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Abstract

Motivated by the evidence of the effects of monetary policy on the evolution of inequality, and the importance of insurance mechanisms to deal with idiosyncratic risks, the paper explores the relationship between household inequality and monetary policy in the context of a dynamic stochastic general equilibrium model. In contrast to the traditional approach where the demand–side of the economy is summarised by a single representative agent, the model considers heterogeneous households which face idiosyncratic shocks which they can not fully insure against. The model, which is calibrated using data from Mexico, is able to capture the main features that characterise both the business cycle dynamics, as well as the distribution of income and wealth across households. The results stemming from a series of counterfactual experiments indicate that the the presence of heterogeneity impinges upon the transmission of monetary policy, and that the design of monetary policy has important distributive effects.

Keywords: Monetary Policy, Heterogeneous Agents, Redistribution
JEL Codes: D31, D53, E12, E52, O11

1 Introduction

The results discussed in chapter 2 of Villarreal (2016) indicate that monetary policy raises households' labour–income inequality in Mexico. The increased inequality is the result of a differentiated effect on the response of labour–income of households whose head is formally employed, versus those whose head is employed informally, where formality is proxied by access to social security. Employment informality severely restrict access to certain key markets such as the one for financial services, which in principle help households to insure themselves against the realisation of idiosyncratic risks such as spells of illness or unemployment.

*The views expressed in this document are those of the author and do not necessarily reflect the views of the United Nations Organisation.

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Motivated by these findings, the objective of this paper is to explore the relationship between monetary policy and household heterogeneity when markets are incomplete, in the context of a dynamic stochastic general equilibrium model which can be used to examine counterfactual policy scenarios. In particular, the impact of monetary policy design on household inequality, and the feedback from inequality to the transmission of monetary policy are studied.

The model is calibrated using data from Mexico, and is able to replicate the main features of the distribution of income and wealth across households, as well as of the business–cycle fluctuations. Moreover, the properties under the baseline case are consistent with the evidence regarding the effect of monetary policy on inequality discussed in chapter 2 of Villarreal (2016). Counterfactual experiments are carried out to examine the response of the economy's aggregates to monetary policy shocks, under different assumptions regarding the degree of market incompleteness and preference heterogeneity, as well as the impact of the formulation of monetary policy on household inequality over the short– to medium–term.

The paper contributes to the emerging literature on the distributive effects of monetary policy by building upon the analytical framework proposed by McKay and Reis (2016) to formally examine the channels through which monetary policy and household heterogeneity interact for the case of Mexico.

The results indicate that the presence of heterogeneity exacerbates the response of the economy to monetary policy shocks. In particular, it is found that in order to achieve a given inflation reduction, the short–run effects on aggregate activity and consumption are larger when markets are incomplete. Regarding preference heterogeneity, the evidence indicates that a larger differential of discount factors among household types, reflecting subjective evaluations of risk, affects both the magnitude of the effects as well as the adjustment dynamics of the economy in response to unanticipated increases of nominal interest rates.

Concerning the effect of the design of monetary policy on household heterogeneity it is found that while contractionary shocks generally increase inequality, under strict inflation targeting a more aggressive policy stance reduces the differential in the responses of the two types of households considered, thus attenuating inequality across households. Moreover, the addition of an explicit output target to the policy rule provides further flexibility to ease the impact of monetary policy on inequality.

From the perspective of public policy, the findings are taken to suggest that despite the distributive impact of monetary policy, the appropriate strategy should delegate addressing inequality concerns to fiscal policy, while at the same time focusing on the underlying causes which give rise to the differentiated impact of monetary policy on households' income, consumption and wealth. Chief amongst them is the development of mechanisms which would allow households to effectively insure themselves against the realisation of idiosyncratic risks. Specific policies include fostering financial inclusion and strengthening the labour market.

The rest of the paper is organised as follows. Section 2 describes the model. An overview of the solution algorithm, as well as the details of the calibration strategy and the model's properties are discussed in section 3. The results from counterfactual experiments is reported in section 4. Finally, section 5 concludes with a discussion of the policy implications of the findings as well as directions of future work.

2 Model

The model is a simplified version of the model used by McKay and Reis (2016), which combines the production structure of a standard New–Keynesian model as in Woodford (2003), with a demand–side characterised by heterogeneous households which cannot fully insure against idiosyncratic risks because markets are incomplete, as developed by Bewley (1986), Imrohoroğlu (1989), Huggett (1993) and Aiyagari (1994), and distilled in Heathcote et al. (2009). Following McKay and Reis (2016), the model is solved numerically using a procedure that combines projection and perturbation methods due to Reiter (2009).

2.1 Demand

The demand-side of the economy is comprised by two types of households, *entrepreneur* households which directly own the capital in the economy and can insure themselves against idiosyncratic risks, and *worker* households which do not own capital and can not trade in state–contingent securities which would allow them to offset idiosyncratic risks.

2.1.1 Entrepreneur Households

The entrepreneur households, of which there exists a continuum with unit mass, maximise utility by choosing current consumption c_t, labour supply n_t, and investment which determines the next period's available capital k_{t+1}:

$$\max_{\{c_t\},\{n_t\},\{k_{t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log c_t - \varphi_1 \frac{n_t^{1+\varphi_2}}{1+\varphi_2} \right] \tag{1}$$

$$\text{s.t} \qquad p_t[c_t + k_{t+1}] + \Delta b_{t+1} = p_t \left[(i_{t-1}/p_t) b_t + d_t + (1-\tau_t) w_t \bar{s} n_t + (1+r_t) k_t - \frac{\zeta}{2} \left(\frac{\Delta k_{t+1}}{k_t} \right)^2 k_t \right] \tag{2}$$

where β denotes the discount factor, φ_1 is the relative willingness to work, and φ_2 is the inverse of the Frisch elasticity of labour supply[1].

Entrepreneur households maximise utility subject to budget constraint (2), whose right– and left– hand sides describe, respectively, the resources available and their uses. In addition to final goods purchased at price p_t, which can be consumed or used as capital, households can save using single–period nominal bonds b_{t+1}, which are indexed according to their maturity date and can be traded with worker households and the government. Available resources include the nominal return of bond holdings from the previous period $i_{t-1} b_t$; dividends accruing from ownership of intermediate–goods producers d_t; labour–income $w_t \bar{s} n_t$ which is the product of the wage rate w_t, productivity $\bar{s}$ and hours worked n_t, and is subject to income tax rate τ_t; and net returns from the rental of capital which earns real rate r_t, and are subject to quadratic adjustment costs whose intensity is governed by parameter ζ.

[1]The Frisch elasticity measures changes in labour supply as a response to changes in wages when the marginal utility of wealth is held constant.

A key assumption is that entrepreneur households can insure perfectly against idiosyncratic risk, which takes the form of productivity shocks and are discussed below. In particular, it is assumed they have access to trade in Arrow-Debreu type securities. Since all trades in contingent securities take place among entrepreneur households, they are in zero net–supply and thus drop out of the representative entrepreneur's household budget constraint. Moreover, since they can insure against specific realisations of labour productivity, only average productivity $\overline{s}$ enters the budget constraint.

2.1.2 Worker Households

Worker households, of which there is a measure of mass η and are indexed by $h \in [0, \eta]$, solve a similar optimisation problem although subject to a different budget constraint:

$$\max_{\{c_{h,t}\},\{n_{h,t}\}} \quad \mathbb{E}_0 \sum_{t=0}^{\infty} \hat{\beta}^t \left[\log c_{h,t} - \varphi_1 \frac{n_{h,t}^{1+\varphi_2}}{1+\varphi_2} \right] \tag{3}$$

$$\text{s.t} \quad p_t c_{h,t} + \Delta b_{h,t+1} = p_t \left[(i_{t-1}/p_t) b_{h,t} + (1-\tau_t) w_t s_{h,t} n_{h,t} \right] \tag{4}$$

where crucially, following Krusell and Smith (1998), it is assumed that $\hat{\beta} \leq \beta$ to be able to match the skewness that characterises the distribution of wealth in the data. The lower discount factor is interpreted as a higher subjective assessment of the uninsurable risk faced.

As a reflection of the limited participation of the majority of households in capital markets, it is assumed that worker households do not own capital[2]. Note that this does not preclude their participation in financing capital accumulation through net lending to entrepreneur households via the bond market, where they face the borrowing constraint $b_{h,t+1} > 0$.

