\gamma_{t+1}}\right)^{\eta} c_t$$

The coefficient $-\eta$ represents the interest elasticity of money demand. The coefficient ω scales the level of the money demand. The previous equality yields that the money demand of unconstrained households is only affected by the substitution effect depending on the opportunity cost to hold money.

3.1.2 Firms

We assume that all markets are competitive and the only good consumed is produced by a representative firm with an aggregate Cobb-Douglas technology. Let K_t and L_t stand for aggregate

capital and aggregate employment rate respectively. It is assumed that capital depreciate at a constant rate δ and that it is installed one period before production. As there is no aggregate uncertainty, aggregate employment and, more generally, aggregate variables are constant.

The output is given by

$$Y_t = F(K_t, L_t) = K_t^{\alpha} L_t^{1-\alpha} \quad 0 < \alpha < 1$$

with

$$L_t = n_t^h e^h + n_t^m e^m + n_t^l e^l$$

Prices are set competitively:

$$\tilde{w}_t = (1-\alpha)(K_t/L_t)^{\alpha} \tag{16}$$

$$\tilde{r}_t + \delta = \alpha (K_t/L_t)^{\alpha-1} \tag{17}$$

with

$$\tilde{w}_t^h = e^h \tilde{w}_t, \qquad \tilde{w}_t^m = e^m \tilde{w}_t, \qquad \tilde{w}_t^l = e^l \tilde{w}_t \tag{18}$$

And the aggregate demand for capital by firms is given by

$$K_t^d = L_t (\alpha/(\tilde{r}_t + \delta))^{\frac{1}{1-\alpha}}$$

3.1.3 Government

The government levies taxes to finance a public good, which costs G unit of final goods at each period. Taxes are proportional to the revenue of capital and labor, with a coefficient χ_t^a and χ_t^w at period t. In addition, the government gets the revenue of the new money created at period t, which is denoted τ_t in real term.

It is assumed that the government does not issue any debt. The government budget constraint is given by

$$G = \chi_t^a \tilde{r}_t K_t + \chi_t^w \left(n_t^h e_t^h + n_t^l e_t^l + n_t^m e_t^m \right) \tilde{w}_t + \tau_t \tag{19}$$

3.2 Equilibrium

Market Equilibria

Let $\lambda_t : E \times \mathbb{R}^+ \longrightarrow [0,1]$ denote the joint distribution of agents over productivity and wealth. Aggregate consumption C_t, aggregate money holdings M_{t+1}, and aggregate financial savings A_{t+1} are given by

$$C_t = \int\int c_t \left(e^k, q\right) \lambda_t \left(e^k, q\right) dqde$$

$$M_{t+1} = \int\int m_{t+1} \left(e^k, q\right) \lambda_t \left(e^k, q\right) dqde$$

$$A_{t+1} = \int\int a_{t+1} \left(e^k, q\right) \lambda_t \left(e^k, q\right) dqde$$

The sequence of market openings is the same as in the previous section : the labor, financial, money and good markets open successively. Equilibrium in the final good market implies

$$C_t + K_{t+1} + G_t = Y_t + (1 - \delta) K_t \tag{20}$$

Equilibrium in the financial market implies

$$K_{t+1}^d = A_{t+1} \tag{21}$$

The money market equilibrium is defined by

$$M_{t+1} = \Omega_t \tag{22}$$

where Ω_t is the real quantity of money in circulation at period t.

Monetary Policy

The monetary policy is assumed to follow a simple rule. At each period, the monetary authorities create some new money by selling on the money market a nominal amount of money which is proportional with a factor π to the nominal quantity of money in circulation, $P_t\Omega_t = P_{t-1}\Omega_{t-1} + \pi P_{t-1}\Omega_{t-1}$. This process of money creation is a shortcut of open market practices and implies that the State gets all the revenue from the inflation tax. Indeed, the profits of central banks are redistributed to the State and are not used for specific purposes. Moreover, this process is more suited to the heterogenous agents framework than the helicopter drops of money, as it is argued in Akyol (2004). As a result,

$$\Omega_t = \frac{\Omega_{t-1}}{\Pi_t} + \pi \frac{\Omega_{t-1}}{\Pi_t} \tag{23}$$

As a consequence, the value of the inflation tax is

$$\tau_t = \pi \frac{\Omega_t}{\Pi_t} \tag{24}$$

Note that if the real quantity of money in circulation is constant (which is the case in equilibrium), equation (23) implies that $\Pi = 1 + \pi$, and hence $\tau = \frac{\pi}{1+\pi}\Omega$, what is the standard expression of the inflation tax.

Competitive equilibrium

A stationary competitive equilibrium for this economy consists of decision rules $c(e, q)$, $a(e, q)$, and $m(e, q)$ respectively for consumption, financial asset holdings and real balances, the steady state joint distribution over wealth and productivity $\lambda(e, q)$, the real return of financial asset r, the real wage w, the real return on real balances $1/\Pi$, and tax transfers χ^a , χ^w , consistent with the exogenous supply of money π and the government public spending G such that

1. The long run distribution of productivity is given by a constant vector n^*.
2. The functions a, c, m which solves the problem of the households
3. The joint distribution λ over productivity and wealth is time invariant.
4. Factor prices are competitively determined, by equation (16)-(18).
5. Markets clear, equations (20)-(22).
6. The quantity of money in circulation follows the law of motion (23)
7. The tax rates χ^a and χ^w are constant and are defined to balance the budget of the State (19), where the revenue from the inflation tax τ is given by (24).

Note that because of equilibrium on the money market and the stationarity of the joint distribution imply that the real quantity of money in circulation is constant.

