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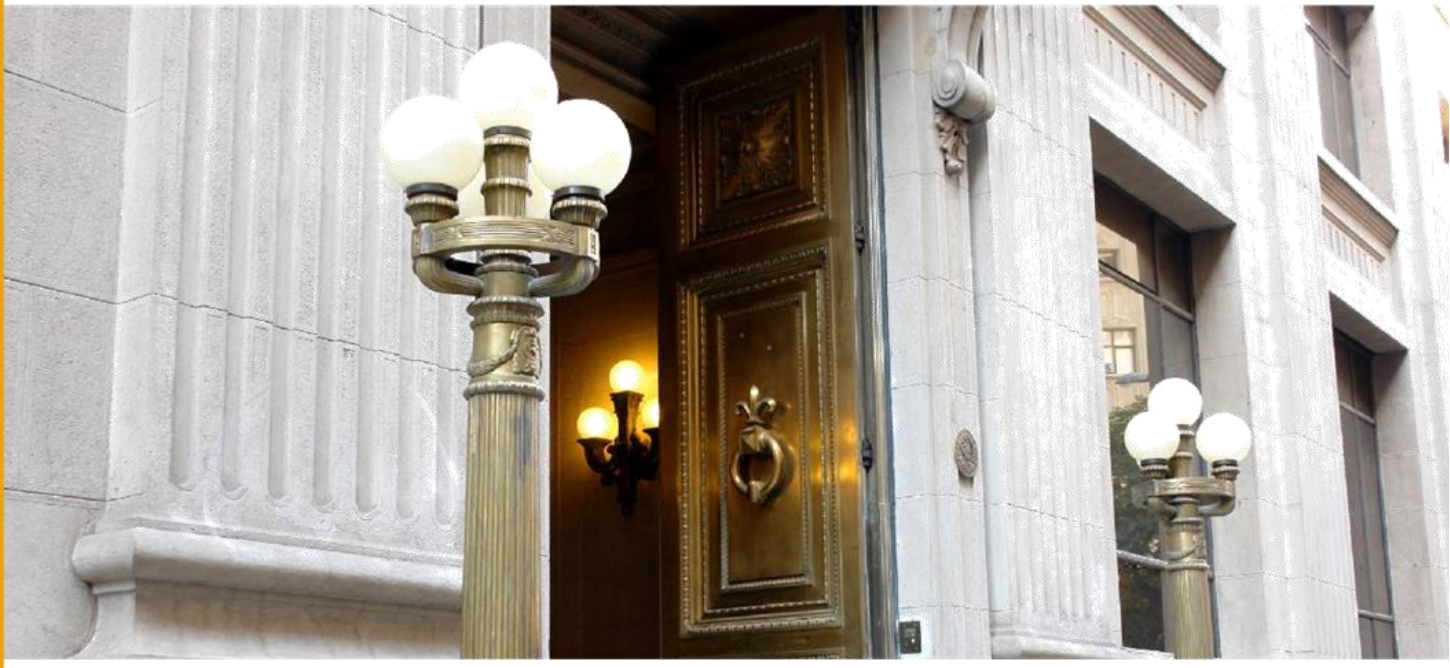

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Forward Guidance: Estimating a Behavioral DSGE Model with System Priors*

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Abstract

We introduce cognitive discounting into a full fledged monetary DSGE model to cope with the forward guidance puzzle and propose an estimation strategy that relies on system priors to guide the model into delivering data-consistent IRFs for monetary policy and forward guidance shocks. We find that the successful implementation of this behavioral hypothesis crucially hinges on allowing agents to entertain a cognitive discount factor specific for future monetary policy announcements. The estimated model attains a significantly better fit to the data than its rational expectations counterpart, while relying on only slightly modified estimates of structural parameters and substantial degrees of forward guidance discounting. Cognitive discounting of future events triggered by non-forward guidance shocks in our model is limited, and so is its contribution to the improvement of the marginal data density. We further find that professional forecasts are consistent with rational expectations and, thus, not appropriate for the estimation of forward guidance cognitive discounting.

Resumen

Introducimos descuento cognitivo en un modelo DSGE de gran tamaño para lidiar con el forward guidance puzzle, a la vez que proponemos una estrategia de estimación basada en system priors que guían el modelo para que genere funciones de impulso respuesta, para shocks de política monetaria y forward guidance, consistentes con evidencia empírica. Encontramos que una implementación exitosa de esta hipótesis conductual depende crucialmente en permitir a los agentes tener factores de descuento cognitivo que sean específicos a los anuncios de política monetaria futuros. El modelo así estimado logra un ajuste a los datos significativamente mejor que su contraparte racional, con parámetros estructurales que se mantienen mayormente sin cambios y con grados de descuento cognitivo substanciales. En nuestro modelo, el descuento cognitivo de eventos futuros generados por shocks distintos a forward guidance es limitado, y también lo es su contribución a la mejora de la densidad marginal de los datos. Adicionalmente, encontramos que proyecciones de profesionales de inflación y tasa de interés nominal futura son consistentes con expectativas racionales y, por tanto, no son apropiadas para la estimación de factores de descuento cognitivo asociados a forward guidance.

*The views expressed are those of the author and do not necessarily represent the views of the Central Bank of Chile or its board members.

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1 Introduction

"Unless I see the nail marks in his hands and put my finger where the nails were, and put my hand into his side, I will not believe." - John 20:24-29

Even though their heyday came as a response to the restrictions posed by the effective lower bound brought about by the financial crisis and its aftermath, a quick glance over recent official statements shows that the announcements of future monetary policy intentions remain as relevant as ever. As federal funds rates were raised in February 2023, the Federal Reserve communicated that the "Committee [anticipated] that ongoing increases in the target range [were going to] be appropriate in order to attain a stance of monetary policy that [was] sufficiently restrictive to return inflation to 2 percent over time."[1] One day later, the ECB increased its monetary policy rate and announced that "[in] view of the underlying inflation pressures, the Governing Council [intended] to raise interest rates by another 50 basis points at its next monetary policy meeting in March[.]"[2] The Central Bank of Chile, for its part, had communicated a few days earlier that its Board was going to keep the monetary policy rate at 11.25% until macroeconomic conditions indicated that convergence to the inflation target had consolidated.[3]

However, for most potential solutions proposed in the literature to overcome the inability of standard monetary DSGE models to feature anticipated monetary policy shocks - Del Negro et al. (2023), McKay et al. (2016) and others - relevant empirical tests continue to be scarce or are all together lacking. This paper aims at contributing in this regard by introducing the behavioral approach proposed by Gabaix (2020) - which assumes agents discount future events due to cognitive reasons - into a full-fledged monetary DSGE model and empirically test it.

Our main finding is that the successful implementation of this strategy - in terms of enabling forward guidance policy - critically depends on allowing for shock-specific cognitive discount factors. We argue that the nature of future monetary policy announcements differs from that of expected future events that are understood as the consequences of the endogenous propagation of current states or of already realized shocks. Our intuition is that whereas agents can learn over time the future consequence of, say, a conventional monetary policy shock - e.g. by estimating the persistence of the nominal rate in the policy rule - there are certain considerations associated to forward guidance shocks, such as credibility or commitment uncertainty, that drive agents to discount them more heavily. Indeed, while we find that cognitive discounting of future events

[1] Federal Reserve FOMC statement, February 1st, 2023. This sentence - word for word - was also part of the previous statement; see the FOMC's statement of December 14th, 2022.

[2] ECB Monetary Policy Decisions, February 2nd, 2023.

[3] Banco Central de Chile, Monetary Policy Meeting statement (Comunicados de RPM in Spanish), 26th January 2023.

not generated by future monetary policy announcements to be limited, future events triggered by forward guidance shocks are discounted at a rate of up to 50% to 70% per quarter.

As such, this paper points to the potential detrimental tension that the standard implementation of cognitive discounting can create within a model as it imposes a uniform discounting of all future events, see Brzoza-Brzezina et al. (2022), Billi and Walsh (2023), Paeuti and Seyrich (2022), among others.

A second contribution of our work is the proposal of an estimation strategy based on *system priors*. This bayesian approach, defined in Andrle and Benes (2012), allows us to condition our cognitive discounting estimates on empirical evidence on the dynamics of forward guidance shocks in addition to the information contained in standard macro time series. For this, we rely on Brubakk et al. (2022) and Ferreira (2022), who find that conventional monetary policy and forward guidance shocks have similar - or not significantly different - effects on inflation and activity.

The estimated rationally bounded model successfully resolves the *forward guidance puzzle* while attaining a considerably better fit to the data. Compared to its rational expectations counterpart, introducing forward guidance shocks together with their specific cognitive discount factor increases the marginal data density by about 100 log points, while extending cognitive discounting to the rest of the model improves the fit in at most an extra 5 log points or could even deteriorate it. Furthermore, the model featuring cognitive discounting solely of forward guidance-triggered events, presents largely unmodified structural parameters' estimates. As such, this strategy for implementing forward guidance in standard monetary DSGE models constitutes a largely non-disruptive alternative, something specially valued in policy institutions.

Finally, adding professional forecasters' expectations about future inflation and the monetary policy rate as observables, we find that they align well with rational expectations - consistent with virtually no cognitive discounting - and that by imputing them to households or firms, the resulting model adjusts more poorly to the data and creates problems, especially for the investment dynamics; suggesting those expectations are note suited - at least in Chile - for the estimation of forward guidance cognitive discounting.

1.1 Related Literature

Forward guidance (FG) is not a new concept. Following Nelson (2021) we learn that the Federal Reserve acknowledged the effect that announcements about the future monetary policy stance can have on long-term rates and these on economic decisions already in the 1950s; but that it was not until the 1990s that a consensus emerged about its viability and not until the 2000s when policymakers began to accept its implementation. The Fed introduced a policy bias or policy tilt in 1999, but abandoned it after a year; four years later a new attempt to introduce forward guidance was made and lasted until 2005. In 1999, the Norges Bank also engaged in forward guidance by issuing statements such as "the probability that the next change in interest rates will be an increase is greater than the probability of a reduction." The ECB, in turn, began using a system of communication resembling a "traffic-light" to signal its next policy move around 2005. Other countries embarked in forward guidance around the same time: the Central Bank of New Zealand has been publishing forecasts of the short-term interest rates since 1997, the Norges Bank started publishing the future path of its policy rate in 2005, the Sveriges Riksbank and the Bank of Israel followed in 2007 and the Czech National Bank began publishing the path of a ninety-day policy rate in 2008.[4]

Research on this policy measure at that time was limited but with important exceptions such as Woodford (1999). That seminal work showed that the gradual adjustment of interest rates can be optimal, as it amplifies the effect of monetary policy on long rates and that, therefore, a generalization of the Taylor rule that incorporated inertia in the form of an autoregressive component was desirable.[5] Eggertsson and Woodford (2003), in turn, studied how commitment to expansionary monetary policy could help stimulate activity when a lower bound on interest rates is binding, in line with Krugman (1998) proposals for Japan. But, as underlined before, it was the financial crises of 2007-2008 and its consequences what prompted forward guidance to become instrumental for stabilizing prices and boosting activity. The Federal Reserve resorted to using explicit forward guidance extensively since the FOMC meeting of December 16th, 2008, the Bank of Canada followed in April of 2009 and the ECB and the Bank of England were next in July and August of 2013, respectively. And it was also then, understandably, when analytical work on forward guidance began to surge and to realize the shortcomings presented by standard monetary DSGE models.[6]

As it has now been well established in the literature, standard New Keynesian DSGE models are not well suited for the study of forward guidance policy. Even though they are built upon the precondition of forward-looking agents, they deliver unrealistically large responses of prices

[4] See Geraats et al. (2008), Olsen (2014), Kool and Thornton (2015) and McDermott (2016).