Worker households are assumed to face a single uninsurable idiosyncratic risk, namely shocks to labour productivity s_h which give rise to a non–degenerate distribution of labour–income. Given the absence of meaningful unemployment benefits in the Mexican labour market, the vast majority of workers which are laid off from the formal sector usually migrate to the informal sector, which acts as a buffer for the labour market across the business–cycle (Fernández and Meza, 2015). Consequently, unemployment is not explicitly considered. Instead the transition matrix for the Markov–process driving the occurrence of productivity shocks is calibrated to match the dynamics of entry to and exit from the informal sector, which is characterised by lower wages as well as a certain degree of hysteresis (Bosch and Maloney, 2005).

2.2 Supply

Following the standard formulation in the new–Keynesian literature, the supply–side of the economy is comprised of a representative competitive final–goods producing firms, and a continuum of monopolistic intermediate–goods producing firms.

[2]According to the most recent household survey data (INEGI, 2015a) the top quintile receives over 90 % of business income.

2.2.1 Final–goods firm

The representative final–goods firm combines differentiated intermediate goods according to the following function:

$$y_t = \left(\int_0^1 y_{j,t}^{-\mu_t} dj \right)^{\mu_t} \tag{5}$$

where y_t denotes final–goods output, and μ_t is the elasticity of substitution between intermediate inputs $y_{j,t}$, which reflects the markup imposed by monopolistic intermediate–goods producers. The final–goods firm is assumed to be a price taker in the intermediate–goods market, which along with cost minimisation implies that demand for intermediate goods is given by:

$$y_{j,t} = \left(\frac{p_{j,t}}{p_t} \right)^{\frac{\mu_t}{1-\mu_t}} y_t \tag{6}$$

where $p_{j,t}$ is the price of the j–th intermediate input. Given the functional form in 5, the price of final goods is given by:

$$p_t = \left(\int_0^1 p_{j,t}^{-(1-\mu_t)} dj \right)^{1-\mu_t} \tag{7}$$

2.2.2 Intermediate–goods firms

Intermediate goods are produced by a continuum, with mass normalised to one, of monopolistic producers which seek to maximise dividends:

$$d_{j,t+s} = \frac{p_{j,t}}{p_t} y_{j,t} - w_t \ell_{j,t} - (r_t + \delta) k_{j,t} - \xi \tag{8}$$

subject to the demand schedule for intermediate goods (6). Production costs include wages w_t, the rent paid to capital r_t, plus depreciation δ and fixed production cost ξ.

Following Calvo (1983), it is assumed that there is an exogenous probability θ that intermediate–goods firms can adjust their prices during a particular period. When adjusting prices, monopolistic producers seek to maximise current and future profits $d_{j,t+s}$ for $s \geq 0$ by choosing a sequence of prices $\{p_{j,t+s}\}$ subject to the available production technology:

$$\max_{p_{j,t+s}} \quad \mathbb{E}_t \left[\sum_{s=0}^{\infty} (1-\theta)^s \lambda_{t,t+s} d_{j,t+s} \right] \tag{9}$$

$$\text{s.t} \quad y_{j,t+s} = a_{t+s} k_{j,t+s}^{\alpha} \ell_{j,t}^{1-\alpha} \tag{10}$$

where $\lambda_{t,t+s}$ denotes the stochastic discount factor of the representative entrepreneur household, which owns all the intermediate–goods firms[3]. The production function combines capital k_j and effective labour ℓ_j at productivity level a_t. The marginal rate of return of capital is given by α.

[3] From the entrepreneur household's Euler equation (16) it can be shown that the stochastic discount factor is given by: $\lambda_{t,t+s} \equiv \beta^s \frac{(1+i_{t+s})/(c_{t+s+1}\pi_{t+s+1})}{(1+i_t)/(c_{t+1}\pi_{t+1})}$, where $\pi_t \equiv p_t/p_{t-1}$ denotes period t's final–goods inflation.

2.3 Policy and shocks

Monetary policy is assumed to follow a Taylor–type rule (Taylor, 1993):

$$i_t = \bar{i} + \phi_p \Delta \log(p_t) + \phi_y \log(y_t/\hat{y}) + \varepsilon_t \tag{11}$$

which states that the nominal interest rate is adjusted by the central bank around its steady–state level $\bar{i}$, in response to inflation $\Delta \log(p_t)$ and deviations of output y_t from its steady–state level $\hat{y}$, with respective intensities $\phi_p > 1$ and $\phi_y > 0$. The evolution of the nominal interest rate is subject to exogenous shocks ε_t which capture the non–systematic element of monetary policy, and are referred to as monetary policy shocks.

It is assumed that the government issues a constant real amount of debt B, whose service is financed by means of the receipts of the labour–income tax τ_t, which yields the government budget constraint:

$$\frac{1 + i_{t-1}}{\pi_t} B = B + \tau_t w_t \left[\int_0^{\eta} s_{h,t} n_{h,t} dh + \bar{s} n_t \right] \tag{12}$$

Note that the fact that the amount of debt is fixed implies that the labour–income tax rate will evolve countercyclically. This means that fiscal policy will in general exacerbate cyclical fluctuations. This is in line with the evidence for Mexico, where at least until recently fiscal policy has been markedly procyclical, adopting a contractionary stance during downturns, and an expansionary stance during booms (Moreno and Villarreal, 2014).

In addition to idiosyncratic productivity shocks faced by entrepreneur households, and aggregate monetary policy shocks, the dynamics of the model economy are driven by two additional types of aggregate shocks: productivity and markup shocks. All aggregate shocks are assumed to follow stationary first–order autoregressive processes.

2.4 Equilibrium

The equilibrium for this economy is given by the vectors of aggregate quantities ($y_t, k_t, c_t, n_t, b_{t+1}, d_t$) and prices ($p_t, w_t, r_t$); worker households' decision rules ($c_{h,t}(b, s), n_{h,t}(b, s)$) which in the presence of heterogeneity depend on their wealth, as measured by their bond-holdings $b_{h,t}$ and the realisation of the idiosyncratic productivity shock $s_{h,t}$; a distribution of households $\Gamma(b, s)$ over wealth and individual productivity levels; firm–level quantities[4] ($y_{j,t}, k_{h,t}, \ell_{j,t}, d_{j,t}$) and prices ($p_{j,t}$); and government policy functions such that:

1. The representatibve entrepreneur household solves the problem described in section 2.1.1
2. Worker households solve the problem described in section 2.1.2
3. The distribution of households over wealth and individual productivity levels is consistent with their decision rules and idiosyncratic shocks.
4. Final–goods firms solve the problem described in section 2.2.1
5. Intermediate–goods firms solve the problem described in section 2.2.2

[4] As defined in equation (13), $\ell_{j,t}$ denotes firm j's skill–weighted demand for labour.

6. Monetary policy is conducted as described by equation (11)

7. Fiscal policy is conducted subject to the budget constraint (12)

8. The labour, capital and bonds markets clear:

$$\int_0^1 \ell_{j,t} dj = \int_0^\eta s_{h,t} n_{h,t} dh + \overline{s} n_t \tag{13}$$

$$k_t = \int_0^1 k_{j,t} dj \tag{14}$$

$$B = \int_0^\eta b_{h,t} dh + b_t \tag{15}$$

The model just described contains both the standard new–Keynesian monetary policy model, and the standard heterogeneous–agents model as special cases. The former is obtained by setting parameter η equal to zero, while the latter is obtained by allowing all households to own capital and precluding trade in state–contingent securities[5].

3 Solution and model properties

3.1 Solution algorithm

The main challenge in solving the model just described is that the state vector includes the distribution of wealth across households $\Gamma(b, s)$, which under the assumption of a continuum of heterogeneous agents is an infinite–dimensional object. The most widely used method to solve this class of models was developed by Krusell and Smith (1998). The procedure, known as approximate aggregation, reduces the dimensionality of the state–space by summarising the wealth distribution by means of a finite, and relatively small, set of moments. Since the interest of this investigation lies on the relationship between monetary policy and the heterogeneity of households, a richer characterisation is utilised. Instead, the solution method of Reiter (2009), which approximates the distribution by means of a histogram, is employed.

The solution algorithm consists of four stages. During the first stage the cross–sectional distribution of wealth is discretised by projecting it onto a histogram for each of the possible productivity level realisations in which the worker households can find themselves in. For their part, individual decision rules for savings and labour supply are approximated by means

[5] Under the heterogenous–agent model specification all households would solve the following optimisation problem:

$$\max_{\{c_{h,t}\},\{n_{h,t}\},\{k_{h,t+1}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log c_{h,t} - \varphi_1 \frac{n_{h,t}^{1+\varphi_2}}{1+\varphi_2} \right]$$

s.t $\quad p_t[c_{h,t} + k_{h,t+1}] + \Delta b_{h,t+1} =$

$$p_t \left[(i_{t-1}/p_t) b_{h,t} + d_{h,t} + (1-\tau_t) w_t s_{h,t} n_{h,t} + (1+r_t) k_{h,t} - \frac{\zeta}{2} \left(\frac{\Delta k_{h,t+1}}{k_{h,t}} \right)^2 k_{h,t} \right]$$

of linear splines. The main idea during this stage is that instead of having to keep track of the whole distribution to solve for aggregate quantities during the second stage, it is approximated by the the mass of households in each bin of the histogram.