Summary of the effects of monetary policy

In the presence of credit constraints, inflation is expected to affect private savings because of four effects. 1) *Tobin Effect :* It has been shown that an increase in the cost of money induces a different shift toward consumption and financial savings for unconstrained and constrained agents. As proven in the previous section, this effect exists only because of credit constraints. Moreover, it can be decomposed in a substitution and a revenue effect for constrained households. 2) *Redistributive Effect:* As public spending is assumed to be constant and equal to G, the inflation tax changes the tax structure of the government revenue, which has redistributive effect because of the linear tax schedule. But redistribution has a real effect because it can either increase or decrease the insurance in case of binding credit constraints. This real effect of a non distorting tax exists only because of the binding credit constraints. 3) *Distorting tax effect :* Inflation raises additional resources which can induce a decrease in the linear tax schedule on capital, which alleviate the negative effect of this distorting taxation scheme. This effect does not depend on credit constraints, and can be found in various types of model (Chari, Christiano and Kehoe, 1996) and was mentioned by Phelps (1973). 4) *Price effect :* Finally, as inflation affects savings, it affects capital accumulation, the real interest rate and the real wage. This change in prices affect the behavior of private agents. The next section provides a quantitative evaluation of these different channels.

3.3 Calibration

Technology and Utility

The model period is one year and the model is calibrated on the US economy. Since the primary interest of the paper lies on the interactions between wealth heterogeneity and monetary policy, the key goal of the calibration is to match the observed distributions of wealth and consumptions.

Table 2 reports the preference and technology parameters. The parameters relating to the production technology and the discount factor are standard with a capital share α set equal to 0.36, the capital depreciation rate is 0.1 and the discount factor is set to 0.96.

Regarding the utility function, we follow the literature by choosing a CES general specification

$$u(c,m) = \frac{1}{1-\sigma}\left(\omega c^{\frac{\eta-1}{\eta}} + (1-\omega)\, m^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta(1-\sigma)}{\eta-1}} \tag{25}$$

We draw on the money demand literature to choose the parameter values of the utility function. We follow Chari et al. (2000) who estimated an interest elasticity $\eta = 0.39$ on the United States for the postwar period. We set the share parameter $\omega = 0.98$ to reproduce the observed amount of money on GDP. As there is no standard definition of money in this literature (M1 or M2), we use the average value of M1/GDP and M2/GDP which is about 0.30 on the same period.

Table 1: Benchmark calibration

Parameters	β	α	δ	ω	η
Values	0.96	0.36	0.1	.98	0.39

Employment Process

Regarding the employment process, the key goal of the calibration is to find a stylized process for wages empirically relevant and which is able to replicate the US wealth distribution - in particular the fraction of people who are borrowing constrained.

We follow Domeij and Heathcote (2003) who estimated a rather stylized process to match some of these criteria. The authors found that one needs at least three employment states to match two main features of the wealth distribution estimated by Diaz-Gimenez et al. (1997): a Gini coefficient of 0.78 and the fact that the two poorest quintiles of the distribution hold only 1.35 percent of the total wealth. Thus $e = \left\{e^h, e^m, e^l\right\}$ where e^h stands for high productivity, e^m for medium productivity, e^l for low productivity. The ratio between the different productivity levels and the transition probabilities are set in order to match the autocorrelation $\rho = 0.9$ and the innovation $\sigma = 0.224$ in the individual earnings estimated on the PSID. The implied ratio of productivity values are $e_1/e_2 = 6.06$ and $e_2/e_3 = 5.02$. And the Markov chain consistent with the observed earning process is $p_{1,1} = p_{3,3} = 0.9$ and $p_{2,2} = 0.988$

$$Q = \begin{bmatrix} p_{1,1} & 1-p_{1,1} & 0 \\ \frac{1-p_{2,2}}{2} & p_{2,2} & \frac{1+p_{2,2}}{2} \\ 0 & 1-p_{1,1} & p_{1,1} \end{bmatrix}$$

Yet it is important to stress that Domeij and Heathcote (2003)'s calibration still fails to reproduce the fraction of people who are borrowing constrained since this fraction is equal to zero in their set-up. However a bulk of empirical evidence suggest that the fraction of household liquidity constrained is sizeable. In our benchmark calibration, 31 percent of the population is credit constrained. This number is a little bit higher than the one found by Jappelli (1990) in the 1983 Survey of Consumer Finance that about 20 percent of the US population was liquidity constrained. But, recent estimations (Grant, 2003) show that this number is not unrealistic.

Table 2 reports the main statistics reproduced by our model under the benchmark calibration with endogenous prices and distorting inflation taxes. The benchmark calibration matches closely the key observed ratio of capital $K/Y = 2.8$, of money $(M/P)/Y = 0.32$ and of public debt $G/Y = 0.22$. Moreover, the calibration yields a tax rate on labor and capital $\chi = 0.31$ quite close to the observed one (Domeij and Heathcote, 2003). Importantly enough, the benchmark set-up matches the Gini coefficient of wealth and consumption and is able to replicate both the upper tail and the lower tail of the wealth distribution.

Table 2: Benchmark calibration

Values	Data	Benchmark economy
K/Y	2.5	2.8
(M/P)/Y	0.30	0.32
G/Y	0.20	0.22
χ	0.36	0.31
Gini Wealth	0.78	0.80
Gini Consumption	0.22	0.23
Wealth 80-100	79.5	84

4 Results

We first consider the benchmark version of the model presented in the previous section. We document in this set-up the effects of monetary policy on individual behavior and aggregate

variables. Secondly, we disentangle the different channels through which inflation is likely to affect aggregate economic outcomes.

4.1 Inflation and individual policy rules

As a first stage we document the effect of inflation on individual policy rules and the induced interactions between asset holdings and real money balances.