[5] Inertia is, perhaps, usually thought of as the persistent effect of the past on the present. But, similarly, it also tells agents of the effect of the present on the future.

[6] Thinking of forward guidance as providing some information about future policy settings - Svensson (2015) - one can consider other episodes as examples and other strands of literature as precedents. For instance, fix exchange rate systems - such as Argentina's Convertibility Plan implemented in April 1991 - entail strong commitments on future monetary policy (e.g. on the rate of money growth). Inflation targeting regimes - and increased transparency in general - can also be considered to fall within this category, insofar they provide more detailed indications on how future monetary policy is to evolve.

and activity, which, additionally, tend to increase as the announced future interest rate policy change moves further away in time; even reaching explosive dynamics in some cases (see McKay et al. (2016) and Carlstrom et al. (2015), respectively). Del Negro et al. (2023) conceptualized this condition as the *forward guidance puzzle*. The main culprits for these shortcomings are an implausible high sensitivity of consumption to future interest rate changes and the front-loading associated with the New Keynesian Phillips curve. Since then, the literature has been proposing alternative modifications to the standard NK DSGE model in order to prevent this from happening.

McKay et al. (2016) consider two alternatives to mitigate the problem, one based on incomplete markets and borrowing constraints and the other on an approximation resulting in a discounted Euler equation. Regarding the first one, the risk of hitting a borrowing constraint in the future effectively shortens the planning horizon, simply because agents cannot react to interest rate changes that take place after the borrowing constraint becomes binding. Additionally, agents' precautionary motives will temper their response to future interest rate shocks, as running down their assets becomes costly. The second one, directly dampness the effect future interest rates changes have on consumption.[7] Del Negro et al. (2023), in turn, propose to introduce perpetual youth as in Blanchard (1985) and Yaari (1965), a set up that has agents dying with a given probability while at the same time entering in an annuity contract which entitles them to a fraction of the wealth left behind by those who die under the condition of surrendering their own wealth once they themselves die. This prevents a fraction of the population - the ones that have not yet been born - from reacting to future interest rate changes announcements and so containing the response of consumption decisions.[8]

Michaillat and Saez (2019), in turn, take a relative wealth approach: they introduce wealth in the utility function of households as they value social status. Cochrane (2017) argues that the puzzle can be averted by the appropriate equilibrium selection strategy while Angeletos and Lian (2018) show that relaxing the standard assumption that agents have common knowledge of news and face no uncertainty about how others will respond gives rise to a form of aggregate myopia which resolves the forward guidance puzzle. Mankiw and Reis (2002)'s sticky information has

[7]Werning (2015) argues, however, that although incomplete markets always have an effect on the level of aggregate consumption, the sensitivity of consumption to future interest rate changes is not as clear and varies significantly, concluding that incomplete markets are not a sufficient condition for solving the puzzle.

[8]Perhaps a brief but important digression to make before moving forward is that the fact that in a given model forward guidance does not generate unrealistically large responses, does not necessarily mean that the causes of the problem have been resolved. The work of McKay et al. (2016), for instance, among other things, correctly shows how financially constrained agents cannot react to announcements of future interest rate cuts and therefore, help reduce the effect of forward guidance on current activity and inflation. However, the underlying transmission mechanisms of the economy may still very well affect or distort other dimensions of a model. Welfare, for example, would be such a dimension. It does not appear realistic that agents may experience the same incentives or urges to change their decisions in the face of an announced interest rate cut two quarters ahead than in fifty years, irrespective of whether they are able to or not.

also been proven successful to mitigate the problem as they render the Phillips curve less forward looking and, hence, make the front loading of it less of an issue; see Carlstrom et al. (2015) and Kiley (2016).

Finally, an important strand of literature resorts to bounded rationality as researchers consider the excessive knowledge imputed on agents by the *rational expectations hypothesis* the source of the problem. For example, Gertler (2017) adopts a hybrid adaptive/rational expectations belief mechanism that helps cope with the puzzle; adaptive on macro aggregates and rational on policy; Garcia-Schmidt and Woodford (2019) propose an explicit cognitive process by which agents may form their expectations of future endogenous variables; Farhi and Werning (2019) introduce heterogeneous agents and incomplete markets together with level-k thinking, and argue that the interaction of both frictions is necessary to successfully answer the forward guidance puzzle (see footnote 7); and Beqiraj et al. (2019) tempers the effects of forward guidance by considering heterogeneous agents of which a part remains rational while the rest features bounded rationality and forecasts future variables as a fraction of their past value. Also falling in this category, Gabaix (2020) - building on previews work of his - proposes an alternative, though related, bounded rationality framework that, among other things, resolves the forward guidance puzzle by assuming agents that cognitively discount future deviations from steady state. This amounts to introducing a type of myopia which results in decreasing sensitivity to future events, as they take place further away in time. We discuss this framework in more detail later on, as it is the one we will implement it in our model and test.

In addition to allowing us to study forward guidance policy properly, a successful resolution of the puzzle is important for studying standard monetary policy. As Milani and Treadwell (2012) argue, conventional estimates of MP shocks in DSGE models typically emerge as a combination of both anticipated and unanticipated shocks, when only the former are allowed for. The impulse response functions corresponding to a surprise monetary policy (MP) shock, in a model that does not feature forward guidance shocks, lie between the IRFs of a *surprise* and a *news* shock produced by a model that allows for both those types of MP shocks.[9] This can lead to wrong assessments of policy and to unwanted conclusions. Reinforcing Milani and Treadwell (2012) conclusions, English et al. (2003) find that a positive persistence of the unanticipated MP shock can improve a model's fit to the data when they do not have FG shocks.

Parallel to the body of analytical work on forward guidance partially reviewed above, a substantial body of literature emerged on the empirical effects of future monetary policy announcements.[10] A particular relevant sub-strand of this empirical literature uses high frequency

[9] See figure (3) in their paper.

[10] For instance, Del Negro et al. (2023), Kiley and Roberts (2017), Chung et al. (2019) and Coenen et al. (2021)

data together with sign and zero restrictions to try to identify forward guidance shocks which are then included in VARs to obtain their effect on aggregate macro variables (see Andrade and Ferroni (2021), Brubakk et al. (2022) and Ferreira (2022)).[11] In particular, we will heavily rely on Brubakk et al. (2022), as they provide simultaneous estimates of the impact on inflation and activity that forward guidance and surprise monetary policy shocks have. More concretely, they find that an Odyssean forward guidance shock has similar or not significantly different effects on inflation and activity compared to an unanticipated monetary policy shock of the same magnitude.[12] This is discussed in more detailed in section (2).

Closely related to our work, Ilabaca et al. (2020), Andrade et al. (2019), Yasuo et al. (2022), Kolasa et al. (2022), and Brzoza-Brzezina et al. (2022) estimate DSGE monetary models under cognitive discounting. The first two papers estimate the three-equations, behavioral New Keynesian model introduced in Gabaix (2020). Ilabaca et al. (2020), using data for the US estimate cognitive discounting factors ranging from about 0.4 to 0.6 for firms and from 0.7 to 0.85 for households. Andrade et al. (2019), in turn, analyze identification issues and find a maximum likelihood estimate of their single cognitive discount factor of about 0.67 (somewhere between the estimates found for firms and households in the previous paper). Yasuo et al. (2022) consider a similar New Keynesian model, but with a more sophisticated monetary policy rule and allowing for ZLB constraints, and using Bayesian methdos, they find a cognitive discount parameter estimate of about 0.85. The two last papers introduce cognitive discounting into small open economy models and study its effect on their dynamics, finding that it improves the model's ability to account for certain phenomena, for example related to the UIP. Kolasa et al. (2022) estimate a cognitive discount parameter of about 0.5, whereas Brzoza-Brzezina et al. (2022) find a value of about 0.7. Moreover, Brzoza-Brzezina et al. (2022) claim that monetary policy is less powerful when agents are behavioral, a result that we also find when imposing a uniform cognitive discount factor. However, we find that conclusion to be at odds with empirical evidence stemming from VARs, e.g. Aruoba et al. (2021), and that to avoid this a forward guidance specific cognitive discount factor is needed.

In yet another related work, Mueller et al. (2020), estimate a modified version of the New Area

study the effects of forward guidance in a low interest rate context.

[11]Whereas Andrade and Ferroni (2021) impose sign and zero restrictions on interest rates and inflation expectations and finds that the ECB was able to stimulate the economy with Odyssean forward guidance policy; the other two papers impose, as Jarocinski and Karadi (2020), restrictions on stock market price variations and interest rates. Closely related to D'Amico and King (2015), these papers try also to differentiate between Delphic and Odyssean - using the terminology of Campbell et al. (2012b) - forward guidance; that is shocks that convey information about the future outlook of the economy and shocks which inform about future deviations from the policy rule. They add survey forecasts to an otherwise standard VAR for the US and find quite sizable effects of forward guidance, and that the effects increase with the horizon.

[12]Smith and Becker (2015) find that forward guidance yields quantitatively similar effects on US employment and inflation as conventional policy shocks.

Wide Model of the ECB using data on expectations (on inflation, activity and interest rates). Their modification of the model is closely related to ours, in that they introduce a discount factor in the Euler equation of the model. Even though there are differences with our set-up - most importantly that we have discount factors affecting all future looking variables - their estimates of the discount parameter for all the specifications they consider are very close to 1, leading them to conclude that there is no scope for a discount parameter in their model. Moreover, in line with Campbell et al. (2016) they find that by adding forecast data as observables in the estimation strategy, forward guidance is significantly mitigated.

We ran estimations conditional on forecast data also, and for all the cases we considered, our estimates for the cognitive parameters ended up very close to one too. We evaluated, then, a version in which the model's expectations matched to the data are generated by an ad-hoc "professional forecaster" with its own specific cognitive discount factor. Under this assumption, which attains a better fit to the data, while our discount factors estimates for households and firms do not vary relative to the versions estimated without forecast data, the discount factor associated to forecast data was virtually one. We use professional forecasters' expectations, as they are the ones available for Chile, leading us to conclude that this type of expectations - which are well described by the model's rational expectations - are not representative of households and firms cognitive discounting of expectations. [13]

The rest of the paper is structured as follows. Section 2 presents empirical evidence which aims at measuring the effects of forward guidance shocks on inflation and activity. Section 3 briefly describes the DSGE model we will use as our laboratory. Section 4 describes the strategy we use in the estimation of the behavioral model. Section 5 presents the results and section 6 concludes.

2 Empirical evidence

In this section we consider in more detail the evidence presented by Brubakk et al. (2022), which will serve as a major building block of our estimation strategy. The idea, as already explained, is to condition the estimation of the model by means of a *system prior* so as to obtain IRFs for a conventional surprise monetary policy shock and for anticipated future monetary policy shocks that are aligned with the data. This will then help us identify the cognitive discounting parameters of our behavioral model, as these parameters strongly affect the impact of forward

[13] It should be said that Ilabaca et al. (2020) also ran an estimation of the behavioral three equation model of Gabaix (2020) using data from the Survey of Professional Forecasters and their estimates are not significantly different as a consequence of it.

guidance shocks. Brubakk et al. (2022) provide the necessary evidence: announcing that the nominal interest rate will remain unchanged during a certain period within the next two years to be then inmediately increased/decreased for one period, has a similar or not significantly different effect - on prices and activity - comprared to a surprise monetary policy shock of the same magnitude.