During the second stage, the model economy's steady–state is found by a procedure which iterates between solving for the aggregate variables and solving for the worker households' policy rules and wealth distribution, under the assumption that aggregate shocks are equal to zero. While the resulting steady–state is characterised by the absence of aggregate shocks, a key feature is that it does contain the idiosyncratic uncertainty.

The third stage linearises the system of equations that the discretised model must satisfy. The system is linearised around the steady–state using the automatic differentiation procedure proposed by Reiter (2009). The equations, which are described in detail in appendix 5, include those related to the worker households' problem and the wealth distribution, those related to the representative entrepreneur household's consumption and labour supply decisions, as well as those related to the firms' optimisation problems.

In the fourth stage, the linearised system is solved numerically as a linear rational expectations model following Sims (2002).

3.2 Calibration

Considering that the wealth distribution is a state variable of the model, and that the interest of the paper is to examine the relationship between monetary policy and household heterogeneity, the calibration strategy aims to match the main features of the distribution of income and wealth in the steady–state for the case of Mexico at a quarterly frequency. To the extent possible, parameters are calibrated based on official data. The remaining parameters are calibrated using estimates found in the literature. Table 1 summarises the parameter calibration values used in the baseline case.

Table 1 – Parameter calibration: Baseline case

Parameter	**Description**	**Value**	**Target / Source**
I – Household preferences			
β	Entrepreneurs' discount factor	0.9950	Average ex-post real interest rate
$\tilde{\beta}$	Workers' discount factor	0.9949	Capital income of top quintile
φ_1	Relative willingness to work	38.0000	Average hours worked
φ_2	Inverse of labour supply elasticity	2.8571	Literature estimates
II – Household heterogeneity			
η	Measure of worker households	5.5000	Business income of top quintile
$\bar{s}$	Average entrepreneur households' productivity	1.7900	Labour and capital income of top quintile
$\Pi_{s,s'}$	Skill transition probability matrix	See Table 2	Labour survey
s_1	Low-skilled productivity	0.7264	Median labour – income of informally employed workers
s_2	Middle-skilled productivity	1.2499	Median labour – income of employers and own–account workers
s_3	High-skilled productivity	1.3701	Median labour – income of formally employed workers
III – Firms			
θ	Calvo price stickiness	0.3333	Average price duration
μ	Markup	1.3000	Average manufacturing markup
α	Coefficient of capital in production	0.3500	Production function estimate
δ	Capital depreciation rate	0.0166	Average aggregate depreciation rate
ζ	Capital adjustment cost	15.0000	Standard deviation of private investment
ξ	Fixed production cost	0.3188	Dividends/GDP
IV – Policy			
τ	Labour-income tax	0.0443	Average income tax revenue
ϕ_p	Policy responsiveness to inflation	1.2400	Best (2013)
ϕ_y	Policy responsiveness to output	0.0000	McKay and Reis (2016)
V – Economic structure			
ρ_μ	Autocorrelation of markup shock	0.6400	Best (2013)
σ_μ	Std. dev. of markup shock	0.0080	Best (2013)
ρ_a	Autocorrelation of productivity shock	0.7900	Best (2013)
σ_a	Std. dev. of productivity shock	0.0090	Best (2013)
ρ_ε	Autocorrelation of monetary policy shock	0.6400	Best (2013)
σ_ε	Std. dev. of monetary policy shock	0.0080	Best (2013)

Table 2 – Productivity transition matrix

$Current/Futureskill$	s_1	s_2	s_3
s_1	0.6782	0.2251	0.0967
s_2	0.1500	0.8085	0.0415
s_3	0.2146	0.1409	0.6445

Source: Author based on household–level labour–income data from INEGI (2007).

3.2.1 Household preferences

The first panel summarises the parameters which determine the behaviour of households. The discount factor for entrepreneur households β is calibrated to match the average ex–post real interest rate of 2% observed over the period 2001–2014 (Banxico, 2016). The discount factor for worker households $\tilde{\beta}$ was chosen to match the proportion of capital income received by the top wealth quintile, which according to official data is approximately 85%[6].

Regarding preferences with respect to labour supply, as in McKay and Reis (2016) the parameter φ_1 is calibrated so that in steady–state, the average of hours worked in the model match the approximately 45 weekly hours reported in labour survey data (INEGI, 2007) over the period 2005–2015. While a value of 2 is generally assumed for parameter φ_2, implying a Frisch elasticity of 0.5, the empirical evidence for Mexico (Fajnzylber and Maloney, 2001; Martínez, 2012) points to a lower elasticity, reflecting the absence of meaningful means of insurance in case of unemployment. Moreover, recent work by Reichling and Whalen (2012) for the case of the United States points to an average estimate of 0.4. In view of this, and considering it is reasonable to assume that in the absence of significant unemployment insurance and limited financial inclusion, the supply of hours worked in Mexico should be less sensitive to changes in wages than in the United States, a Frisch elasticity of 0.35 is assumed. The elasticity implies a value of 2.8571 for parameter φ_2.

3.2.2 Household heterogeneity

Jointly with the difference between the discount factors of entrepreneur and worker households, the parameters in panel II influence the model economy's distribution of income and wealth.

The parameter η which determines the relative magnitude of the mass of worker households with respect to entrepreneur households, is calibrated to match the proportion of business ownership income which accrues to the top wealth quintile, which according to data from the latest household income and expenditure survey (INEGI, 2015a) is equivalent to 90.6%. In a similar fashion to McKay and Reis (2016), the value of average productivity of entrepreneur households $\bar{s}$ targets the proportion of capital and labour–income received by the top quintile in household survey data, which is approximately 55%.

In order to calibrate the worker households' possible skill levels and corresponding Markov

[6] In the absence of official estimates for the wealth distribution, the strategy relies on the assumption that the distribution of wealth is proportional to the distribution of income accruing from the ownership of capital as reported in the most recent households' income and expenditure survey INEGI (2015a).

transition matrix, wage data from the Mexican quarterly labour survey (INEGI, 2007) is used[7].

Focusing on wages for individuals working aged 25–65 and employed full time, following Rodríguez-Oreggia (2007), median wages are computed for the following categories of workers: those employed informally, as proxied by not having access to social security; (self–declared) employers and own–account workers; and workers employed formally in the public or private sector. Wages are computed on a quarterly basis for the sample spanning the period 2005.I through 2015.IV. The resulting median wages are normalised so that the average wage income equals one. The process yields the level estimates for parameters s_1, s_2 and s_3, which indicate that informally employed workers earn 73% of the average wage, while employers and own–account workers, and formally employed workers earn wages which are respectively 25% and 37% above the mean wage.

The transition probability matrix between the current s and future s' skill levels $\Pi_{s,s'}$ is computed non-parametrically from survey data. Inspection of table 2 reveals that despite large probabilities of remaining in the same employment categories, particularly for employers and own–account workers, there is a significant probability of switching categories at any given moment. Moreover, for employers and own–account workers, as well as for formally employed workers, the odds of becoming and staying informally unemployed are very high.

3.2.3 Firms

Panel III groups the parameters which determine the supply–side of the economy.

The inverse of parameter θ is the average frequency between price adjustments. Using data for the period 1992–2007 under a hybrid New Keynesian Phillips curve framework, Ramos-Francia and Torres (2008) find that average price duration in Mexico was roughly three quarters, implying a parameter θ of 0.3333.

Regarding the markup, while Castañeda (2003) finds evidence of a decline in the average manufacturing markup as a consequence of increased competition in the aftermath of Mexico's entry into the North American Free Trade Agreement (NAFTA), it was still a sizeable 1.8 in the late 1990s. Moreover López Noria (2013) suggests that despite the initial decline in the mid 1990s, markups in the manufacturing sector had remained constant at a level of between 1.2 and 1.4 depending on the liberalisation schedule imposed by NAFTA. In view of this, the markup parameter μ is set to 1.3.