Figure 1 reports the consumption policy rule as a function of both the level of labor productivity and the current period total wealth q, which includes financial and monetary wealth. Consumption is an increasing function along these two dimensions. As a standard result, the increase is not linear, the marginal propensity to consume being much higher for low level of wealth and low values of productivity. Indeed, the level of consumption is smaller for low wealth, low productivity agent and the value function is much more concave for this type of agent compared to high productivity worker.

Figure 1 also reports the level of next period financial asset holdings and real money balances as a function of the level of labor productivity and the current period total wealth. Both policies are an increasing function of total current wealth . Medium and low productivity workers are always dis-savers in financial asset while high productivity households are net savers in financial assets except at very high level of wealth. This behavior is the result of the three states model used to simulate the status on the labor market, and it is also found in Heathcote (2005). The asset holdings policy rules for medium and low productivity households display kinks at low level of current wealth. In this case these two types of workers dis-save all their capital stock and only carry on real balances into next period to smooth their consumption.

Figure 2 reports the ratio of next period money balances over next period total wealth $\frac{m'}{q'}$ as a function of current total wealth q across the three levels of productivity. When the level of current wealth decreases, medium and low productivity households carry on more cash in their total wealth into the next period. Indeed, when q becomes very small these households become credit constraint an use only money as a store of value. Indeed, the ratio $\frac{m'}{q'}$ tends toward 1 when q become smaller and smaller. By contrast, this ratio is lower for the high productivity households at low level of current wealth q, since they are always net-savers in asset holding. For higher value of q the high productivity households, who have a high income, holds relatively more money in their total wealth, because, as they have a high income they consume more and hold relatively more money because of its liquidity services. As a consequence, we find that low wealth households hold relatively more money than high wealth households. This behavior is empirically relevant and is obtained as an endogeneous outcome of credit constraints contrary to Erosa and Ventura (2002).

Figure 3 reports the evolution pattern of consumption, savings and money balances as a

function of time. For the sake of illustration, we simulate the time path of a given individual who starts with zero net wealth in the highest labor market state and then alternates between each labor market states every forty periods. Figure 3 illustrates that individuals save both in financial assets and in real balances in the highest productivity states only and dis-save in the two lower ones. Thus these two different stores of value behave exactly in the same manner in order to smooth consumption intertemporaly. But since real balances also yields liquidity services, they follow a much closer path to that of consumption compared to asset holdings.

Let us now turn to the effect of inflation on the different individual policy rules. Figure 4 reports the impact of a one percent rate increase in inflation from $\pi = 2\%$ to $\pi = 3\%$ on next period asset holdings and money balances as a function of beginning of period total wealth. The focus is put on the policy rules around the kink where the main non-linearity lies. We focus on the high and the low productivity states, households in the medium state having similar policy rules as the low productivity ones. For high value of productivity, an increase in inflation provides more incentives to save in financial assets at the expense of real money balances whose value has been slashed by inflation. This behavior stands in sharp contrast with that of households in lower productivity states. These households are borrowing constrained on asset holdings at low level of total wealth. In this case they have no other choice than increasing their level of money balances following a rise in inflation in order to sustain their level of consumption. Indeed, money is used as a store of value, and the revenue effect dominates the substitution effect when wealth is low, as explained in the discussion of equality (15). Their level of real money balances decreases only at higher level of total wealth for which credit constraints on financial assets are no longer binding. This contrasted effect suggest that the impact of inflation on economic outcomes and welfare crucially depends on borrowing constraints. This analysis is carried on in the next section.

4.2 Aggregate outcomes of inflation

This section assesses the aggregate outcomes of inflation. We focus on a policy experiment in which the inflation rate rises by one point from $\pi = 2$ percent to $\pi = 3$ percent. As a first step, we focus on the general equilibrium effect of inflation in the benchmark model. We then sort out the different channels identified in the model through which inflation affects the economy, namely the price channel, the redistributive tax channel and the Tobin channel. Eventually, the welfare effects of inflation are quantified depending on the productivity and the wealth of households.