In a similar spirit as Jarocinski and Karadi (2020), D'Amico and King (2015), and Andrade and Ferroni (2021), they begin by recognizing the existence of three main different types of monetary policy shocks. Firstly, there is the conventional monetary policy surprise which captures contemporaneous deviations from the policy rule. Then, there are shocks that convey information about the future. Of this sort there are two types: *delphic*, which reveals information about the central bank's assessment of the economic outlook, and *odyssean*, which expresses a commitment to a certain future policy path.[14] To identify these different shocks, they depart by using high-frequency data on both interest rates and stock prices to control for the systematic component of monetary policy. Measured changes in market rates within an appropriately narrow window - they use 30-minute windows - around monetary policy announcements isolate unexpected variation in policy and, in this way, capture the effect of monetary policy on real activity and prices. Finally, they add sign and zero restrictions to disentangle the different shocks.

The imposed sign restrictions respond to the following insights: first, a conventional monetary policy shock produces a negative correlation between interest rates and equity prices. An increase in interest rates dampens activity, cutting dividends, and increases the discount rate, reducing prices on both accounts. Second, a surprise increase in interest rates that conveys additional information about the future economic stance, suggests an improvement associated with an increment in profits and consequential rise in stock prices. Finally, they consider an additional zero-restriction, based on the assumptions from Gurkaynak et al. (2004) that forward guidance shocks do not affect the current short-term rate, but only longer maturity interest rates.

The monetary shocks identified in a first stage, as described above, are then included as exogenous variables in a VAR containing five macroeconomic variables: the monetary policy rate, a one-year interest rate, core inflation, an activity measure and the nominal exchange rate. The estimation of this VAR allows them to compute the corresponding IRFs for the different macro variables and monetary policy shocks. They use data for Norway and Sweden for a period extending beyond effective lower bound conditions, allowing them to obtain more general conclusions about the effect of monetary policy.

[14] As earlier work has shown, it is very important to account for this information channel when identifying the macroeconomic effects of policy surprises extracted from financial data, since not doing so could lead to a biased evaluation of monetary policy shocks (Campbell et al. (2012a); Nakamura and Steinsson (2012); Andrade and Ferroni (2021); Jarocinski and Karadi (2020); Miranda-Agrippino and Ricco (2021).

They find that forward guidance about the first two years is the most relevant when it comes to affecting core macroeconomic variables and, hence, contradicting the predictions of standard New Keynesian models. Moreover, they find that the effects of a surprise forward guidance shock that increases the future interest rate are similar to the effects of a conventional monetary policy shock. It is precisely this last result which we will impose on our estimation by means of a system prior; penalizing significant differences between the effects on prices and activity of these two shocks. Regarding the size of the effects and the precise trajectory they follow, we will take an agnostic view, and rely on the data and the model - both specific to Chile - to determine them.

3 A large DSGE model

The X-MAS model, documented in Garcia et al. (2019), is the main Central Bank of Chile's dynamic stochastic general equilibrium (DSGE) model of the Chilean economy for monetary policy analysis and macroeconomic forecasting purposes. The model includes the typical elements of second-generation New Keynesian DSGE models à la Christiano et al. (2005) and Smets and Wouters (2007), such as sticky prices and wages, habit formation in consumption, physical capital with adjustments costs in investment, and variable capacity utilization, and of small open economy models, such as a simple financial friction, a debt-elastic country premium, and delayed pass-through of global prices and productivity. In addition, the model features a series of non-standard elements, such as non-Ricardian households and oil imports as an intermediate input for consumption and production. Furthermore, it includes a commodity sector with endogenous production - conducted through sector-specific capital, subject to adjustment costs and time-to-build frictions in investment - and an augmented fiscal block which includes government consumption, investment, and transfers on the spending side, and a set of distortionary taxes on consumption, labor, and capital income and a standard non-distortionary lump-sum taxes (and one-period debt) on the income side. Spending items are determined jointly under a structural balance rule. Finally, the model features search and matching frictions with endogenous separation and involuntary unemployment in the labor market.

This is a rather large and rich model which is at the core of Central Bank of Chile staff's monetary policy recommendations to the Board. As such, it is continuously updated and improved upon, and the emergence of FG as a monetary policy tool triggered the evaluation of the model's capability to accommodate it. As was to be expected, the XMAS model suffers from the *forward guidance puzzle*. The standard way of showing this is by plotting the impact of a forward guidance shock relative to the impact of a conventional unanticipated monetary policy shock on prices and activity.

Figure (1) depicts such ratios as a function of the FG horizon and shows how, in this model, an anticipated interest rate cut 30 periods ahead has about seven times the effect on activity as a contemporaneous cut of the same magnitude; this ratio is about 25 in the case of inflation.[15] Clearly, it is not realistic that the announcement of a 10 basis point cut in the real interest rate eight years ahead has such a significantly greater effect than a current cut of the same magnitude, nor that the relative effects grow with the horizon.

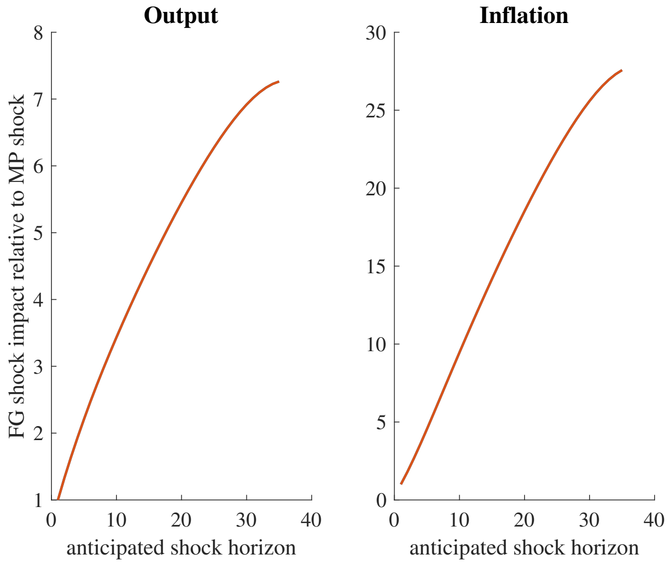

Figure 1: Forward guidance relative impact; benchmark XMAS model, 'XMAS RE'.

As mentioned in the introduction, the reason for this lies in the excessive sensitivity of consumption to interest rate changes and to the front-loading of the Phillips curve. Borrowing from McKay et al. (2016), consider the Euler equation of the canonical New Keynesian monetary policy model:

$$c_t = E_t(c_{t+1}) - \sigma^{-1} E_t(i_t - E_t[\pi_{t+1}] - r_t^n) \tag{1}$$

where c_t stands for consumption, i_t for the short-term nominal interest rate, π_t for price inflation, r_t^n for the natural real interest rate, σ^{-1} is the intertemporal elasticity of substitution and $E_t[\cdot]$ denotes the rational expectations operator. Iterating (1) forward we can see how current consumption depends on all future real interest rate changes until infinity, and that a change, say in period $t+j$, has the same *direct* effect as a change in period t,

$$c_t = -\sigma^{-1} \sum_{j=0}^{\infty} E_t(i_{t+j} - \pi_{t+1+j} - r_{t+j}^n) \tag{2}$$

However, an expected change, say a cut, in the future interest rate of period $t+k$ with $k > 0$, also increases all expected consumption between period t and $t+k$. Then, taking a look at the

[15]The exercise consists of considering forward guidance announcements of future 10 basis points cuts in the real interest rate and keeping it at the steady state level before and after the cut.

New Keynesian Phillips curve and iterating it forward,

$$\pi_t = \beta E_t[\pi_{t+1}] + \kappa c_t \implies \pi_t = \kappa \sum_{j=0}^{\infty} \beta^j E_t[c_{t+j}] \tag{3}$$

we can see how current inflation is affected by the sum of current and expected future deviations of consumption from its steady state/balance growth path. Therefore, the sum in equation (3), and therefore the effect on inflation, grows with the horizon of the announced future interest rate cut. This effect on inflation further reduces the real interest rate upon which consumption depends - see equation (2) - further increasing consumption between periods t and $t+k$ and thus triggering a feedback process that amplifies the effects. That is the main mechanism behind the *forward guidance puzzle*: the high sensitivity of consumption to expected interest rates - which does not diminish with the horizon - and the amplification mechanism triggered by the Phillips curve. That mechanism is the one the literature has proposed to break by introducing frictions that limit how forward-looking agents are, e.g. bounded rationality, or by preventing agents from reacting to expected future monetary policy changes, e.g. using binding borrowing constraints.

3.1 Introducing behavioral features

In order to solve the *forward guidance puzzle* in the XMAS model, we deviate from the rational expectations (RE) hypothesis and adopt Gabaix (2020)'s behavioral approach for inputting agents' expectations. This concept assumes agents are partially myopic and do not fully understand events taking place in the future, with the degree of understanding decreasing exponentially with the horizon. As this happens, agents increasingly rely on a focal point for their projections: the steady state.[16] This is instrumentalized by means of a *cognitive discount factor* applied to expected future deviations from the steady state.

Following Lemma 1 in Gabaix (2020), we see that under this concept of bounded rationality (BR) agents form expectations discounting rational expectations (RE) deviations from their focal point, i.e.

$$E_t^{BR}[\bar{x} + \hat{x}_{t+k}] = \bar{x} + m^k E_t[\hat{x}_{t+k}] \tag{4}$$

where the parameter m denotes the cognitive discount factor. Variables in the model, x_t, are expressed as the sum of its steady state value, $\bar{x}$, and its deviation from it, $\hat{x}_{t+k}$. [17] One can re-write equation (4) to see that expectations of future variables under cognitive discounting

[16] As Gabaix (2020) explains the focal point is, however, not limited to the steady state.

[17] Gabaix (2020) provides a series of possible - though not universal - micro-foundations for this setup, including how other specifications - even under rational expectations - can give rise to a similar discount factor.

are a weighted average of the focal point x_{t+k}^{fp} - the steady state in this case - and the rational expectations of the variable $E_t[x_{t+k}]$, i.e.

$$E_t^{BR}[x_{t+k}] = (1-m^k)x_{t+k}^{fp} + m^k E_t[x_{t+k}] = (1-m^k)\bar{x} + m^k E_t[x_{t+k}] \tag{5}$$

Then, if $|m| < 1$, as agents forecast events further away in time, their projections tend to be increasingly centered in the variable's steady state, $\bar{x}$. Sufficiently distant events, i.e. deviations from the steady state, become, then, negligible and so do their direct effects on current decisions. Note that this specification nests the rational expectations hypothesis, which holds when $m = 1$.

The implementation of this type of cognitive discounting assumes that all expected future deviations, independently of how they are generated, are discounted with the same factor.[18] This turned out to be a problem when we first implemented cognitive discounting in our DSGE model. Requiring the model to generate similar impulse responses of activity and inflation to a conventional monetary policy and a forward guidance shock of the same magnitude drives the cognitive discount factors downwards. This is understandable as the model attempts to reduce its excessive response to forward guidance shocks and the modification of other structural parameters can help only so much without heavily deteriorating the likelihood of the model. But as the cognitive discount factors are driven downwards, the forward-lookingness of the model, so-to-speak, drastically diminishes. In particular, it renders conventional monetary policy extremely weak and at odds with VAR estimates (e.g. Aruoba et al. (2021)).[19] Again, this is to be expected, as conventional monetary policy acts mainly through its impact on expectations, specially about the future monetary policy stance; see Figure 2.[20] In light of this insight, we propose shocks-specific cognitive discount fac-

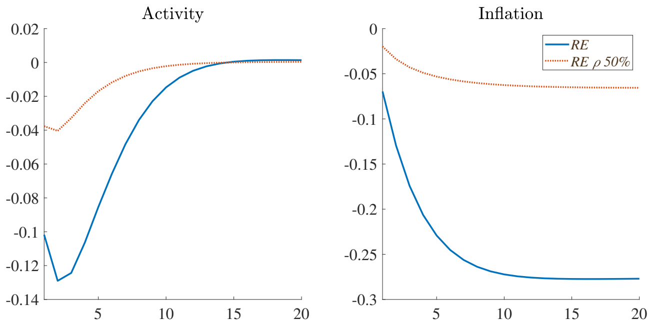

Figure 2: Impact of a monetary policy shock on activity and inflation. XMAS model and a counterfactual specification with 50% nominal interest rate persistence in Taylor rule.