For the coefficient of capital in production α, a production function was estimated from industry–level data (INEGI, 2014) using the estimation method proposed by Ackerberg et al. (2015) over the period 1990–2014, which yields a parameter value of 0.35[8]. For the case of the capital depreciation parameter δ, the average depreciation rate implied by the ratio of capital consumption to capital stock over the period 2003-2014 in national accounts data is used (INEGI, 2015b), which yields an estimate of 1.66% for quarterly depreciation.

In a similar fashion to McKay and Reis (2016), the variable capital cost adjustment parameter ζ is calibrated to match the variance of (detrended) private investment observed

[7]Survey data reports wage income in current prices. In order to compare data across time, wage data is converted into constant prices using consumer price data.

[8]To solve the model the parameter α is multiplied by parameter μ to approximate the share of value added that accrues to capital at the aggregate level.

Table 3 – Income and wealth distribution by quintiles
(Proportion of total)

	Income		Wealth	
Wealth quintiles	Model	Data	Model	Data
I	6.6	3.1	1.6	0.7
II	10.8	7.9	3.1	2.7
III	13.3	13.1	4.5	3.9
IV	15.0	20.9	6.6	7.7
V	54.3	55.0	84.2	85.0

Note: The distribution of income from the data comprises labour and capital income, and excludes income from other sources not considered in the model, such as transfers and imputed rent. The distribution of wealth in the data refers to the proportion of capital income accrued to each quintile, which implicitly assumes is proportional to the wealth stock held by each quintile.

in the national accounts data (INEGI, 2013). Considering the scale of own–account work in Mexico, instead of using the ratio of gross operating profit to gross domestic product (GDP), which includes mixed–income, as the target for the fixed production cost parameter ξ as is done by McKay and Reis (2016), the ratio of dividends to GDP is used instead (INEGI, 2015b), resulting in a value of 0.3188.

3.2.4 Policy and aggregate shocks

For the policy parameters, which are detailed in panel IV, the income tax parameter τ is calibrated using the average income revenue (as a percentage of GDP) of the Mexican federal government for the period 1990–2015 SHCP (2016).

The value for the Taylor–rule policy parameters ϕ, as well as the values for the persistence ρ and standard deviation σ shock parameters, summarised in panel V, correspond to the posterior estimates of the benchmark model in Best (2013). Under the baseline scenario the policy parameter of output ϕ_y is set to zero as in McKay and Reis (2016).

3.3 Properties of the model

Table 3 contrasts the distribution of income and wealth from the data, with the steady–state results from the model. Although the parameter calibration targeted explicitly only the proportions held by the top quintile, the model approximates the income and wealth distribution observed in the data relatively well, although it overestimates the income and wealth of the bottom three quintiles. The Gini coefficients for income and wealth found by the model are 0.42 and 0.71 respectively, which are roughly in line with conservative inequality estimates for Mexico.

The results discussed in chapter 2 of Villarreal (2016) suggest that monetary policy affects inequality through a differentiated impact on the labour–income dynamics of the formal and informal sector. In particular, the results indicate that although unanticipated increases in monetary policy raise overall labour–income levels and their dispersion over the medium–

Table 4 – Marginal propensities to consume

	Wealth percentile				
Skill level	10th.	25th.	50th.	75th.	90th.
s_1	0.020	0.011	0.008	0.006	0.005
s_2	0.012	0.008	0.007	0.006	0.005
s_3	0.012	0.009	0.006	0.005	0.005

Note: s_1 includes informally employed workers, s_2 includes employers and own–account workers, and s_3 includes workers employed formally in the public or private sector.

Table 5 – Standard deviation of economy aggregates.

	Model	Data
Output	2.3636	2.6845
Private consumption	1.5341	2.2988
Private investment	4.8589	4.6101

Note: Aggregate data excludes public consumption and investment as they have no counterpart in the model. The standard deviations from the data are computed from the (log) level of detrended quarterly series for the period 2001.I – 2015.IV. Trends were computed using the Hodrick–Prescott filter with a smoothing parameter of 1,600.

term, the impact on the poorest informally–employed workers is to reduce income levels and compress their distribution. Since ultimately welfare depends on consumption, differences in the marginal propensity to consume out of disposable income could accentuate the effect of monetary policy on households' welfare.

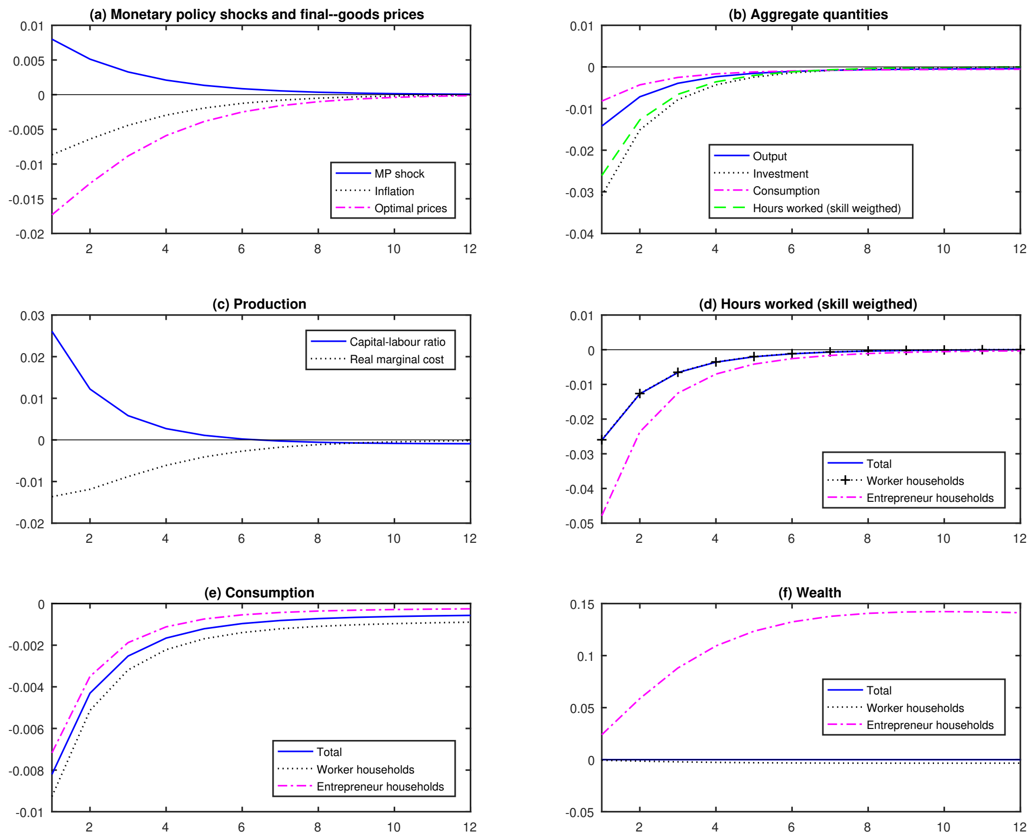
Table 4 summarises the marginal propensities to consume implied by the model for the different worker groups across selected percentiles of the distribution. Despite the relatively low level of the estimates[9], it can be seen that in general terms the marginal propensity to consume is highest for the lower skill level group, that is for the group of workers employed in the informal sector. Moreover the effect becomes more pronounced as wealth declines. This means that to the extent that monetary policy affects households disposable income, the magnitude of the response of poorer and less skilled households will be larger, highlighting a key redistributive propagation mechanism.

Turning to the dynamic properties of the model, table 5 compares the standard deviation of the main aggregates in the model with the moments in the data. The model is able to capture the magnitude of fluctuations in both aggregate output and private investment, and while it captures the fact that private consumption is less volatile than output, it underestimates its magnitude. This could be reflecting the omission of certain features such as financial and intermediate input frictions which have been found to play an important role in fitting DSGE models to data from developing countries (García-Cicco, 2009).

From the equation for the monetary policy Taylor rule (11) it can be verified that a positive monetary policy shock increases the nominal interest rate, which as shown in panel (a)

[9] In an evaluation of the impact of transfers on consumption among poor households in Mexico, Skoufias et al. (2008) estimate marginal propensities to consume in the range of 0.14 to 0.17.

Figure 1 – Impulse response functions: Baseline case



Note: Impulse response functions are normalised by the respective variables' steady–state values.

of figure 1 contemporaneously reduces the optimal prices chosen by price–adjusting firms, and thus overall current and expected inflation. In addition, as summarised in panel (b) the shock has a contractionary effect on the economy's main aggregates: consumption, investment and consequently output which in turn result in a reduction of hours worked. The effects, which are consistent with the findings in the literature (Cushman and Zha, 1997; Galí and Monacelli, 2005; Lubik and Schorfheide, 2007) dissipate over a 12–quarter horizon[10].