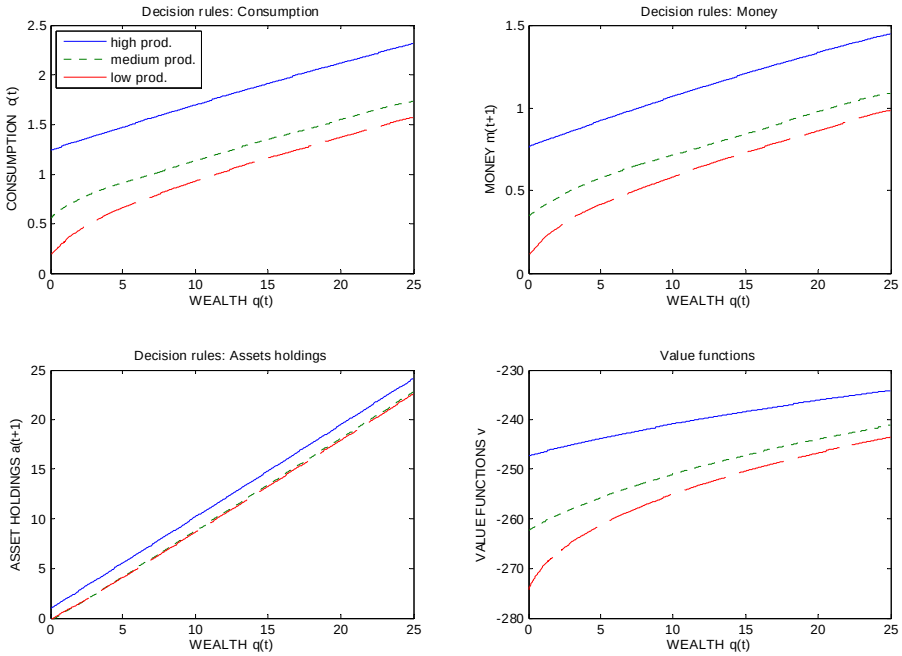


Figure 1: Individual policy rules

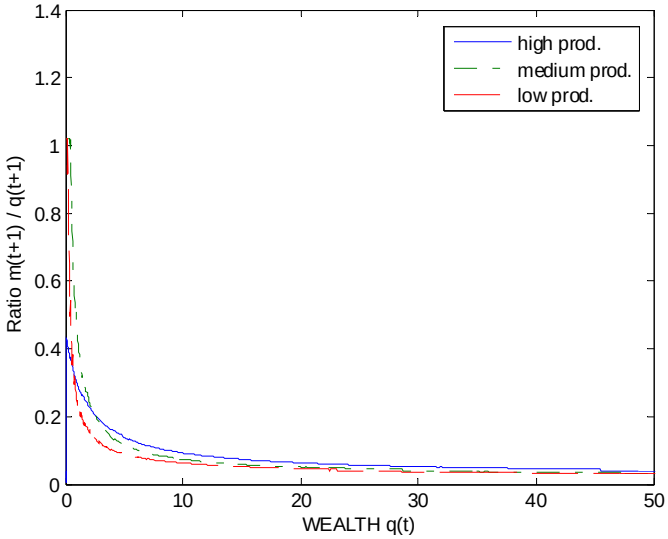


Figure 2: Ratio of real balances over total wealth

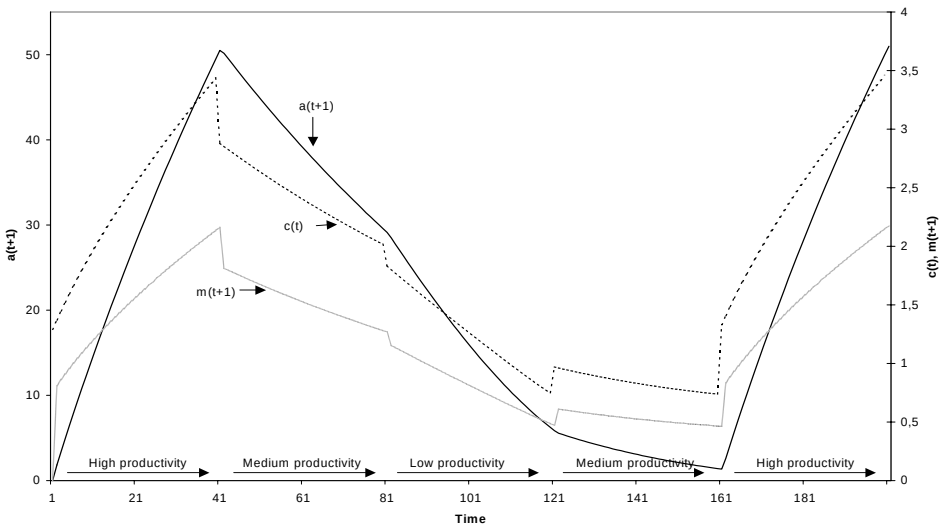


Figure 3: Evolution pattern of consumption, capital and money

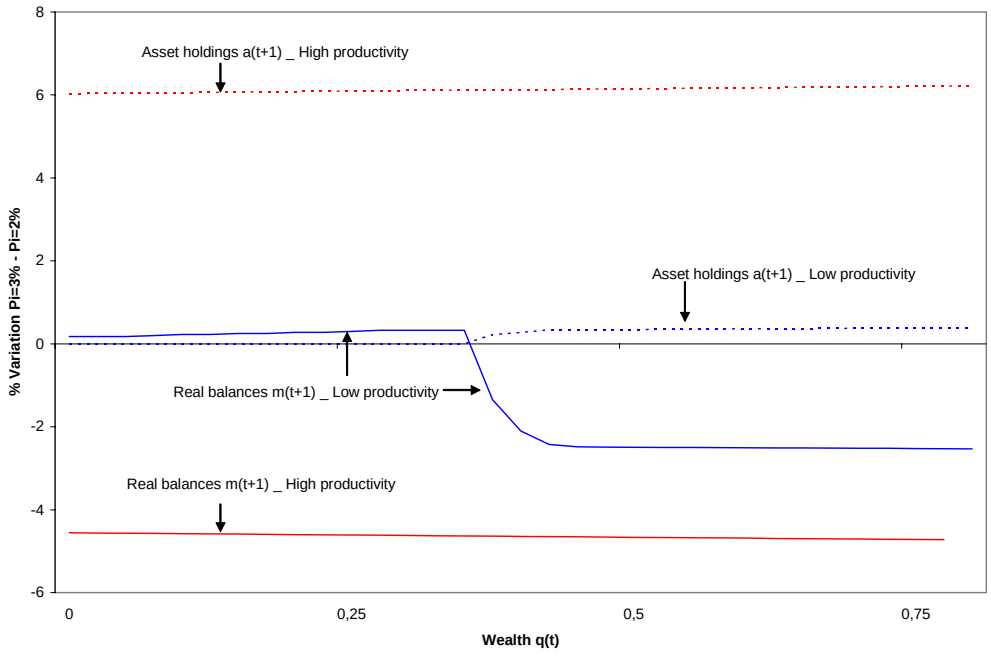


Figure 4: Effect of inflation on individual policy rules

4.2.1 General equilibrium effect

To gauge the impact of inflation, we assume that the inflation rate rises by one point from $\pi = 2$ percent to $\pi = 3$ percent. Table 3 presents the aggregate outcome of such a monetary shock for different assumptions concerning the adjustment process of the economy. The benchmark situation corresponds to the model presented in the previous section, where taxes and the interest rate are endogenous.