[18]To be clear, we are not suggesting here that it assumes that all agents have the same discount factors. As Gabaix (2020) assumes - and we will also consider - different types of agents could entertain different cognitive discount factors. It seems sound to assume that households, firms or particular investment sectors, for example, have different incentives and abilities to forecast the future.

[19]As mentioned in the introduction, Brzoza-Brzezina et al. (2022), also find a weakening of the effect of monetary policy.

[20]In line with Woodford (1999), empirically relevant monetary policy rules present auto correlation terms (see the monetary policy rules, for instance, in the NAWM II (Coenen et al. (2018)), FRBNY (Cocci et al. (2013)), COMPASS (Kapetanios et al. (2019)) of the ECB, FED, BoE respectively). This implies that the realization of a monetary policy shocks - or a deviation from steady state of the nominal interest rate - is accompanied by a type of forward guidance. An increase of the rate today informs agents (who understand the monetary policy rule) that

tors that - given that the model is solved upon a first order linearization - need to be introduced via a different and novel specification for the focal point. Namely, we introduce a focal point that allows for the discounting of expectations' deviations from the steady state only when these are generated by a forward guidance shock.

Consider a model $\mathcal{M}$ featuring forward guidance shocks and a model exactly the same but without those shocks, say $\mathcal{M}^\star$. We propose that agents use model $\mathcal{M}^\star$ to determine their focal points in model $\mathcal{M}$. In other words we assume that the focal point for a given variable x_{t+k} in model $\mathcal{M}$ is the expected value of x_{t+k} in model $\mathcal{M}^\star$. Clearly, when a shock different from a forward guidance one hits, both models react in the same way and the rationally bounded expectation of a given variable collapses to its rational expectation, i.e.

$$\begin{aligned} E_t^{BR}[x_{t+k}] &= (1-m^k)x_{t+k}^{fp} + m^k E_t[x_{t+k}|\mathcal{M}] \\ &= (1-m^k)E_t[x_{t+k}|\mathcal{M}^\star] + m^k E_t[x_{t+k}|\mathcal{M}] = E_t[x_{t+k}|\mathcal{M}] \end{aligned} \tag{6}$$

However, when a forward guidance shock hits the economy, while it affects the economy $\mathcal{M}$, the economy $\mathcal{M}^\star$ remains unchanged at its steady state since it simply does not feature those shocks. In this case, the rationally bounded expectation of a given variable coincides with the proposed cognitive discounting of Gabaix (2020), i.e. the weighted average between its steady-state value and its rational expectation value:

$$\begin{aligned} E_t^{BR}[x_{t+k}] &= (1-m^k)x_{t+k}^{fp} + m^k E_t[x_{t+k}|\mathcal{M}] \\ &= (1-m^k)E_t[x_{t+k}|\mathcal{M}^\star] + m^k E_t[x_{t+k}|\mathcal{M}] = (1-m^k)\bar{x} + E_t[x_{t+k}|\mathcal{M}] \end{aligned} \tag{7}$$

Figure 3 shows the effects on activity of a conventional monetary policy shock and of a forward guidance shock in both models $\mathcal{M}$ - main model - and $\mathcal{M}^\star$ -focal point model - capturing how a variable behaves relative to its focal point.

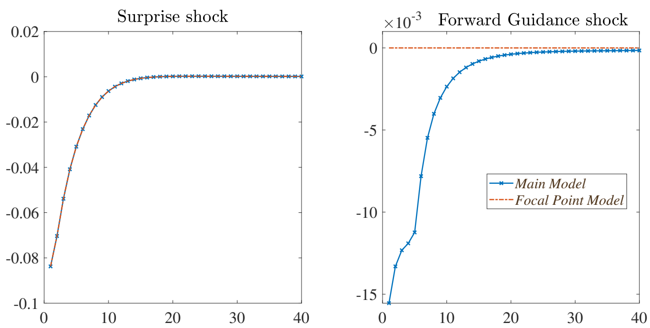

Figure 3: Monetary policy shock effect on inflation and on the inflation focal point.

We find the rationale for our shock-specific cognitive discount factor in the nature of the forward guidance shocks.

the rate will be high also the next periods, and that it will return to steady state only gradually. Mechanically, cognitive discounting tempers this channel, rendering monetary policy, in particular, less powerful. This also happens in the model used by Gabaix (2020) as soon as the policy rule assumed incorporates persistence. This argument can be further generalized to the endogenous persistence of the variables appearing in the monetary policy rule, such as inflation. Paeuti and Seyrich (2022) study monetary policy in a simple HANK model where households feature cognitive discounting. They find that their behavioral HANK model generates amplification of contemporaneous monetary policy through indirect effects while resolving the forward guidance puzzle. They assume a simple monetary policy rule in the line of Gabaix (2020); in particular, without persistence.

Future monetary policy announcements
are surrounded by uncertainty considerations that already realized shocks and their future consequences do not posses. From this perspective, one can think of the main and the focal point models as representing two extreme worlds, one in which future monetary policy announcements are fully certain ($\mathcal{M}$), and one in which those announcements are completely ignored ($\mathcal{M}^{\star}$). One can, then, interpret the cognitive discount factor as a horizon-dependent measure of certainty: when equal to zero, agents do not believe announcements will occur and when equal to one they fully believe they will. Of course, in this case the cognitive discount parameters will not only capture this idea of uncertainty but also the same cognitive limitations assumed by Gabaix (2020). In sub-section (5.4) we consider a version of the model that features, in addition to our shock-dependent cognitive discount, a discount factor for deviations from steady state generated by non-forward guidance shocks. Cognitive discounting of deviations generated by forward guidance shocks is found to be more severe than the one applied to deviations generated by non-forward guidance shocks. For most of the paper, however, we keep with the specification that assumes cognitive discounting of forward guidance triggered expected future events.

One important point to note from this approach is that it allows to introduce forward guidance shocks into an already operational model without directly disrupting its mechanisms. Moreover, the actual implementation is rather simple: one proceeds by linearizing around the steady state all equations of the model featuring expectations of future variables and, then, one replaces the rational expectations operator by the corresponding behavioral one as prescribed by equation (5).[21] Finally, one write an auxiliary model equal to the original one that does not feature forward guidance shocks - our focal point model $M^{\star}$.[22] Note that the behavioral model nests the rational expectations one, when the cognitive discount factors equal one.[23]

In appendix (B) we describe how to implement cognitive discounting in Dynare in a simple form and how to impute shock-specific cognitive discount shocks.

Introducing cognitive discounting leaves us with the need to take a decision about whether this parameter should be homogeneous or whether a certain heterogeneity is desirable.[24] Here we are referring to agent heterogeneity, not to the above addressed *event heterogeneity*. Departing from an agnostic view, we consider several alternatives for how to group agents, and impose common CD factors. For instance, we consider a version with a common CD factor for all

[21] There is a difference between the proper cognitive discount parameter, m, and the parameters that we will estimate for our model and which pre-multiply rational expectations. The latter are called macro parameters of attention and denoted by capital Ms and are functions of structural parameters and m.

[22] We denote the variables in that model with fp indices, i.e. x_t^{fp}

[23] For a complete and detailed derivation of the XMAS model interested readers are referred to Garcia et al. (2019). For a complete and detailed discussion of cognitive discounting, in turn, see Gabaix (2020). The model's equations modified to accommodate behavioral features are presented in appendix (**??**).

[24] All other assumptions about the model are taken from Garcia et al. (2019).

agents, i.e. with a homogeneous CD factor; a case in which households and unions share a common factor, while all firms share another; and a heterogeneous case, in which each type of agent in the model entertains its own idiosyncratic factor.

In this context, and given our preliminary insights from initial estimations, we introduce a mutual fund that allows us to isolate the bond allocation decision from the rest of the decisions households need to take each period. Under this specification, households continue to decide how much to work and consume but their saving decision is restricted to investing in capital or buying shares of the mutual fund. That is, they no longer decide how to allocate their savings between the two types of available bonds, as that decision is taken over by the mutual fund. In this manner, we can assume the mutual fund has its own CD factor, or impute the one entertained by firms, understanding that the mutual fund could behave more similar to firms than to households. In the end, we let the data guide our conclusions. Under rational expectations, the models with and without mutual funds are indistinguishable. See section (C) in the appendix for a detailed derivation.

4 Estimation strategy: System Priors

Succinctly, *system priors* use ex ante probability distributions on certain desired model properties - e.g. dynamics, moments, etc - to guide the model into satisfying them. Working as standard priors on model parameters, they constitute a simple and clear way to impose intuitive and economic priors about the dynamics of the model, which can still be redirected by the evidence contained in, say, macro time series. We will use a system prior to induce our behavioral model to deliver IRFs for conventional monetary policy and forward guidance shocks that are similar to each other, in accordance with the evidence presented in section (2).

The approach, proposed by Andrle and Benes (2012) is closely related to Del Negro and Schorfheide (2015) and to the *endogenous priors* concept of Christiano et al. (2011). Considering our DSGE model, $\mathcal{M}$, the standard Bayesian approach for estimating its parameters, θ, consists in updating the prior beliefs about those parameters, $p(\theta \mid \mathcal{M})$, with the evidence stemming from the data, Y, as seen through the model, i.e. by means of the model's likelihood, $L(Y \mid \theta, \mathcal{M})$. We can then obtain the posterior of the parameters applying Bayes rule,

$$p(\theta \mid Y, \mathcal{M}) = \frac{L(Y \mid \theta, \mathcal{M}) \times p(\theta \mid \mathcal{M})}{p(Y \mid \mathcal{M})} \tag{8}$$

the prior specification in the previous rule is not restricted to the marginal priors of parameters contained in θ. Andrle and Benes (2012) propose, instead, to employ a composite prior built as the combination of the standard marginal distributions for individual parameters and a system prior on the desired properties of the model. For this, in addition to - usually - independent marginal priors on parameters, i.e. $p(\theta \mid \mathcal{M}) = p(\theta_1) \times p(\theta_2) \times ... \times p(\theta_n)$, one specifies a distribution on a set o model properties, Z. Then, conditional on the parameters and the model M we have a likelihood function for the properties Z. The composite prior takes the form

$$p_c(\theta \mid Z, \mathcal{M}) \propto p_s(Z \mid \theta, \mathcal{M}) \times p(\theta \mid \mathcal{M}) \tag{9}$$

where $p_c(\cdot)$ and $p_s(\cdot)$ denote the composite and system prior respectively. The posterior distribution of the model's parameters can be, then, obtained from

$$p(\theta \mid Y, Z, \mathcal{M}) \propto L(Y \mid \theta, \mathcal{M}) \times p_c(\theta \mid Z, \mathcal{M}) \propto L(Y \mid \theta, \mathcal{M}) \times p_s(Z \mid \theta, \mathcal{M}) \times p(\theta \mid \mathcal{M}) \tag{10}$$

and can be simply explored and constructed using, for instance, a standard Metropolis-Hastings algorithm.