A key finding is that the effects on consumption and leisure, from which households derive utility, are differentiated across households reflecting their heterogeneity with respect to the risks they face, the availability of insurance mechanisms and their preferences. In particular, as a result of an unanticipated increase in the nominal interest rate, consumption is reduced by more for the case of worker households, than for entrepreneur households, thus exacerbating the model economy's inequality.

[10]Unless otherwise noted all impulse response functions measure deviations from the respective variable's steady–state level.

The differentiated effect operates through two channels (Kaplan et al., 2016). The first occurs as households adjust their intertemporal consumption schedules in response to the direct effect of the monetary policy shock. As can be verified from the entrepreneur and worker households' Euler equations, equations (16) and (19) respectively, the effect of an increase in the nominal interest rates and a reduction in anticipated inflation, leads households to substitute away from current consumption by making future consumption 'less costly'. However the effect is stronger on worker households due to their relatively higher level of impatience, i.e. $\hat{\beta} < \beta$.

The second channel operates through the general equilibrium effects of the monetary policy shock on households' disposable incomes. As a consequence of the fall in output and in the presence of costly capital adjustment costs, intermediate–goods producers use installed capital more intensively to the detriment of labour demand. This results in the rise of the capital–ratio shown in panel (c) of figure 1, and the fall of hours worked shown in panel (b). Since entrepreneur households are more productive than worker households, e.g. $\overline{s} > s_h \; \forall h$, and thus more costly to hire, the fall in their worked hours is steeper than that of worker households as shown in panel (e) of figure 1.

Notwithstanding the larger reduction in hours worked, in contrast to worker households entrepreneur households benefit from the general equilibrium effects of the monetary policy shock, to the extent that the rise in real interest rates implies additional flows from the ownership of capital. Moreover, as shown in panel (c) real marginal costs fall as a result of the positive monetary policy shock which, given the presence of sticky prices, implies that markups are countercyclical leading to additional revenue in the form of dividends from the ownership of firms (see equation (23)). The combined effect is that the reduction of disposable income is more acute, and consequently the reduction on consumption more pronounced for the case of worker households, as illustrated in panel (d) of figure 1.

Regarding wealth, as measured by bond holdings, the incentive of higher interest rates for entrepreneur households is to unambiguously increase bond holdings. In contrast. for the case of worker households there are two opposing forces at work.

The first is to save more and take advantage from the higher yields. The magnitude of this effect is attenuated by the relative impatience of worker households which make it more costly to forego current consumption. The second force is that in the presence of uninsurable idiosyncratic risks, worker households have an incentive to save precautionarily[11]. In the case of an unanticipated increase of interest rates which leads to lower expected inflation, the precautionary motive is diminuted leading to lower savings. As shown in panel (f) the net effect of the differentiated impact upon households' disposable incomes and the preference heterogeneity is that worker households actually reduce the proportion of total assets held, with entrepreneur households significantly increasing their bond holdings.

As discussed by Kaplan et al. (2016) and documented empirically for the United States by Coibion et al. (2012) and Gornemann et al. (2015), the differentiated effect of monetary policy on households' disposable income is the main channel through which monetary policy can influence household inequality.

[11]See, for example, Mengus and Pancrazi (2015) for a thorough discussion of the conditions under which the motive for precautionary savings arise.

4 Results

In order to further explore the relationship between household heterogeneity and monetary policy, in this section two complementary sets of counterfactual experiments are conducted. In the first, the focus is on the effect of the design of monetary policy on inequality, while the second explores the feedback from household heterogeneity to the transmission of monetary policy.

4.1 The effect of monetary policy on households' inequality

Under the baseline model specification, monetary policy is conducted according to the Taylor rule in equation (11) under the assumption that the central bank adheres to a strict inflation targeting regime where $\phi_p > 1$ and $\phi_y = 0$. To examine the effect of policy responsiveness to inflation on inequality, the first experiment analyses the effects on the differentiated response of households' consumption and hours worked.

In the first scenario, monetary policy adjusts the nominal interest rate almost proportionally to inflation, i.e. $\phi_p = 1.01$. As discussed by Woodford (2003) the so–called Taylor principle states that, from a welfare perspective, in the traditional new Keynesian model simple rules, such as the Taylor rule, can approximate optimal monetary policy by responding more than proportionally to inflation[12]. Thus, the assumption of proportionality is a useful benchmark since it represents borderline policy sub–optimality.

The second counterfactual assumes instead that policy responsiveness to inflation is more robust than under the baseline scenario, i.e. $\phi_p = 2.37$. The value used for the coefficient under the aggressive policy counterfactual corresponds to the posterior value estimated in chapter 2 of Villarreal (2016) under the benchmark calibration. In contrast to the parameter value used in the baseline estimation, which was estimated by Best (2013) using data up to 2005, the alternative value was estimated taking into consideration the response of monetary policy to the financial crisis of 2009, thus providing a realistic value of the magnitude that the policy parameter can take.

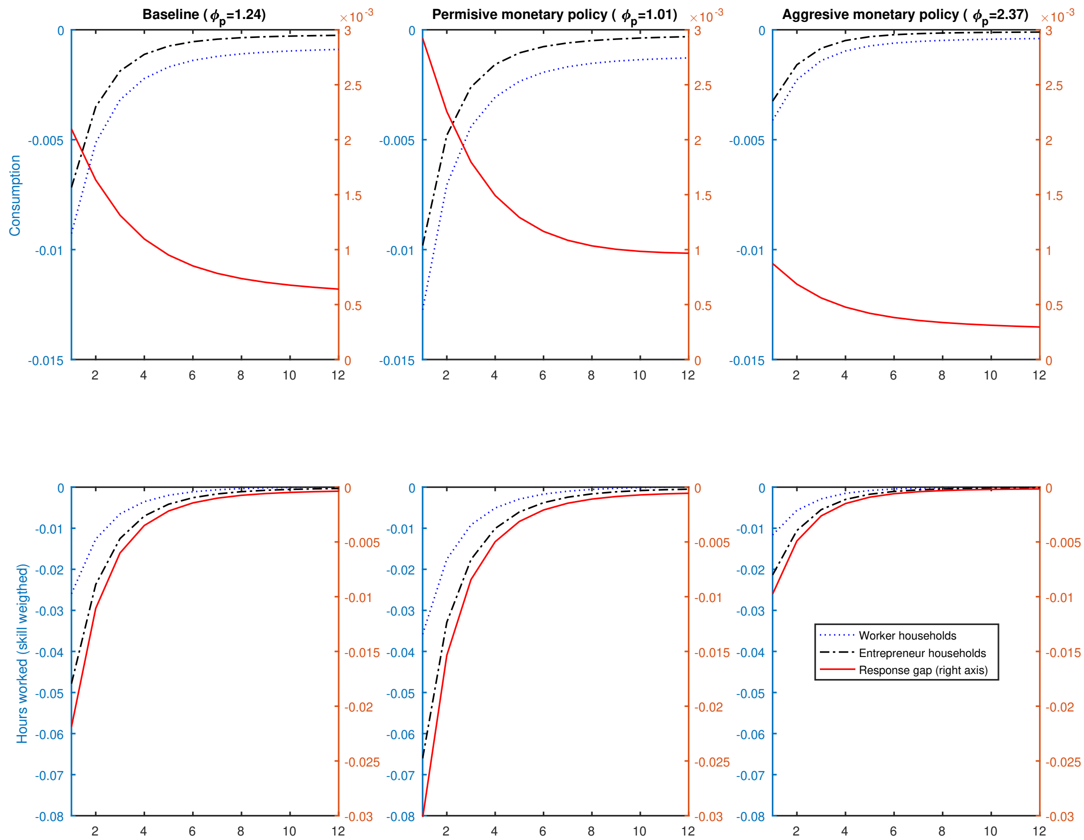
4.1.1 Policy responsiveness to inflation

Figure 2 plots the response function of households' consumption (top row) and labour (bottom row) to a monetary policy shock, as well as the gap between them, under the baseline case and the two alternative scenarios. Positive values for the gap, which are measured off the right axis, indicate that the response of the worker households' respective variable is greater in magnitude than the one experienced by entrepreneur households. The focus of the analysis of inequality is placed on the differentiated responses of consumption to unanticipated increases in the nominal interest rate.