Table 3 reports the results of different simulation to disentangle the effect of inflation. Column A provides the total value of financial savings, column M is the total real quantity of money in circulation, C is total consumption, χ^a is the coefficient for the tax on capital and χ^w is the coefficient of the tax on labor. In the benchmark model, these two values are equal, what will not be the case in other simulations, finally the last column gives the value of the real interest rate. Table 3 - line 1 reports the variables normalized to 100 in the benchmark situation with $\pi = 2$ percent.

Table 3 - line 2 reports the general equilibrium effect of a rise by one point in inflation. In this set up both interest rates, wages, and taxes on capital and labor wages are endogenous, and adjust to the rise in inflation. Consistently with individual behavior, inflation crowds out the aggregate level of money demand by 6.11% at the benefit of aggregate capital which rises by 1.2 percent. This rise leads to an overall increase in stationary consumption by 0.13 percent. Capital and labor income are taxed at the same rate. Since more resources are levied by the inflation tax, the tax rate on labor and capital income decreases by 1.2 percent. This decrease in the tax on capital favors capital accumulation. By contrast, the variation in the interest rate lowers the incentive to save in general equilibrium. The rise in aggregate capital supply leads to a decrease in the interest rate by 0.65 percent. Since the effects of inflation heavily depend on taxes and interest rates, the next two sections sort out these channels.

4.2.2 Decomposition of inflation effects

Redistributive effect of inflation tax

We first focus on the inflation effect transiting through distorting taxes, namely the Phelps effect. Table 3 - line 3 reports the aggregate impact of a rise in inflation to $\pi = 3$ percent when the distorting tax on capital χ^a is constant and equals to its value in the benchmark case. The real interest rate adjusts to balance financial markets, and the tax on labor is determined such that the budget of the government is balanced. Since the inflation tax is no longer used as a means to decrease tax on capital, the latter one is higher and the incentives to save are lower. Thus the aggregate capital stock only increases by 0.16 percent which is lower compared to the general equilibrium situation. Meanwhile, the demand for money decreases by 6.16% since the

Table 3: Aggregate impact of inflation

Economies	Aggregate effects of an increase in inflation $\pi = 2\% \rightarrow 3\%$					
	A	M	C	χ^a	χ^w	r
1) Benchmark at 2%	100	100	100	100	100	100
2) Benchmark at 3%	100.39	93.89	100.13	98.8	98.8	99.35
3) Redistributive inflation tax effect	100.16	93.84	100.07	100	98.65	99.8
4) General equilibrium prices effect	101.05	94.00	100.27	100	98.5	100
5) Tobin effect	100.50	93.50	99.58	100	100	100

value of real balances is slashed by inflation. Thus these two offsetting effects on capital and real balances lead to a slower increase in consumption by 0.07% compared to the benchmark economy. Regarding tax on labor, its level is lower compared to the benchmark set-up since all the resources brought about by the seigniorage rents are used to decrease this tax. Eventually, since there is less capital accumulation, the interest rate decreases only by 0.2%.

General equilibrium price effects

We push further the analysis by controlling for the effect of inflation transiting through interest rate and wages. For that purpose we set these prices at their value in the benchmark economy with an inflation rate of 2 percent. The tax on capital χ^a is also held constant and kept at is value in the benchmark economy with a 2 percent inflation rate. But, the tax on labor adjusts to balance the budget of the State. This situation typically refers to the one of a small open economy with perfect capital mobility, and hence where the interest rate *before* and *after tax* is determined by the rest of the world[3] and are the same as in the benchmark economy.

Table 3- line 4 reports the implied effect of inflation in this set-up. The increase in aggregate capital by 1.05 percent is much higher compared to the situation with endogenous prices since the return on capital is no longer decreasing as the aggregate savings increase. It turns out that the general equilibrium price effects are sizeable since the rise in aggregate capital is about six times as large as the one yielded with endogenous prices and the same tax structure on capital (Table 3 - line 3). As before the resources levied by the inflation tax are higher than in the

[3] Households can save in foreign financial markets, and private firms can be financed abroad.

benchmark economy, what contributed to decrease the resources levied by labor taxes χ^w. The real money demand decreases, but a little bit less than in the previous economy since households are wealthier on average. They also consume more for the very same reason.

Tobin effects

We end up this analysis of inflation by isolating the Tobin effect. This channel boils down to a substitution effects between asset holdings and real balances only due to a change in the opportunity cost to hold money while income and taxes remain constant. To that end, Table 3 - line 5 reports the effect of a one percent rise of inflation to $\pi = 3\%$ when: i) the after tax real interest rate takes on the same value as the one in the benchmark set-up with $\pi = 2\%$ and ii) the after tax labor income is the same as in the benchmark set-up. Hence, any effects of inflation on the tax system and hence on the revenue of households are cancelled out. The economy behaves as the one of a small open economy in which the State consumes all the revenue from the inflation tax.

The Tobin effect turns out to be sizeable. Table 3 - line 5 indicates that financial savings increase by 0.5%. Money demand decreases by 6.5%. Importantly enough, consumption now decreases by 0.42%. This negative impact stems from the fact that government not only finances the public good but also consumes the additional resources levied by inflation tax. Hence, it now consumes more than in the previous frameworks.