As our system prior we will assume a rather tight normal distribution on a simple statistic, $st^{sp}(\cdot)$, constructed to capture the distance between two impulse response functions. The statistic, computed for both inflation, $st^{sp}(\pi)$, and GDP, $st^{sp}(GDP)$, is constructed as follows: for each parameter draw, θ, the IRFs delivered by the model $M(\theta)$ are computed; both for a standard contemporaneous monetary policy shock and for a forward guidance shock that promises to keep the nominal interest rate unchanged during one year and to change it at the end of that year by the same magnitude as the standard shock. Then - treating the IRFs as vectors - the statistic is simply the product of the third power of the element-wise difference between both IRFs (the cube is taken to penalize larger deviations proportionally more than small ones, while at the same time being able to use a symmetric distribution, like a normal). Finally, we assume $st^{sp}(\cdot) \sim N(0, 0.01)$.

To estimate the model we further use data on 23 macroeconomic variables covering the period between 2001Q3 and 2017Q2.[25] The Chilean and foreign quarterly data used consists of: mining and non mining GDP, an indicator of export-weighted real GDP of Chile's main trading partners as a proxy for foreign aggregate demand, private and government consumption, aggregate private, government and commodity related investment, government transfers, total employment as a fraction of the labor force, total hours per employee, nominal wages, core, food, and energy components of the CPI, an external price index, price of West Texas Intermediate crude oil in

[25] This is done to make the estimation comparable to Garcia et al. (2019). Some exercises, such as the historic shock decomposition, are done by extending the sample until 2022Q2 and re-estimating the model.

dollars per barrel, London Metal Exchange price of refined copper in dollars per metric pound, the imports deflator, short-term central bank target rate, London Interbank Offered Rate as a proxy for the foreign interest rate, real exchange rate, J.P. Morgan Emerging Market Bond Index Global (EMBIG) spread for Chile as a proxy for the country premium, and the trade balance to total GDP. With the exceptions of the interest rates, the risk spread, the real exchange rate and trade balance, all variables are log-differentiated with respect to the previous quarter and all variables are demeaned.

Most of the model parameters are calibrated or estimated and a few are endogenously determined so as to match some exogenous steady state moment. For details on the calibration, the marginal priors of individual parameters and further specifications please see Garcia et al. (2019). For the cognitive discount factors we assume a rather agnostic prior, we assume they are beta distributed with mean 0.5 and standard deviation 0.25.

The estimation also includes i.i.d. measurement errors for all local observables with the exception of the interest rate. The variance of the measurement errors is calibrated to be 10% of the variance of the corresponding observable. The posterior estimates are obtained by means of a random walk Metropolis-Hastings algorithm, with one million draws and five thousand burn-in. Conventional convergence test are checked. Posteriors, together with the prior specifications, are reported in tables (1) and (2).

5 Results

5.1 Estimation

Tables (1) and (2) present the estimation results of the non-cognitive discounting parameters, together with the assumed priors.[26] The estimation of the original model under rational expectations, 'RE', is shown as a *benchmark* side-by-side our *baseline* behavioral model,'BR III', which features three different cognitive discount factors: one for the households and the unions, one for the firms and the mutual fund, and one for the copper sector.

The estimation results show how structural parameters remain largely unchanged; something that also holds true for the exogenous shock structure. This has to do with the non-distruptive manner in which cognitive discounting was introduced, namely, only affecting the expected future deviations from steady state generated by future monetary policy announcements. In contrast, when the default cognitive discount specification is implemented - in which agents discount all

[26]The priors are the ones used in the original rational expectations model found in Garcia et al. (2019).

expected future events equally, independently of how they were produced - the power of several shocks diminishes as their effect on current variables mainly occurs through the expectations channel.[27] Under that setup, then, the estimation of the model tends to strongly modify certain parameters in an attempt to compensate for that decreased power yielding unwanted dynamics and properties, e.g. the parameters driving investment in the model such as ϕ_I or .

One parameter that does change and is worth noticing, however, is the one for the persistence of the monetary policy shock. While in the rational expectations model estimated without forward guidance shocks, the persistence parameter was found to be of about 0.3, under the bounded rationality model with forward guidance the monetary policy shock is about half that: 0.15. This, along the findings of Milani and Treadwell (2012) discussed in the introduction, suggest that the original model was using, at least partially, the persistence of the conventional monetary policy shock to capture forward guidance policy.

As the model encompasses several types of agents - households, price setting firms, a whole sale firm, a union, etc - a question that naturally arises is whether they all share the same degree of cognitive discounting or not. Something that other papers also consider, though in models featuring less types of agents (e.g. Gabaix (2020) and Ilabaca et al. (2020)). Departing from an agnostic perspective, we consider several alternatives for grouping agents, where each group shares a common cognitive discount factor (CDF). In total we show four different specifications under bounded rationality, BR: I) an homogeneous CDF case; II) a version featuring two different factors - one for households and unions, and one for firms (including the copper firm) and the mutual fund; III) a version with three CDFs - our *baseline* version - which assumes one for households and unions, one for firms and the mutual fund, and one for the copper firm (as it is to be expected that, given the mid-/long-term characteristic of their investment decisions, this firm may be more sophisticated when it comes to forming expectations, e.g. the model features time-to-build); and, VI) a version in which unions, the wage bargaining firm and the mutual fund are also endowed with their own cognitive discount factors.

[27]Remember the discussion about monetary policy around Figure 2.

Parameter	Description	Initial Prior			Posterior RE				Posterior BR III			
		distr.	mean	s.d.	mode	mean	pct. 5	pct. 95	mode	mean	pct. 5	pct. 95
ς	Habit formation	B	0.75	0.1	0.60	0.61	0.51	0.72	0.75	0.77	0.68	0.85
ν	Preferences endogenous shifter	B	0.5	0.2	0.04	0.06	0.02	0.12	0.03	0.06	0.01	0.10
ϕ	Inverse Frisch elasticity	G	5.0	1.0	1.25	1.51	1.05	2.15	1.18	1.54	0.85	2.23
μ	Match elasticity parameter	B	0.5	0.2	0.91	0.91	0.85	0.96	0.92	0.92	0.87	0.97
$\sigma_{\tilde{C}}$	Worker's adm. costs dispersion	IG	0.25	Inf	5.24	5.80	4.93	6.96	5.51	6.15	4.95	7.22
100ψ	Country premium debt elast.	IG	1.0	Inf	0.23	0.24	0.18	0.30	0.22	0.23	0.17	0.29
ρ_R	Taylor rule smoothing parameter	B	0.85	0.025	0.74	0.74	0.71	0.77	0.76	0.76	0.73	0.79
α_π	Taylor rule response to total inflation	N	1.7	0.1	1.94	1.95	1.81	2.09	1.84	1.83	1.69	1.97
α_Y	Taylor rule response to GDP growth	N	0.125	0.05	0.13	0.13	0.06	0.20	0.14	0.13	0.05	0.20
α_{π^z}	Taylor rule response to core inflation	B	0.75	0.1	0.73	0.71	0.55	0.86	0.73	0.73	0.58	0.89
η_Z	Elast. of subst. H/F in core cons.	G	1.5	0.25	1.67	1.76	1.35	2.21	1.69	1.79	1.37	2.24
η^*	Elasticity of foreign demand	G	0.25	0.05	0.31	0.34	0.24	0.45	0.32	0.34	0.23	0.45
η_A	Elast. of subst. H/F in agriculture	G	1.0	0.25	0.99	1.07	0.67	1.54	0.99	1.07	0.64	1.50
η_O	Elast. of subst. Z,O in H prod.	G	0.5	0.25	0.37	0.54	0.17	1.02	0.40	0.56	0.14	0.96
η_C	Elast. of subst. CZ,O,A goods	G	1.0	0.25	0.63	0.66	0.42	0.94	0.63	0.66	0.40	0.92
η_I	Elast. of subst. H/F in investment	G	1.0	0.25	1.08	1.18	0.76	1.68	1.09	1.22	0.74	1.69
η_{Co}	Elast. of subst. H/F in comm. inv.	G	1.0	0.25	0.97	1.03	0.64	1.50	0.97	1.04	0.62	1.43
η_{KG}	Elast. of subst. priv. and pub. capital	G	1.0	0.5	0.35	0.60	0.26	1.11	0.38	0.63	0.23	1.03
$\eta_{\hat{C}}$	Elast. of subst. priv. and pub. cons.	G	1.0	0.5	2.07	2.24	1.37	3.30	2.33	2.62	1.46	3.77
ρ_O	Oil price smoothing param. 1	B	0.5	0.2	0.70	0.70	0.66	0.74	0.70	0.70	0.66	0.74
α_O	Oil price smoothing param. 2	B	0.5	0.2	0.42	0.43	0.24	0.62	0.40	0.40	0.22	0.57
ϑ_W	Indexation wages	B	0.25	0.075	0.30	0.31	0.19	0.45	0.29	0.29	0.17	0.42
$\varkappa_W$	Wage Smoothing	B	0.75	0.025	0.81	0.83	0.79	0.87	0.83	0.85	0.81	0.89
θ_H	Calvo probability domestic prices	B	0.75	0.025	0.82	0.82	0.80	0.85	0.84	0.84	0.82	0.87
ϑ_H	Indexation domestic prices	B	0.25	0.075	0.19	0.21	0.12	0.30	0.16	0.16	0.09	0.24
θ_F	Calvo probability import prices	B	0.75	0.05	0.73	0.73	0.70	0.77	0.76	0.76	0.73	0.79
ϑ_F	Indexation import prices	B	0.25	0.075	0.23	0.25	0.13	0.38	0.21	0.23	0.11	0.34
θ_{H*}	Calvo probability export prices	B	0.75	0.05	0.74	0.73	0.64	0.81	0.75	0.75	0.66	0.84
ϑ_{H*}	Indexation export prices	B	0.25	0.075	0.24	0.26	0.14	0.39	0.24	0.26	0.13	0.38
ϑ_π	Indexation CPI over core	B	0.25	0.075	0.24	0.27	0.14	0.41	0.24	0.25	0.13	0.38
$\Phi_{\bar{u}}$	Capital utilization cost, non-mining	G	1.5	0.25	1.11	1.07	0.76	1.43	1.00	0.95	0.64	1.25
Φ_I	Inv. adjustment cost elast.	G	5.0	1.0	2.79	3.09	1.97	4.50	3.71	3.83	2.51	5.05
Φ_{ICo}	Inv. adjustment cost elast., mining	G	0.5	0.25	0.40	0.49	0.28	0.79	0.45	0.57	0.29	0.84
Γ^{Co}	Global pass-through, mining prod.	B	0.5	0.2	0.51	0.50	0.17	0.83	0.51	0.51	0.17	0.84
Γ^H	Global pass-through, home prod.	B	0.5	0.2	0.56	0.57	0.28	0.84	0.54	0.57	0.31	0.83
Γ^{Co*}	Global pass-through, copper price.	B	0.5	0.2	0.53	0.52	0.33	0.70	0.53	0.51	0.31	0.69
Γ^{O*}	Global pass-through, oil price.	B	0.5	0.2	0.84	0.77	0.54	0.93	0.84	0.76	0.59	0.96
Γ^*	Global pass-through, foreign prices.	B	0.5	0.2	0.74	0.75	0.64	0.88	0.74	0.76	0.64	0.87
Γ^{M*}	Global pass-through, imports prices.	B	0.5	0.2	0.33	0.34	0.25	0.44	0.30	0.31	0.21	0.40

Table 1: Prior and posterior distributions - Structural parameters. The prior distributions are: beta (B), inverse gamma (IG), gamma (G), and normal (N).