As previously discussed, under the baseline case despite the larger relative reduction in hours worked by entrepreneur households, and corresponding fall in wage income, their lower discount factor and the additional income accruing from the ownership of capital attenuate the impact on their consumption, resulting in a smaller relative fall with respect

[12] In fact, the equilibrium of this class of models becomes indeterminate when the response to inflation is exactly or less than proportional.

Figure 2 – Policy responsiveness to inflation



Note: The figure plots the impulse response functions of worker (dotted line) and entrepreneur (dashed line) households' consumption (top row) and skill–weighted hours worked (bottom row) to a monetary policy shock, as well as the gap (continuous line) between the responses, under three alternative assumptions regarding policy responsiveness. Positive (negative) values for the gap, which is measured off the right axis, indicate that the decrease in the respective variable for worker households is greater (lesser) that the one experienced by entrepreneur households.

to worker households' consumption. Since entrepreneur households are richer and have higher consumption levels in steady state, this means that inequality of consumption increases in response to a contractionary monetary policy shock.

The results in columns two and three of figure 2 plot the responses that would be observed under the assumption of, respectively, a permissive and an aggressive monetary policy response to inflation. While it is clear that under strict inflation targeting, the response of consumption inequality remains countercyclical regardless of the responsiveness of policy to inflation, the magnitude of the reduction of consumption and hours worked for both types of households, as well as of the size of the gap between responses, is greater under a permissive response to inflation. This occurs because under a permissive policy response, the expectation of relatively higher levels of inflation incentivates precautionary savings, which result in a steeper reduction of consumption, as well as an increase in its inequality reflecting the fact that the incentive for precautionary savings, and the marginal propensity to consume, is stronger for poorer households.

4.1.2 Output target

The second experiment examines the evolution of the response of consumption and hours worked under the assumption that, in addition to inflation, monetary policy targets deviations of output from its steady–state level. Two scenarios are considered. In the first, the inflation policy parameter is kept at its baseline value and it is assumed that the output policy parameter takes the value of $\phi_y = 0.37$ which corresponds to the values estimated by Best (2013). The second considers the estimates from the benchmark case in chapter 2 of Villarreal (2016), which are roughly double in magnitude to the parameter values under the first scenario.

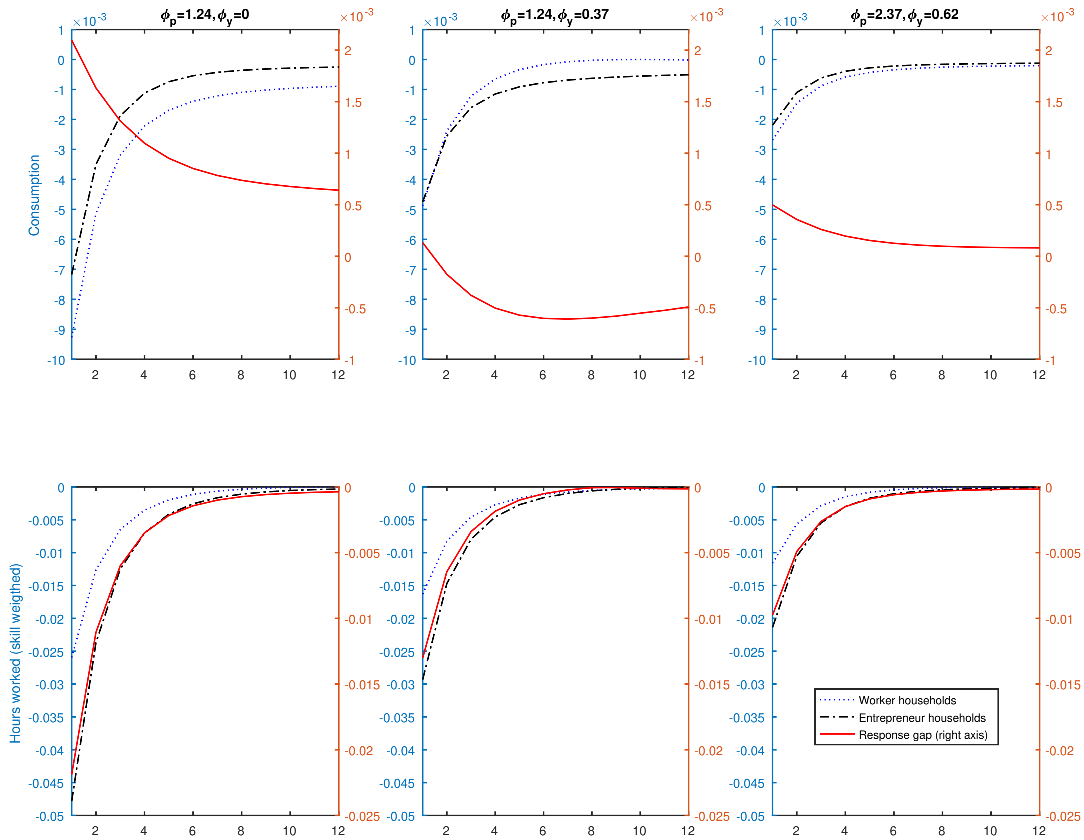
As before the first column of figure 3 shows the response of consumption and hours worked under the baseline case, whereas the second column summarises the impact of introducing a target for output in the policy function. Finally, the third column illustrates the results that would be observed under a more aggressive policy response to both output deviations and inflation, than that considered in the second column.

Regarding the magnitude of the responses, as should be expected it is clear that introducing a target for output attenuates the impact on both consumption and hours worked, and that a more aggressive policy stance further reduces the size of household responses. Moreover, the speed with which variables return to their steady–state levels is faster when output is targeted, and when an aggressive policy stance is adopted. This occurs because forward–looking households anticipate smoother shocks over the business cycles as a result of the adoption of an explicit target for output, as well as of a firmer policy response to deviations from targets.

With respect to consumption inequality, contrasting the dynamics of consumption responses between the baseline case and the first scenario, shown in the top of the first and second columns of figure 3, it can be seen that the introduction of a target for output not only reduces the size of the response, but also has an important distributive effect. In fact, the reduction of the precautionary savings motive that occurs as a result of the introduction of an output target, results in a negative gap between the responses of worker and entrepreneur households, that is a reduction in the relative inequality of consumption across households.

Comparing the response of consumption between the second and third columns of figure 3, indicates that while a firmer policy response further reduces the magnitude of the fall in relative consumption, it again increases consumption inequality, although to a lesser degree than under the baseline case. This suggests that in principle, under the model calibration, there exists a combination of policy response parameter values that is able to reduce the size of consumption losses while remaining close to neutral with respect to its distributive impact.

Figure 3 – Policy target



Note: The figure plots the impulse response functions of worker (dotted line) and entrepreneur (dashed line) households' consumption (top row) and skill–weighted hours worked (bottom row) to a monetary policy shock, as well as the gap (continuous line) between the responses, under three alternative assumptions regarding policy responsiveness. Positive (negative) values for the gap, which is measured off the right axis, indicate that the decrease in the respective variable for worker households is greater (lesser) that the one experienced by entrepreneur households.

4.2 Heterogeneity and the transmission of monetary policy

As discussed in section 2 there are two features of the model which give rise to inequality across households: incomplete markets and preference heterogeneity. A natural benchmark to explore the impact of heterogeneity on the transmission of monetary policy is the case where markets are complete and all households have the same preferences. As discussed earlier, by assuming that the mass of worker households is equal to zero, i.e. $\eta = 0$ the model collapses to the traditional New Keynesian monetary policy model with a single representative agent. Even though households still face idiosyncratic productivity risks, they can insure perfectly against them since they can trade in contingent securities.

4.2.1 Incomplete markets

Figure 4 compares the responses of inflation, aggregate output, aggregate consumption and total hours worked under the baseline case discussed in section 3.3, with the responses that would be observed if markets were complete and household preferences were homogeneous. While qualitatively the response is similar under both cases, with all four aggregates falling as a response to unanticipated increases in the nominal interest rate; with the exception of inflation, under the assumption of complete markets, the magnitude of the contemporaneous effect is markedly smaller, and the period over which the shock effects dissipate shorter.

The reason for this is that as discussed above, the presence of uninsurable idiosyncratic risks gives rise to precautionary savings, which result in higher investment and a higher capital stock with respect to the levels that would be observed in the complete markets economy. Since $\alpha < 1$ in equation 10 implies diminishing returns to capital, a higher capital stock means that with respect to the complete market economy, the real interest rate in the economy with uninsurable idiosyncratic risks will be lower and the wage rate relatively higher. As discussed by Dávila et al. (2012) this signifies that in the baseline case the uninsurable portion of households' income is larger than in the complete markets case, and thus the responses to shocks more pronounced.