Accountability of inflation effects

Table 4 reports the quantitative impact of each channel on aggregate capital. Four effects can be disentangled. The first one transits through the variation in the distorting tax, the so-called Phelps Effect. The size of this effect can be measured by the difference in private savings between lines 3 and 2 of Table 3, what yields an effect of 0.23 percentage point. The second effect is linked to the change in the real interest rate induced by the increase in savings. This general equilibrium price effect is measured by the difference between lines 4 and 3 of Table 3. Table 4 - Column 2 shows that prices have a first order effect as reported. The negative variation of the interest rate in the endogenous price set-up lowers the accumulation of capital by 0.89 percentage point compared to the open-economy framework. The pure Tobin effect is reported in Table 4-Column 4 where the revenue of households has been kept constant, and where the change in financial savings is only due to the change in inflation. This effect creates an increase of 0.5 percentage point in private savings. Finally, Table 4-Column 3 reports the pure redistributive effect of inflation which amounts to 0.55 percentage point. This effect is measured by the increase in savings when the after tax interest rate has been kept constant to control for price effects, and when the Tobin effect has been removed. As a consequence, this effect corresponds to the difference between line 4 and line 5 of Table 3. Note that the three

previous effects only arise in the context of binding credit constraints.

Table 4: Decomposition of inflation effects

Phelps tax effect (1)	Price effect (2)	Tobin effect (3)	Redistributive effect (4)	Total effet (1)+(2)+(3)+(4)
0.23	-0.89	0.5	0.55	0.39

Comparison with complete markets

It is worthwhile to quantify the specific contribution of credit constraints and incomplete market in the analysis of the effect of inflation. For that purpose we compare the previous results to a complete market economy. In this set-up the real interest rate is determined by the standard equilibrium relationship $1+(1-\chi^a)\,r^{cm}=\frac{1}{\beta}$, where the left hand side is the real after tax interest rate. The upperscript *cm* stands for complete markets. The equilibrium capital stock is given by the equality between r^{cm} and the marginal productivity of capital.

First, when taxes on capital are the same as in the benchmark economy, one finds that the financial savings with complete markets are 13.3% smaller than the one obtained in the benchmark economy. The reason for this result is that the savings of private agents are higher with credit constraints because of the precautionary motive : Unconstrained agents self-insure against the risk of facing credit constraints.

Second, if markets are complete and there are no distorting taxes on capital ($\chi^a=0$), the equilibrium interest rate is given by $1+r=\frac{1}{\beta}$. This situation yields a value of financial savings which is 21% higher than the value obtained in the benchmark case. As a consequence, although there is over-accumulation in the credit constrained economy compared to an economy with complete markets and the same distorting taxes, there is under-accumulation compared to the first best capital stock.

4.3 Welfare

4.3.1 Average welfare

We use the standard Aiyagari-McGrattan average welfare criterion defined as the expected discounted sum of utilities under the equilibrium stochastic stream of consumption and real balances of infinitely lived agents. The welfare function denoted W weights all agents equally and is defined at the stationary equilibrium. The welfare function is given by

$$W = \int \int v(e,q) d\lambda(e,q)$$

Following Lucas' tradition, we measure the welfare gain of inflation as the percentage of consumption one must give to households living in an environment with low inflation rate to leave them indifferent with living in another economy with higher inflation rate. The monetary policy experiment is the same as below and consists of an increase by one point in the inflation rate from $\pi = 2\%$ to $\pi = 3\%$. Let $c(\epsilon, q)$ and $m(\epsilon, q)$ be the level of consumption and real balances of the household having a labor productivity ϵ and a level of wealth q. These quantities are defined at the stationary equilibrium under the benchmark level of inflation $\pi = 2\%$ used in the calibration. Let $c^{\Delta\pi}(\epsilon, q)$ and $m^{\Delta\pi}(\epsilon, q)$ be the level of these quantities after a change in the inflation rate, and let $\lambda^{\Delta\pi}$ be the new stationary joint distribution after a change in inflation. The average welfare gain Δ^{av} is thus defined as

$$\int \int u\left((1+\Delta^{av})c(e,q), m(e,q)\right) d\lambda(e,q) = \int \int u\left(c^{\Delta\pi}(e,q), m^{\Delta\pi}(e,q)\right) d\lambda^{\Delta\pi}(e,q)$$

Table 5-Line 1 reports the average welfare effects of inflation depending on the different assumptions on prices and taxes. Table 5-Col. 1 reports the average welfare cost of inflation in the benchmark equilibrium model with endogenous prices and taxes. In this set-up, a rise in inflation decreases average welfare by 0.04 percent of consumption. But as shown below, this welfare cost is much smaller compared to the complete market economy. This result stems from two contradictory effects of inflation since it leads to an increase in capital and thus in consumption on one hand, and a decrease in money holdings on the other hand. But the negative impact of inflation on money holdings outweight the former one in general equilibrium.

Table 5-Line 1 - Col. 2 reports the average welfare effect of inflation when taxes on capital are held constant at their benchmark value when $\pi = 2$ percent and when the real interest rate adjusts to balance the financial market. In this case, taxes on capital are no longer reduced by inflation through the seigniorage rents. Thus the rise in capital brought about by inflation is less pronounced than in the benchmark case. As a matter of fact, the average welfare cost of inflation increases to -.17 percent of permanent consumption.

Table 5-Line 1 - Col. 3 shows the average welfare effect of inflation when interest rate and wages are held constant irrespective of the level of inflation. Note that the capital tax is still assumed to be fixed and that the tax on labor adjusts to balance the budget of the government. Hence, before and after tax interest rates are fixed. In this environment, the results are completely overturned. On average, inflation is welfare improving, leading to a rise in average permanent consumption by 0.32 percent. This result is mainly explained by the key role played by the interest rate in the incentive to hold asset holdings. Since the return on capital no longer decreases, it becomes less costly to use this asset to offset the drop in the value

of real balances. As Table 3 made clear, the average level of capital supply steadily increases in this case, allowing a much higher consumption. This effect more than outwheigths the decline in real balances. Thus result suggests that inflation might be welfare-improving in open economies.