Parameter	Description	Initial Prior			Posterior RE				Posterior BR III			
		distr.	mean	s.d.	mode	mean	pct. 5	pct. 95	mode	mean	pct. 5	pct. 95
ρ_{ϱ}	Preference shock	B	0.5	0.2	0.84	0.81	0.67	0.91	0.66	0.60	0.38	0.84
ρ_{ϖ}	Inv. tech. shock, non-mining	B	0.75	0.075	0.47	0.45	0.35	0.55	0.45	0.44	0.34	0.53
$\rho_{\varpi^{Co}}$	Inv. tech. shock, mining	B	0.5	0.2	0.08	0.11	0.03	0.22	0.08	0.11	0.01	0.20
ρ_{z}	Transitory tech. shock, non-mining	B	0.85	0.075	0.69	0.73	0.60	0.87	0.71	0.73	0.62	0.86
$\rho_{z^{Co}}$	Transitory tech. shock, mining	B	0.85	0.075	0.81	0.78	0.64	0.89	0.81	0.78	0.66	0.90
ρ_{z^*}	Transitory tech. shock, foreign	B	0.85	0.075	0.91	0.89	0.81	0.96	0.91	0.89	0.82	0.97
ρ_{z^A}	Transitory tech. shock, agriculture	B	0.75	0.075	0.91	0.90	0.85	0.94	0.91	0.91	0.87	0.95
ρ_{a}	Global unit root tech. shock	B	0.5	0.2	0.63	0.57	0.32	0.78	0.66	0.61	0.41	0.83
ρ_{ζ^o}	Obs. country premium shock	B	0.75	0.075	0.75	0.74	0.67	0.81	0.75	0.74	0.67	0.81
ρ_{ζ^u}	Unobs. country premium shock	B	0.75	0.075	0.74	0.71	0.62	0.80	0.74	0.71	0.62	0.80
$\rho_{\xi^{CG}}$	Public consumption shock	B	0.75	0.075	0.78	0.77	0.66	0.87	0.77	0.76	0.66	0.86
$\rho_{\xi^{TR}}$	Public transfer shock	B	0.75	0.075	0.80	0.79	0.68	0.88	0.80	0.79	0.69	0.89
$\rho_{\xi^{IG}}$	Public investment shock	B	0.5	0.2	0.18	0.22	0.06	0.41	0.18	0.21	0.04	0.37
ρ_{κ}	Labor supply shock	B	0.5	0.2	0.89	0.73	0.45	0.93	0.78	0.69	0.49	0.91
ρ_{ρ_x}	Job separation shock	B	0.75	0.075	0.71	0.71	0.61	0.81	0.72	0.72	0.62	0.82
ρ_{ξ^O}	Domestic oil price shock	B	0.75	0.075	0.73	0.72	0.57	0.84	0.73	0.72	0.59	0.85
ρ_{e^R}	Monetary policy shock	B	0.5	0.2	0.29	0.27	0.14	0.40	0.15	0.15	0.04	0.25
ρ_{π^f}	Price global factor shock	B	0.5	0.2	0.16	0.17	0.06	0.28	0.14	0.16	0.05	0.26
$\rho_{\xi^{Co*}}$	Copper price shock	B	0.5	0.2	0.74	0.71	0.57	0.80	0.74	0.69	0.57	0.81
$\rho_{\xi^{O*}}$	Oil price shock	B	0.5	0.2	0.77	0.66	0.40	0.85	0.78	0.68	0.48	0.88
$\rho_{\xi^{M*}}$	Imports price shock	B	0.5	0.2	0.86	0.84	0.76	0.91	0.85	0.83	0.75	0.90
ρ_{ξ^*}	Foreign economy price shock	B	0.5	0.2	0.51	0.51	0.17	0.83	0.50	0.50	0.18	0.82
ρ_{R^*}	Foreign interest rate shock	B	0.5	0.2	0.88	0.88	0.84	0.91	0.89	0.88	0.85	0.91
$100\sigma_{\varrho}$	Preference shock	IG	0.5	Inf	2.39	2.52	2.04	3.10	3.14	0.3.44	2.46	4.42
$100\sigma_{\varpi}$	Inv. tech. shock, non-mining	IG	0.5	Inf	7.08	8.14	4.81	12.49	9.42	10.07	6.29	14.12
$100\sigma_{\varpi^{Co}}$	Inv. tech. shock, mining	IG	0.5	Inf	9.86	11.51	6.44	18.38	11.00	12.69	6.43	18.99
$100\sigma_{z}$	Transitory tech. shock, non-mining	IG	0.5	Inf	0.60	0.62	0.54	0.71	0.61	0.63	0.54	0.72
$100\sigma_{z^{Co}}$	Transitory tech. shock, mining	IG	0.5	Inf	2.85	2.81	2.41	3.22	2.85	2.80	2.41	3.19
$100\sigma_{z^*}$	Transitory tech. shock, foreign	IG	0.5	Inf	0.52	0.51	0.43	0.59	0.50	0.48	0.38	0.58
$100\sigma_{z^A}$	Transitory tech. shock, agriculture	IG	0.5	Inf	1.27	1.28	1.09	1.47	1.27	1.27	1.08	1.47
$100\sigma_{a}$	Global unit root tech. shock	IG	0.5	Inf	0.22	0.24	0.15	0.33	0.23	0.26	0.16	0.36
$100\sigma_{\zeta^o}$	Obs. country premium shock	IG	0.5	Inf	0.08	0.08	0.07	0.09	0.08	0.08	0.07	0.09
$100\sigma_{\zeta^u}$	Unobs. country premium shock	IG	0.5	Inf	0.52	0.60	0.38	0.84	0.49	0.52	0.29	0.73
$100\sigma_{\xi^{CG}}$	Public consumption shock	IG	0.5	Inf	1.09	1.09	0.97	1.21	1.07	1.08	0.96	1.20
$100\sigma_{\xi^{TR}}$	Public transfer shock	IG	0.5	Inf	3.12	3.16	2.72	3.63	3.07	3.12	2.68	3.55
$100\sigma_{\xi^{IG}}$	Public investment shock	IG	0.5	Inf	9.71	10.07	8.91	11.30	9.65	9.98	8.78	11.26
$100\sigma_{\kappa}$	Labor supply shock	IG	0.5	Inf	1.65	2.35	1.56	3.42	1.99	2.80	1.50	4.13
$100\sigma_{\rho_x}$	Job separation shock	IG	0.5	Inf	0.27	0.28	0.24	0.31	0.27	0.28	0.25	0.31
$100\sigma_{\xi^O}$	Domestic oil price shock	IG	0.5	Inf	1.97	2.03	1.43	2.65	2.01	2.09	1.47	2.67
$100\sigma_{e^R}$	Monetary policy shock	IG	0.5	Inf	0.13	0.14	0.12	0.16	0.13	0.12	0.10	0.15
$100\sigma_{\pi^f}$	Price global factor shock	IG	5	Inf	3.30	3.31	2.78	3.86	3.28	3.27	2.74	3.79
$100\sigma_{\xi^{Co*}}$	Copper price shock	IG	0.25	Inf	11.34	11.46	10.14	12.81	11.22	11.37	10.04	12.67
$100\sigma_{\xi^{O*}}$	Oil price shock	IG	0.25	Inf	13.71	13.58	12.15	14.98	13.49	13.46	12.06	14.79
$100\sigma_{\xi^{M*}}$	Imports price shock	IG	0.25	Inf	1.46	1.52	1.17	1.90	1.55	1.64	1.25	2.03
$100\sigma_{\xi^*}$	Foreign economy price shock	IG	0.25	Inf	0.12	0.19	0.08	0.40	0.12	0.21	0.05	0.41
$100\sigma_{R^*}$	Foreign interest rate shock	IG	0.5	Inf	0.12	0.12	0.10	0.14	0.12	0.12	0.10	0.14

Table 2: Prior and posterior distributions - Exogenous parameters. The prior distributions are: beta (B), inverse gamma (IG), gamma (G), and normal (N).

Overall, the introduction of cognitive discounting for forward guidance shocks considerably improves the model fit to the data. Table (3) reports the marginal data density of our *baseline* specification, 'BR III', together with the *benchmark* version under rational expectations and the other alternatives described above.[28] Additionally, we include an RE specification featuring forward guidance shocks, 'RE FG' and one featuring forward guidance shocks and estimated using our system prior, 'RE SP'.[29] All versions with bounded rationality improve the model fit to the data relative to their RE counterparts by about 100 log points. This constitutes decisive evidence, according to this criterion, in favor of the behavioral assumption.

CDF	RE	RE FG	RE SP	BR I	BR II	BR III	BR VI
M_{CD}	-	-	-	**0.50** [0.49] (0.41,0.59)	-	-	-
M_{HH}	-	-	-	M_{CD}	**0.37**[0.35] (0.04,0.68)	**0.34** [0.28] (0.02,0.62)	**0.35** [0.26] (0.02,0.65)
M_{FF}	-	-	-	M_{CD}	**0.52**[0.50] (0.43,0.61)	**0.49** [0.46] (0.39,0.58)	**0.18** [0.08] (0.00,0.36)
M_{WB}	-	-	-	M_{CD}	M_{FF}	M_{FF}	**0.59** [0.76] (0.19,0.99)
M_U	-	-	-	M_{CD}	M_{HH}	M_{HH}	**0.47** [0.45] (0.04,0.84)
M_{MF}	-	-	-	M_{CD}	M_{FF}	M_{FF}	**0.47** [0.38] (0.35,0.58)
M_{CC}	-	-	-	M_{CD}	M_{FF}	**0.91** [0.91] (0.85,1.0)	**0.90** [0.92] (0.82,1.0)
LL	-2999.0	-2958	-2914.9	-2860.3	-2859.1	-2857.5	-2853.8
MDD	-3130.0	-3129.2	-3142.8	-3029.8	-3028.3	-3029.0	-3026.7

Table 3: Models' fit and cognitive discount factors' estimates. MDD: Marginal data density, LL: Log likelihood. Between square brackets the table reports the mode and in round brackets the 5^{th} and 95^{th} percentiles of the posterior distributions. M_{CD}: common cognitive discount factor (CDF); M_{HH}: CDF for households; M_{FF}: CDF for price setting firms; M_U: CDF for unions; M_{WB}: CDF for the wage bargainer firm; M_{MF}: CDF for the mutual fund; and M_{CC}: CDF for the copper firm.

Assuming a common cognitive discount factor for all agents, we find a significant deviation from rational expectations with an estimate of about 0.5.[30] This value - in line with the findings of Ilabaca et al. (2020) - hides, however, a much richer story, which can be unraveled once we allow for different levels of heterogeneity. Indeed, different sectors or agents appear to entertain quite different degrees of discounting. The copper firm, for instance, has an estimated CDF of about

[28] We are most likely going to change our baseline model to the one assuming a common CDF for all agents. The marginal data density between all considered behavioral versions is not significant, however, the estimation of the CDF for households, for example, is rather imprecise.

[29] These two last specifications suffer from the forward guidance puzzle.

[30] Though the posterior mean coincides with the prior mean, the posterior std becomes considerably smaller - the assumed prior, $Beta(0.5, 0.25)$, implies a rather uninformative prior; as a robustness we estimate this model assuming an alternative prior for M_{CD} with mean 0.7 and std 0.2: the same posterior mean is obtained.

0.9. On the other hand, price setting firms appear to heavily discount expected future deviations from steady state triggered by forward guidance policies; see coulmn 'BR VI'. In our model, this reflects, again, either *myopia* about the future or, as discussed before, other consideration such as uncertainty concerns. In any case, their estimated CDF implies that announcements about future interest rates beyond one year ahead are no longer relevant.[31]

For our baseline scenario, we chose version 'BR III', where households together with the union are estimated to have a substantial cognitive discounting, $M_{HH} = 0.34$, firms and the mutual fund share a CDF of about 0.5 and the copper firm is estimated to have a CDF of 0.9. It should be noticed that the households' CDF, though consistently below 0.7 considering the 95 percentile, presents a relative disperse posterior. Although we choose one specification as our baseline version, this is mainly for exposition reasons, in the background we will still consider all four alternatives.