4.2.2 Preference heterogeneity

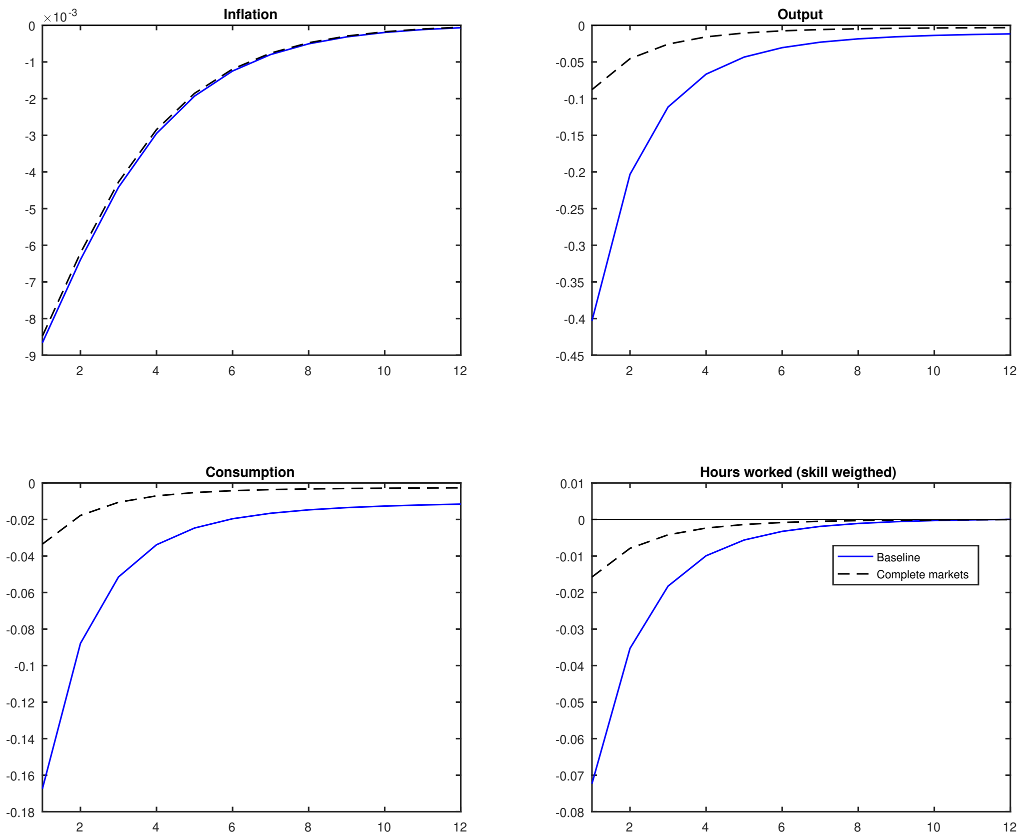
Part of the effect found under the complete markets counterfactual is the result of the imposition of preference homogeneity. In order to investigate the role of preference heterogeneity, the last experiment evaluates the impact of changes in the discount rate of worker households while keeping the baseline specification of incomplete markets. The results are shown in figure 5.

As shown in panel (a) of figure 5, a lower discount factor implies a sharper reduction in inflation in response to a contractionary monetary policy shock. This occurs because lowering the worker households' discount factor is equivalent to rising their marginal propensity to consume. Thus, in response to a given fall in disposable income, as shown in panel (e) worker households reduce their consumption more acutely, leading to a steeper fall in aggregate consumption (see panel (d)), and thus inflation falls further.

As can be verified from the labour supply equation (20), in an attempt to smooth consumption worker households increase their labour supply, shown in panel (h), which through its effect on relative factor prices, causes a larger reduction of marginal costs. Since the lower marginal costs imply higher markups, the result is to attenuate the impact on entrepreneur households' consumption and investment, illustrated in panels (f) and (c) respectively. In fact, as shown in the figure, for sufficiently low levels of the worker households' discount factor, entrepreneur households' consumption and investment actually rise as a response of an unanticipated increase in the nominal interest rate.

The contrasting dynamics of the responses by worker and entrepreneur households explain why the contemporaneous effect of a monetary policy shock on aggregate output, plotted in panel (b), is of a similar magnitude under alternative value for the worker households' discount factor. The faster return of both hours worked and output to their steady state levels with lower discount factors, reflects the fact that poorer households become more

Figure 4 – Complete markets and homogeneous preferences



Note: The figure contrasts the response functions of selected model aggregates to a monetary policy shock under the baseline case (solid lines), with the response functions under the assumption that markets are complete and preferences homogeneous (dashed lines).

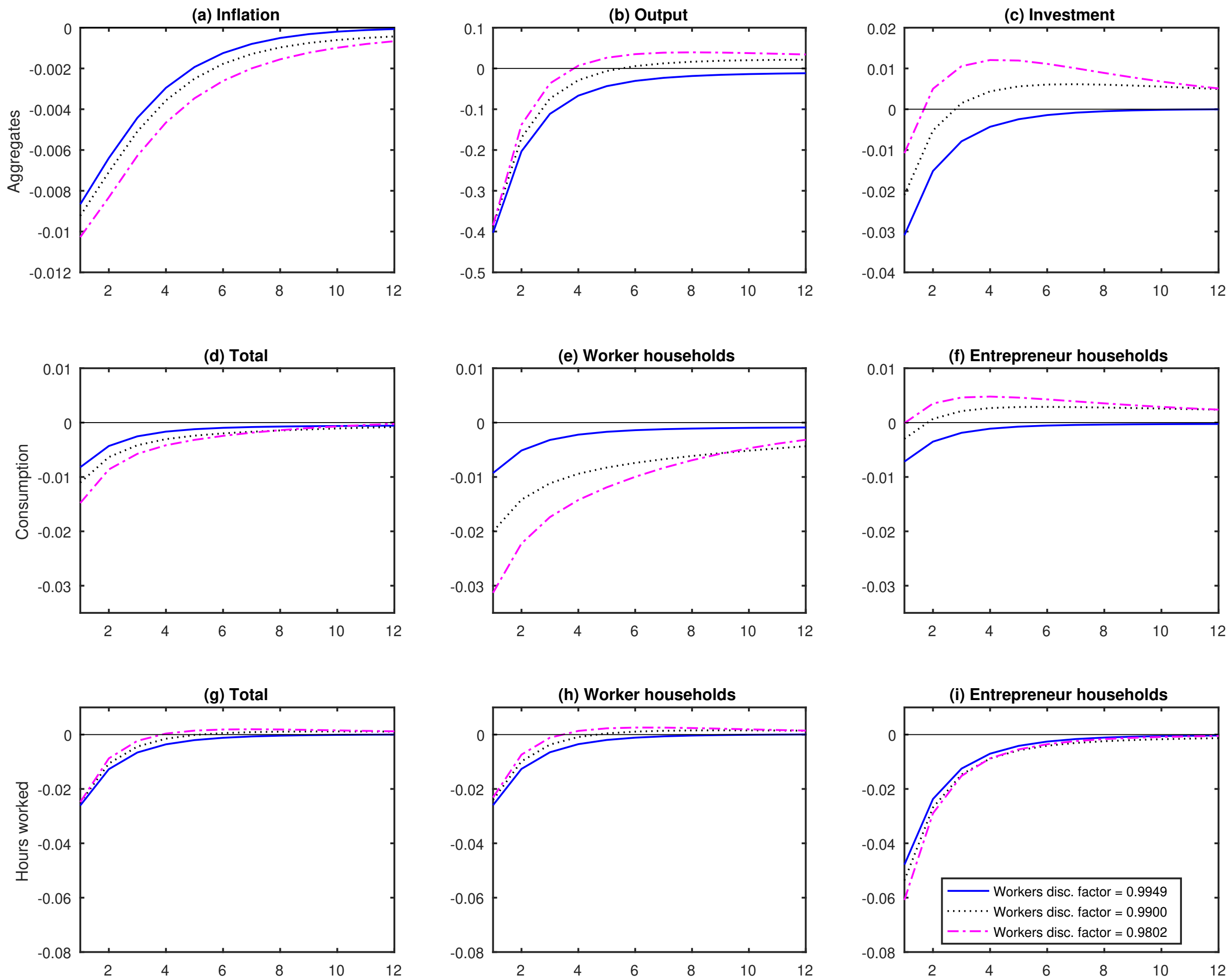
responsive to increases in disposable income.

In summary, the presence of uninsurable idiosyncratic shocks not only affects the response of the economy's aggregates to unanticipated increases in the nominal interest rate, but also exacerbates the already sizeable levels of inequality that characterise the model economy. Moreover, the magnitude of the effect on inequality appears to be larger the more unequal initial conditions are.