Table 5: Average welfare effect of inflation: stationary comparison

Economies	Benchmark economy	Fixed capital tax	Fixed interest rate
Average gains	-0.04	-0.17	0.32

Comparison with complete markets

The importance of credit constraints and incomplete markets in assessing the welfare effects of inflation can be exhibited by comparing the variation in the average welfare in the previous model with the variation in welfare in an economy with complete markets.

In the case of complete markets, all agents are fully insured against idiosyncratic shocks and are identical regarding their level of assets, real balances and consumption. As a consequence, the economy behaves as if a representative agent maximizes her utility with the same taxes and the same inflation rate. Hence, we construct a simple model with a representative agent who has the same utility function (25), who receives all labor incomes and who pays taxes on capital and labor to finance the same amount of public good G. Then, we compute the difference in the stationary utility[4] from a change in inflation in this framework. As before, the coefficients on the taxes on labor and capital are equal.

A change in the steady state level of inflation from 2% to 3% decreases welfare of the representative agent by 0.012 percent. This drop is higher compared to the incomplete market economy. The decrease in average utility in the benchmark economy with credit constraints was reaching 0.009 percent, which corresponded to the steady state decrease in consumption of 0.04 percent shown in Table 6. As a consequence, the drop in the utility of the representative agent is 30 percent higher than that of the average utility in the incomplete market economy. The difference between the two results stems from the positive real effect of long run inflation on aggregate capital and consumption when borrowing constraints are taken into account. As a consequence, the introduction of credit constraint has a first order effect in the assessment of the cost of inflation.

[4] We directly give the levels of utility and not the consumption equivalent in this comparison. Indeed, the marginal utility of consumption of the representative agent is different from the average value in our economy. Hence, comparing consumption equivalent can be misleading.

4.3.2 Welfare inequalities

The previous analysis suggested that the average welfare cost of inflation was lower under incomplete market economies compared to complete markets. Yet this average result might hide important welfare disparities across households depending on their level of productivity and wealth.

To investigate this issue, we calculate the welfare effects of inflation for the wealthiest and the poorest high productivity, medium productivity and low productivity households. Importantly enough, the measure of welfare is defined in expected utility terms and thus considers the cost of transition.[5] We compare the expected utility of agents who start from the same initial level of wealth q and productivity e but who live under two different environments with a lower inflation rate $\pi = 2$ percent and a higher inflation rate $\pi = 3$ percent. More notations are necessary to explain this cost of inflation. Define $s_0 = (e_0, q_0)$ as the initial state of an households. It is defined by the initial status on the labor market and the initial wealth. Let $e^t = \{e_1, ..e_t\}$ be the history of the household at period t. Let $c_t(e^t, s_0)$ be the equilibrium consumption after history e^t for a household with initial state $s_0 = (e_0, q_0)$ in the benchmark case where $\pi = 2$ percent. Let $c_t^{\Delta\pi}(e^t, s_0)$ be the equilibrium consumption in the case in which there is an increase $\Delta\pi$ in inflation from $\pi = 2$ percent to $\pi = 3$ percent. Note that we are considering an household with the same initial state in two different environments. The welfare gain as the result of the rise in inflation is defined as the constant percentage rise Δ_{s_0} in consumption in the low inflation rate case that gives the household the same expected utility as when the inflation is higher. The welfare gain Δ_{s_0} thus solves

$$\sum_{t=0}^{\infty}\sum_{e\in E^t}\beta^t u\left((1+\Delta_{s_0})c(e^t,s_0), m(e^t,s_0)\right)\mu(e^t,s_0) = \sum_{t=0}^{\infty}\sum_{e\in E^t}\beta^t u\left(c^{\Delta\pi}(e^t,s_0), m^{\Delta\pi}(e^t,s_0)\right)\mu^{\Delta\pi}(e^t,s_0)$$

where $\mu(e^t, s_0)$ is the probability of history e^t given initial state s_0, in the economy with $\pi = 2\%$, and $\mu^{\Delta\pi}(e^t, s_0)$ is the same probability in the economy with an increase in inflation. We use this equation to calculate the expected welfare gains for households starting from a level of wealth held by the poorest 5 percent poorest and the wealthiest 5 percent in stationary equilibrium with $\pi = 3$ percent. Moreover we assume that the level of taxes and prices are constant during all the transitions. They take on their stationary equilibrium values found for the two economies with

[5] A standard steady-state comparison would overestimate the gain of inflation, in particular for the wealth-poorest. Actually, as suggested by Figure 4, households who are credit constrained have to increase the level of real balances when inflation rises in order to sustain consumption. Thus in steady state comparison, the wealth-poor low productivity workers turn out to be much better-off. But obviously the increase in real balances is costly in consumption terms during the transition path of accumulation. This cost is taken into account in our expected utility comparison.

low and high inflation rates. This assumption boils down to consider that we focus on a marginal proportion of households who do not influence equilibrium prices during the transitions[6].

Table 6: Distributional welfare effects of inflation: transitions

Economies		Benchmark economy	Fixed capital tax	Fixed interest rate
Productivity	Wealth			
High	Poorest 5%	0.05	0.01	0.35
	Richest 5%	-0.38	-0.42	0.16
Medium	Poorest 5%	0.11	0.08	0.25
	Richest 5%	-0.35	-0.38	0.06
Low	Poorest 5%	0.18	0.12	0.31
	Richest 5%	-0.34	-0.37	0.01

Table 6 - Column 1 reports the various welfare gains of inflation under the benchmark economy with endogenous prices and endogenous capital taxes (that is the economy described in Table 3 - line 2). It turns out that inflation has unequal effects across agents depending on their initial level of wealth and labor productivity. Firstly inflation is welfare-improving for the wealth-poor households while it decreases welfare for the wealthiest 5 percent. Secondly the lower the level of productivity,the higher the welfare gains. In particular regarding the 5 percent wealth-poor, the welfare gain of inflation raises from 0.05 percent for high productivity households to 0.18 percent for low productivity workers. These results are mainly due to a price effect. By increasing the level of average capital, inflation raises the level of wages and decreases that of interest rates. Thus inflation benefits more to people whose main income depends on labor, that is to the wealth-poor. And this increase in wages is relatively more praised by the worker with the lowest labor productivity.