5.2 The Forward Guidance Puzzle

The estimated behavioral model successfully resolves the *forward guidance puzzle*. Figure (4) below is constructed in the same way as Figure (1), namely by plotting the impact on output and inflation of an announced real interest rate cut in the future relative to the impact of a contemporaneous conventional real monetary policy shock of the same magnitude.

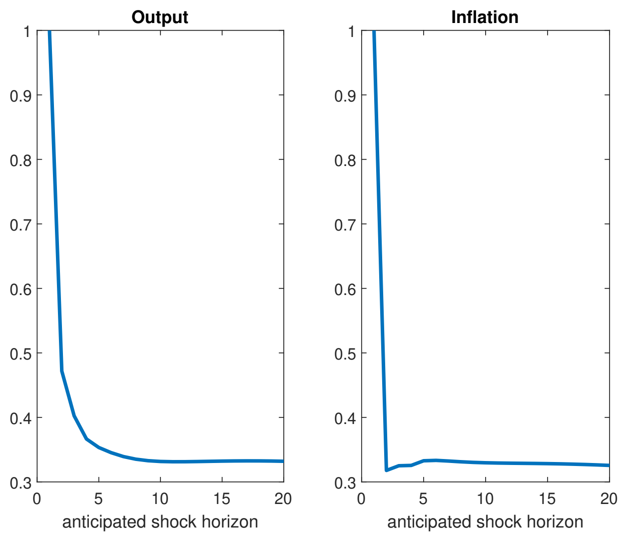

Figure 4: Forward guidance relative impact; baseline model, 'BR III'.

Figure (15) in the appendix plots these graphs for all bounded rationality versions in table (3). All alternative versions also successfully resolve the forward guidance puzzle.

As can be observed, the effect of a forward guidance shock relative to a monetary policy one decreases monotonically on activity, while it presents a hump-shaped pattern on inflation (after the initial large drop). In both cases, however, the effects no longer display the increasing dynamics of the rational expectations model. To look a bit deeper into why this happens, let us go back to the iterated Euler and Phillip's curve equations of the canonical New Keynesian model (2) and (3). Proceeding in the same manner as with the XMAS model, we can

[31] About the same horizon at which the estimated price stickiness suggests prices could be re-adjusted on average.

introduce rationally bounded agents by pre-multiplying the rational expectations operator by cognitive discount factors,[32]

$$c_t = -\sum_{j=0}^{\infty} M^j E_t \left[r_{t+j} - r_{t+j}^n \right] \qquad \pi_t = \sum_{j=0}^{\infty} \beta^j M^j E_t \left[c_{t+j} \right]$$

where, for simplicity, we have set $\kappa = \sigma = 1$ and, since we are considering forward guidance about the real rate, we have defined $r_{t+j} = i_{t+j} - \pi_{t+j+1}$. Let us now consider a conventional monetary policy shock that increases the real interest rate in Δr units. As shown in the first row of Table (4), consequence of that increase of the interest rate, both consumption and inflation will decrease - on impact - by the same amount, namely Δr. Moreover, the effect under rational expectations ($M = 1$) coincides with the effect with rationally bounded agents ($M < 1$). Next, consider a forward guidance announcement stating the real interest rate will be at its steady state level all future periods except for period n when it will be increased by Δr. Looking at consumption, while the impact on current consumption under the RE version stays constant, under the behavioral model the effect is shrunk by M^n, making the ratio of the impacts be constant to one under RE and to decrease monotonically under cognitive discounting.[33] For inflation, the dynamics are a bit more complex. As the announcement horizon moves further away in time, the consumption of an increasing number of periods gets affected, then, because of the front-loading of the Phillips curve, the accumulated effect on inflation increases steadily, i.e. $-\Delta r \sum_{i=0}^{n} \beta^i$. While that is the only force at play under RE, in the behavioral model, as the FG horizon moves further in time, agents exponentially increase their cognitive discounting of the future marginal increments. Eventually, the decrease enforced by M^n dominates the increase

	Effect on Consumption		Effect on Inflation	
T	M=1	M<1	M=1	M<1
0	$-\Delta r$	$-\Delta r$	$-\Delta r$	$-\Delta r$
1	$-\Delta r$	$-M\Delta r$	$-\left(\Delta r + \beta\Delta r\right)$	$-M\left(\Delta r + \beta\Delta r\right)$
2	$-\Delta r$	$-M^2\Delta r$	$-\left(\Delta r + \beta\Delta r + \beta^2\Delta r\right)$	$-M^2\left(\Delta r + \beta\Delta r + \beta^2\Delta r\right)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
n	$-\Delta r$	$-M^n\Delta r$	$-\Delta r \sum_{i=0}^{n} \beta^i$	$-M^n \Delta r \sum_{i=0}^{n} \beta^i$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
∞	$-\Delta r$	0	$-\Delta r/(1-\beta)$	0

Table 4: Intuition behind the resolution of the FG puzzle.

of $\sum_{i=0}^{n} \beta^i$ and the ratio begins to decrease; imprinting the above plotted hump-shape. Finally,

[32] Notice that these equations were already the linearized equations around the steady state.

[33] The constant ratio under RE in this simple canonical monetary model has to do with the simplistic dynamics it features. The forward guidance puzzle manifests in the ratio of impacts on inflation. As shown in Figure (1), the activity impact ratio in our large-scale model increases with the horizon.

observe that in our simple stylized example, the impact of the FG policy exercises converges in all cases - RE and BR - and that it only disappears for the BR case.

To finalize this sub-section, let us consider a simple exercise which illustrates the practical importance of resolving the forward guidance puzzle. For this we compare three different implementations of a 25bp nominal interest rate increase a year from now in our DSGE model. The first alternative is to shock the model with a non-anticipated monetary policy shock in period 5, blue line in Figure (5). As expected, the economy does not react until period 5, when the shock materializes, and, as depicted in the lower-right graph of the figure agents never expected the increase to take place.

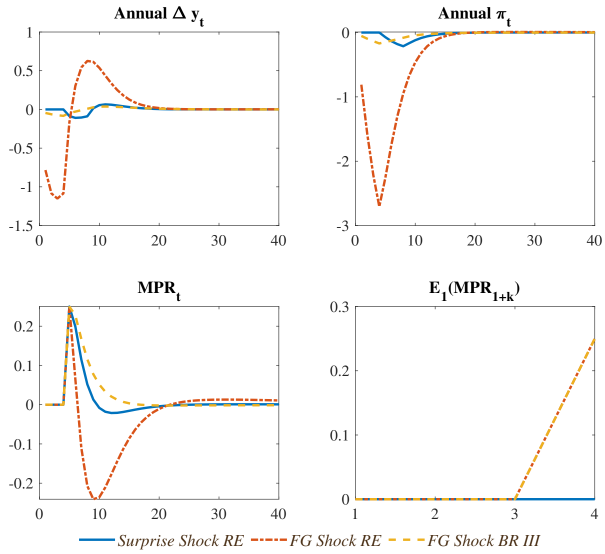

Figure 5: Monetary Policy surprise vs forward guidance announcement.

The problem with implementing this type of shock, besides the unrealistic non-effect until the realization, is that it introduces an asymmetry between the agents inhabiting this economy and the researcher who implements it in the model, since the researcher would know in advance something no one else is aware of. To solve this issue one would like to implement a forward guidance shock, in this case stating that the interest rate is to stay unchanged until period 5 when it would increase 25bp. We implement this shock for the 'RE' version of our model, i.e. the original XMAS model, where we added forward guidance shocks but kept the original estimation and in the behavioral *baseline* model, i.e. 'BR II'. Since the XMAS suffers from the forward guidance puzzle, such an exercise prompts implausible large responses of both activity and inflation, as shown by the red point-dash line. However, in the context of the behavioral model, we obtain a reasonable response and successfully resolve the issues at hand.[34]

5.3 Dynamics

One of the first things we are interested in verifying is whether the implemented *system prior* actually had an effect on the targeted impulse response functions. The explicit purpose of our

[34]The surprise monetary policy shock is simulated in the 'RE' model. Note, in addition, that that IRF need not to be similar to the one generated by a FG shock, since the latter is produced by the behavioral model. Our system prior imposes similarity of the two IRFs within a model.

system prior was to guide the model into delivering conventional monetary policy and forward guidance IRFs on both inflation and activity that, in accordance with the evidence, were similar to each other.

Figure (6) shows us that is indeed the case. To see more clearly that this was the result of using a system prior, we plot in figure (7) the IRFs that of the same model when it is estimated without a system prior and only with the original time series. As we can observe, the trajectories are extremely different from each other, in fact, this estimated model still suffers from the forward guidance puzzle.[35]

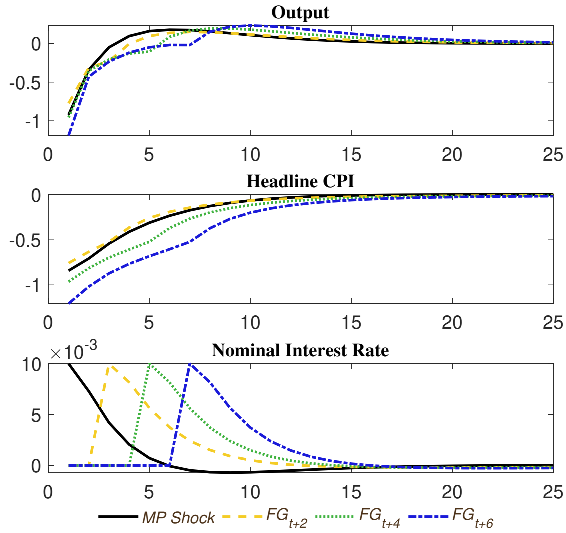

Figure 6: Effect of system priors on model's IRFs.

In what follows we will look into different dimensions of the model's dynamics in order to try gaining a better picture of is properties and performance. We begin with the ability of the model to replicate the moments found in the data.

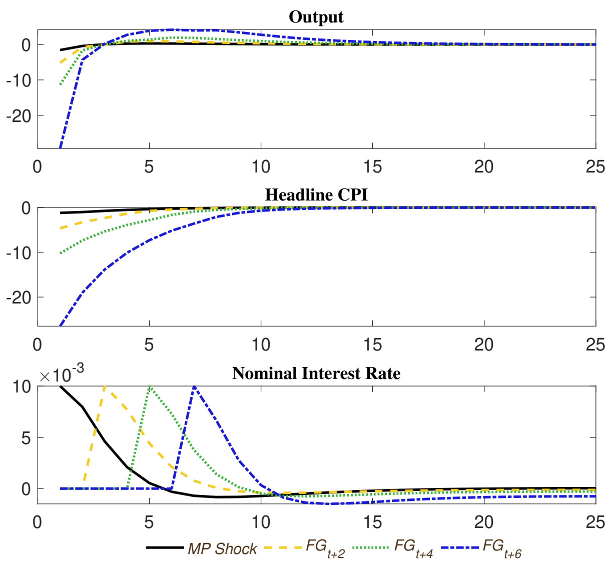

Figure 7: IRFs of baseline model estimated without system prior.

Table (5) summarizes a series of relevant second moments for both the *baseline* and the *benchmark* models and presents them next to the ones of the data. Both models perform well - except for the ability to match a number of correlations with activity - and very similarly.