5 Conclusions

The paper contributes to the emerging literature exploring the distributive consequences of monetary policy, by using a dynamic stochastic general equilibrium model with heterogenous agents which can not insure themselves against idiosyncratic risks because markets are

Figure 5 – Preference heterogeneity



Note: The top row of the figure plot the responses of inflation, output and investment to a contractionary monetary policy shock under alternative assumptions regarding the value of the worker households' discount factor. The first column of the second and third row plot, respectively the impulse response functions of total consumption and skill–weighted worked hours, while the differentiated responses by household type are plotted in the remaining columns.

incomplete, to explore the relationship between monetary policy and household inequality for the case of Mexico.

Under the base calibration, which successfully replicates the main features of the business cycle and the distribution of household income and wealth, the results indicate that the main channel through which monetary policy affects the distribution of income and wealth across households, is through a differentiated effect on the different streams that constitute households' disposable income. As a result of an unanticipated increase in the nominal interest rate, which leads to a fall in aggregate inflation and output, worker households, whose main source of income is that coming from labour, must reduce their consumption by a larger proportional amount than entrepreneur households, which are able to limit the fall in their consumption levels by the additional income resulting from the effect of the shock on business and capital ownership income.

As documented elsewhere in the literature, the incompleteness of markets gives rise to precautionary savings by worker households who cannot insure themselves against idiosyncratic risk. Precautionary savings, however, are suboptimal to the extent that through the effect on factor shares and prices, the proportion of aggregate income that is subject to uninsurable risk increases, thus exacerbating the negative impact of contractionary monetary policy shocks on output, labour and consumption; as well as on their distribution across households.

The findings also suggest that a Taylor–type rule which aggressively targets both inflation and deviations of output from its steady state level, can ameliorate the impact of monetary policy on households' income and consumption levels as well as on the resulting inequality. However, considering the narrowness of the typical mandate for monetary policy, sometimes codified at the constitutional level as in the Mexican case; and the broadness of the instrument through which it is implemented, namely the short–term nominal interest rate; it would seem that despite its distributive impact, monetary policy is ill–suited to effectively address concerns regarding inequality of the magnitude that characterises developing economies such as Mexico.

Dávila et al. (2012) argue that even before considering public policies aimed at addressing market incompleteness, the judicious use of fiscal policy can in principle improve upon the efficiency of a model economy similar to the one used in this paper. This suggests that a fruitful area for future research would be to provide a richer characterisation of fiscal policy, where coordination issues between monetary and fiscal policy could be analysed in depth. Beyond aiming at a realistic representation of the fiscal instruments already used in Mexico, such as consumption and income taxes, as well as several kinds of transfers, a particularly interesting topic for research would be how the impact of monetary policy is affected by the presence of countercyclical fiscal policy rules.

In view of the relevance of uninsurable shocks to labour–income in determining a differentiated household response to monetary policy shocks, another area for future investigation would be to further develop the way the labour market is modelled, by explicitly considering the possibility of unemployment, as well as introducing matching frictions and wage rigidities as in Ravn and Sterk (2015). This would allow correlating the evolution of idiosyncratic shocks to macroeconomic conditions in the spirit of Bloom (2014). Such a framework would be useful to endogeneise the heterogeneity of preferences across households, as well as to consider the introduction of other automatic stabilisers, such as unemployment insurance schemes, which have been discussed in Mexico recently.

As discussed in section 4 the presence of heterogeneity not only accentuates the effects of monetary policy on the level of consumption and labour, but also exacerbates inequality. This implies that from a public policy perspective particular attention should be placed on addressing key sources of heterogeneity, such as the absence of effective insurance mechanisms. Particular policies include fostering financial inclusion, the introduction of an unemployment insurance scheme, moves towards broadening access to social security beyond a particular labour status, as well as incentives aimed at the formalisation of the labour market.

Incomplete markets model equilibrium equations The optimality conditions stemming from the entrepreneur household's optimisation problem can be rearranged to yield the entrepreneur household's Euler equation, labour supply schedule and capital accumulation rule:

$$c_t^{-1} = \beta \mathbb{E}\left[c_{t+1}^{-1}\frac{1+i_t}{\pi_{t+1}}\right] \tag{16}$$

$$\varphi_1 n_t^{\varphi_2} = c_t^{-1}(1-\tau_t)w_t\overline{s} \tag{17}$$

$$c_t^{-1}\left(1+\zeta\frac{\Delta k_{t+1}}{k_t}\right) = \beta \mathbb{E}\left[\left(1+r_{t+1}+\zeta\left(\frac{\Delta k_{t+2}}{k_{t+1}}\right)\frac{k_{t+2}}{k_{t+1}}-\frac{\zeta}{2}\left(\frac{\Delta k_{t+2}}{k_{t+1}}\right)^2\right)c_{t+1}^{-1}\right] \tag{18}$$

Analogously, the worker households' Euler equation and labour supply conditions are given by:

$$c_{h,t}^{-1} = \tilde{\beta}\mathbb{E}\left[c_{h,t+1}^{-1}\frac{1+i_t}{\pi_{t+1}}\right] \tag{19}$$

$$\varphi_1 n_{h,t}^{\varphi_2} = c_{h,t}^{-1}(1-\tau_t)w_{h,t}s_{h,t} \tag{20}$$

where in addition to aggregate uncertainty, the expectation is also taken over idiosyncratic uncertainty.

From the optimisation problem solved by intermediate–goods firms when revising prices at period $t+s$, the following expressions for factor shares are obtained:

$$(r_{t+s}+\delta)k_{t+s} = M_{t+s}\alpha a_{t+s}k_{t+s}^{\alpha}\ell_{t+s}^{1-\alpha} \tag{21}$$

$$w_{t+s}\ell_{t+s} = M_{t+s}(1-\alpha)k_{t+s}^{\alpha}\ell_{t+s}^{1-\alpha} \tag{22}$$

where M_{t+s} denotes the Lagrange multiplier on the production function constraint (10) at date $t+s$, which is equivalent to real marginal cost. Using factor shares and market clearing yields the following expression for aggregate dividends:

$$d_t = y_t - M_t a_t k_t^{\alpha}\ell_t^{1-\alpha} - \xi \tag{23}$$

The intermediate–goods firms optimality condition with respect to its product price yields the following expression for the dividend maximising price $p_{j,t}^*$:

$$\frac{p_{j,t}^*}{p_t} \equiv \frac{\overline{p}_t^A}{\overline{p}_t^B} \tag{24}$$

where

$$\overline{p}_t^A = M_t\mu_t y_t + \mathbb{E}\left[\lambda_{t,t+1}(1-\theta)\pi_{t+1}^{-\frac{\mu_t}{1-\mu_t}}\overline{p}_{t+1}^A\right] \tag{25}$$

$$\overline{p}_t^B = y_t + \mathbb{E}\left[\lambda_{t,t+1}(1-\theta)\pi_{t+1}^{-\frac{\mu_t}{1-\mu_t}}\overline{p}_{t+1}^B\right] \tag{26}$$

$$\tag{27}$$

Since at any given date a fraction θ of intermediate–goods firms adjust prices, given the final–goods production technology the aggregate price index (7) can be written as:

$$p_t = \left[(1-\theta)p_{t-1}^{\frac{1}{1-\mu_t}} + \theta(p_t^*)^{\frac{1}{1-\mu_t}}\right]^{1-\mu_t}$$

which results in the following expression for inflation:

$$\pi_t = \left[\frac{1-\theta}{1-\theta\left(\frac{p_t^*}{p_t}\right)^{\frac{1}{1-\mu_t}}}\right]^{1-\mu_t} \tag{28}$$

The ratio of the intermediate–goods firms optimisation problem's first order conditions with respect to capital an labour implies that, in equilibrium, the capital–labour ratio is constant across firms. This means that aggregate output can be expressed as:

$$\left[\int_0^1 \left(\frac{p_{j,t}}{p_t}\right)^{\frac{\mu_t}{1-\mu_t}} dj\right] y_t = S_t y_t = a_t k_t^{\alpha} \ell^{1-\alpha} \tag{29}$$

where S_t denotes the efficiency loss due to price dispersion, which evolves according to:

$$S_t = (1-\theta)S_{t-1}\pi_t^{\frac{-\mu_t}{1-\mu_t}} + \theta\left(\frac{p_t^*}{p_t}\right)^{\frac{\mu_t}{1-\mu_t}} \tag{30}$$

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