Table 6 - Column 2 reports the heterogeneity in the welfare effects of inflation when taxes on capital are held constant at their value of π=2 percent (the economy described in Table 3 - line 3). In this case, the welfare gains of inflation for the wealth-poor are lower and the welfare costs of inflation for the wealthiest are higher compared to the benchmark economy with endogenous capital tax. This result is driven by the fact that the accumulation of capital is more costly since the tax on capital is higher. This negative effect is all the more pronounced for the wealthiest

[6]This assumption would no longer be relevant if we were to calculate the average welfare gains. This is one additional reason why we focused on stationary equilibrium comparison to calculate the average welfare gain of inflation in the previous section.

people whose income is mainly made up of capital.

Eventually, Table 6 - Column 3 shows that inflation is welfare improving for all categories of households in an open economy with fixed interest rates. This result stems from the fact that the accumulation of capital becomes much less costly since the return on capital does not decrease to balance the financial market. In this case, it is still the case that the wealth-poor agents benefit more from inflation than the wealthiest households due to decreasing marginal utility of consumption. Regarding the high productivity agents for instance, the welfare gain of inflation reaches 0.35 percent of consumption for the wealth-poor against 0.16 percent for the wealthiest. Yet the new important fact is that the high productivity workers now benefit more from inflation compared to the low productivity ones since wages are now fixed but they are more efficient. Moreover interest rate are also fixed but they are set at a higher value compared to the benchmark economy with endogenous prices. As a conclusion, this result suggests that the redistributive welfare effect of inflation crucially depends on price adjustments. In particular this is the upper-class in term of labor productivity which would benefit more from inflation in a small open economy with exogenous prices.

5 Conclusion

This paper has put to the fore a new channel for the non neutrality of money which hinges on credit constraints. Incomplete market and borrowing constraints induce an heterogeneity in households optimal behavior following a change in the inflation rate, because credit constrained households can not substitute away their real balances for financial assets.

First, we have first shown that this channel has a quantitative sizeable impact in economies with an empirically relevant wealth distribution. An increase in inflation leads to a substantial rise in long-run output and consumption. Second, the welfare costs of inflation turn out to be much smaller in this incomplete market set-up compared to the representative agent framework in a steady-state comparison *à la* Lucas. Inflation could even be welfare improving when it induces a steady increase in aggregate variables in a small open economy with exogenous interest rate. Furthermore, we found that some households even gain from inflation depending on their level of wealth and productivity.

The focus of this paper is on long run steady state inflation. But, a promising route for future research to would be to analyze the short run effect of monetary shock in such a model. Credit constraints and heterogeneity allow to study the short run redistributive effects of monetary policy. Moreover, this framework can provide a new relevant channel for the persistence and non neutrality of monetary shocks, alternatively to sticky prices.

A Proof of Proposition 2

In this proof, we assume that credit constraints are binding for L households to derive the equilibrium interest rate. In a second step, Then we check that credit constraints are indeed binding for L agents and not for H agents. The first order conditions of the firm problem yield $1+r=\alpha K^{\alpha-1}$ and $w=(1-\alpha)K^{\alpha}$.

First, using the first order condition (1) and (6) one finds $\frac{c^L}{c^H}=\beta(1+r)$. The equilibrium on the good market yields is $c^H+c^L=rK+w$. Substituting c^H, w and K by their value one finds

$$c^L=\beta\frac{1+r-\alpha}{\beta(1+r)+1}\left(\frac{\alpha}{1+r}\right)^{\frac{\alpha}{1-\alpha}}$$

The budget constraint of L agents, given by (8) yields

$$\frac{m^L}{c^L}-\frac{m^H}{c^H}\frac{c^H}{c^L}=\frac{s^H(1+r)-c^L}{c^L}$$

Using the value of the ratio $\frac{c^L}{c^H}=\beta(1+r)$ and the expressions (2) and (10), one finds

$$\frac{\phi}{1-\phi}\left(\alpha\frac{\beta(1+r)+1}{1+r-\alpha}-\beta\right)=\frac{\beta}{1-\frac{\beta^2}{\Pi}(1+r)}-\frac{1}{1+r-\frac{1}{\Pi}} \tag{26}$$

The left hand side is decreasing with r. The right hand side is unambiguously increasing in r. One can show that the right hand side is increasing in Π. Indeed, define

$$g(\Pi)=\frac{\beta}{1-\frac{\beta^2}{\Pi}(1+r)}-\frac{1}{1+r-\frac{1}{\Pi}}$$

and define the function h such that

$$h(y)=\frac{y^3(1+r)^3}{\left(1+r-\frac{y^2}{\Pi}(1+r)^2\right)^2} \tag{27}$$

The function h is positive and increasing in its argument. Now, the derivative $g'(\Pi)$ can be written as $g'(\Pi)=\frac{1}{\Pi^2}\left(h\left(\frac{1}{1+r}\right)-h(\beta)\right)$. As credit constraints are binding, $\frac{1}{1+r}>\beta$, and hence one finds that $g'(\Pi)>0$.

As a consequence, when the equation (26) has a solution r,by the theorem of implicit function it is a decreasing function of Π. A solution r of (26) is an equilibrium interest rate if $1+r<\frac{1}{\beta}$. Here, we simply assume that the values of the parameters are such that it is the case. This is true for instance for $\beta=0.96$, $\phi=0.5, \alpha=0.3$. and $\Pi=1.02$.

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