Tables (6) through (8), in turn, present the forecast error variance decomposition of output, inflation and the nominal interest rate for, again, both the *baseline* and the *benchmark* models and for various horizons. As should be expected from the manner in which cognitive discounting was introduced, namely only affecting future expected deviations generated by forward guidance shocks, there are no dramatic

[35] For completeness, we also computed the same IRFs for the 'RE' model extended to include forward guidance shocks; see Figure (16) in the appendix. There, we can see the huge divergence between them as a consequence of the forward guidance puzzle. Additionally, Figure (17) presents the responses when forward guidance is about the real interest rate instead of the nominal one.

changes. In general, forward guidance shocks account for a modest fraction of the overall variance of the model, being its contribution highest for the nominal interest rate - almost 5%. Conventional monetary policy, on the other hand, decreases its contribution to inflation and output and stays about the same for the monetary policy rate. For activity, demand shocks do become more relevant, whereas for inflation, they stay about the same.

		s.d. (%)			Corr. with Activity			AC order 1		
	Description	data	RE	BR III	data	RE	BR III	data	RE	BR III
$\Delta \log Y$	GDP growth*	0.98	0.96	0.97	0.92	0.92	0.92	0.31	0.00	0.03
$\Delta \log Y^{NCo}$	Non-Mining GDP growth	1.07	0.99	0.99	1.00	1.00	1.00	0.29	0.02	0.06
$\Delta \log Y^{Co}$	Mining GDP growth	3.04	3.03	3.03	-0.05	0.07	0.07	-0.14	-0.08	-0.08
$\Delta \log C$	Private consumption growth	1.11	1.17	1.16	0.74	0.62	0.64	0.41	0.26	0.26
$\Delta \log C^G$	Gov. consumption growth	1.35	1.45	1.44	-0.12	0.16	0.16	-0.19	-0.00	0.00
$\Delta \log TR^G$	Gov. real transfers growth	3.17	3.15	3.12	-0.08	0.13	0.13	-0.43	-0.09	-0.08
$\Delta \log I$	Total investment growth	3.75	3.71	3.69	0.55	0.82	0.83	0.36	0.27	0.26
$\Delta \log I^G$	Gov. investment growth	13.6	12.95	12.87	-0.18	0.63	0.61	-0.46	-0.39	-0.39
$\Delta \log I^{Co}$	Mining investment growth	8.80	8.60	8.41	0.22	0.13	0.13	0.42	0.81	0.81
TB/Y	Nom. trade balance/GDP	5.17	3.32	3.32	0.37	-0.06	-0.08	0.78	0.88	0.88
$\Delta \log N$	Employment growth	0.42	0.37	0.37	0.46	0.41	0.42	0.25	0.35	0.36
$\Delta \log H$	Hours per employee growth	1.35	1.68	1.68	0.34	0.76	0.75	-0.63	-0.13	-0.10
$\Delta \log HN$	Total Hours growth*	1.37	1.81	1.81	0.47	0.80	0.79	-0.56	-0.07	-0.04
$\Delta \log WN$	Nominal wage growth	0.38	0.76	0.77	-0.11	0.27	0.32	0.52	0.67	0.66
$\Delta \log W$	Real wage growth*	0.63	0.59	0.61	-0.08	0.25	0.27	0.43	0.36	0.39
π	Headline inflation*	0.67	0.73	0.70	-0.19	0.07	0.12	0.59	0.53	0.53
π^Z	Core inflation	0.49	0.57	0.54	-0.19	0.13	0.17	0.59	0.77	0.78
π^A	Food inflation	1.39	1.44	1.42	-0.24	-0.07	-0.04	0.53	0.09	0.08
π^O	Fuel inflation	5.37	5.49	5.41	0.32	0.05	0.07	0.08	0.24	0.23
R	Nominal interest rate	0.40	0.45	0.43	-0.26	-0.09	-0.06	0.88	0.91	0.89
rer	Real exchange rate	5.01	5.85	5.89	-0.22	0.02	0.02	0.75	0.85	0.87
π^S	Nominal depreciation*	5.12	4.94	4.78	-0.27	0.07	0.07	0.22	-0.03	-0.02

Table 5: Second moments. The model moments are the theoretical moments at the posterior mean. *, not observed in XMAS.

For the nominal interest rate, both supply and demand appear to be somewhat less responsible for its variance, whereas labor and foreign shocks - and the above mentioned forward guidance shocks - modestly increase their participation.

	BR III				RE			
	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞
Supply	25.37	24.59	23.91	23.91	26.86	25.15	24.64	24.64
Demand	42.88	37.00	38.32	38.32	36.83	31.42	33.14	33.14
Labor	2.41	1.92	1.95	1.95	2.82	2.25	2.29	2.29
Foreign	2.31	2.57	3.58	3.60	2.12	2.63	3.01	3.02
Fiscal policy	25.71	32.71	30.85	30.84	28.62	36.16	34.32	34.41
Interest rate	1.06	0.95	1.04	1.04	2.61	2.24	2.41	2.41
FG	0.16	0.15	0.20	0.20	–	–	–	–
Other	0.11	0.11	0.15	0.15	0.15	0.15	0.19	0.19

Table 6: Variance decomposition - output. Numbers express percentage contributions; columns - for each variable - add up to 100.

	BR III				RE			
	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞
Supply	25.91	11.52	9.00	9.03	27.44	14.75	11.78	11.80
Demand	13.20	27.21	31.85	31.84	11.36	26.53	32.27	32.25
Labor	4.07	6.42	5.80	5.78	3.45	5.17	4.56	4.55
Foreign	49.05	47.77	45.15	45.11	47.31	43.15	40.55	40.52
Fiscal policy	5.05	2.05	1.81	1.81	6.57	3.00	2.56	2.56
Interest rate	2.32	4.22	4.78	4.76	3.84	7.38	8.19	8.17
FG	0.39	0.80	1.50	1.51	–	–	–	–
Other	0.01	0.02	0.10	0.16	0.01	0.02	0.10	0.14

Table 7: Variance decomposition - Inflation. Numbers express percentage contributions; columns - for each variable - add up to 100.

All these results contrast with Mueller et al. (2020), who find that forward guidance shocks account for about 5% of output movements and for about 3% of inflation. In their work, it should be noticed, their discount factor akin our CD factors - which appears only in the Euler equation - is estimated to be virtually 1, rendering the model a rational expectations one. Here one should keep in mind that the experience with forward guidance in Europe, relative to the one in Chile, meaning frequency and magnitude of announcements, could be a relevant dimension that we are not controlling for.

	BR III				RE			
	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞
Supply	4.83	3.16	2.53	2.82	6.50	5.75	4.92	5.11
Demand	31.92	45.55	49.83	49.45	29.10	47.46	54.79	54.45
Labor	3.11	4.84	4.14	4.07	2.51	3.85	3.28	3.25
Foreign	20.67	30.49	29.94	29.98	20.86	28.32	26.67	26.69
Fiscal policy	3.03	1.02	0.69	0.68	3.25	1.23	0.89	0.88
Interest rate	35.74	12.47	7.52	7.39	37.74	13.36	9.00	8.90
FG	0.68	2.46	4.93	4.88	–	–	–	–
Other	0.04	0.02	0.04	2.16	0.07	0.02	0.46	0.72

Table 8: Variance decomposition - nominal interest rate. Numbers express percentage contributions; columns - for each variable - add up to 100.

We also consider the role of forward guidance in agents' expectations, as they are directly affected by them. Table (10) in the appendix, reports the variance decomposition for households expected one- and two-years ahead nominal interest rate and inflation. There, we can observe that, specially for the nominal interest rate two years ahead, forward guidance becomes an important driver. This is not surprising, since it is precisely in the future when this shocks hit.[36]

Next we take a look at how the introduction of forward guidance shocks together with cognitive discounting modifies the historic shock decomposition inferred by our DSGE model. All

[36]The variance decomposition corresponds to the expectations held by Ricardian households.

figures, except otherwise stated, depict the inference of the *benchmark* model on the top plot, 'RE', and of the *baseline* on the bottom, 'BR'. Grey vertical bars across the whole plots denote the monetary policy effective lower bound (ELB) periods along the studied sample, the dashed vertical line denotes the start of the MPR cut cycle during the financial crises and the solid black line denotes the corresponding variable being decomposed.

Figure (8) shows the decomposition for the short-term nominal interest rate, the effective monetary policy rate (MPR). All shocks present a rather similar evolution along the sample as read by both models. The role of forward guidance shocks, which play a visible role, appear to have helped pull the MPR downwards during the ELB periods, and even during the relatively high inflation of 2015.

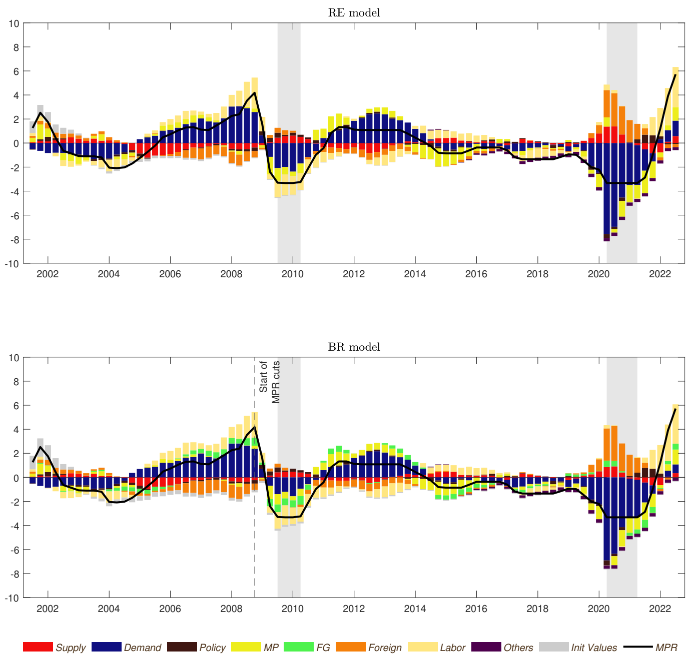

Figure 8: Historical Shock Decomposition - Nominal Interest Rate, 'RE' (top panel) and 'BR III' (bottom panel)

Conventional monetary policy shocks explain relatively less than under 'RE', as one can infer that part of their role was taken over by the forward guidance shocks, in line with the results in Table (8).[37] All and all, forward guidance shocks are difficult to read, since the realization of these type of shocks - as it is anticipated - affects not only the present and the future (through the model's endogenous propagation) but also before - up to eight periods before in the case of a 2-year ahead future monetary policy announcement.

Another issue to take into account at this point, is that forward guidance shocks in the model, as they are constructed, will capture the subjective interpretation of the agents of events that are compatible in their view with future monetary policy announcements. This implies, among other things, that explicit monetary policy announcements may not be fully captured - e.g. if they were not deemed credible - or implicit signals or even signals not intended as forward guidance shocks, such as an emergency meeting of the board, or the tone and wording of a particular speech could be construed as forward guidance shocks.

[37] These shocks are relatively similar under both RE and BR - see Figure (??) in the appendix - though under RE they do display a larger unconditional variance in line with their higher estimated auto-regressive persistence.

Figure (9) plots the shock decomposition for inflation. Particularly during the ELB periods - specially during the latter one - forward guidance shocks appear to have helped push inflation upwards as one would expect.

Around the financial crisis and its aftermath their role was not that clear. As the start of the MPR cut cycle took place, they were positively contributing to increasing inflation. Again, during 2015, a period in which the Central Bank tolerated higher inflation than usual as activity was weak (see Figure (10)), forward guidance shocks appear to have generated some inflation. That seems reasonable, as at the time, there was no clear understanding of whether the Bank was correctly pursuing its inflation target.

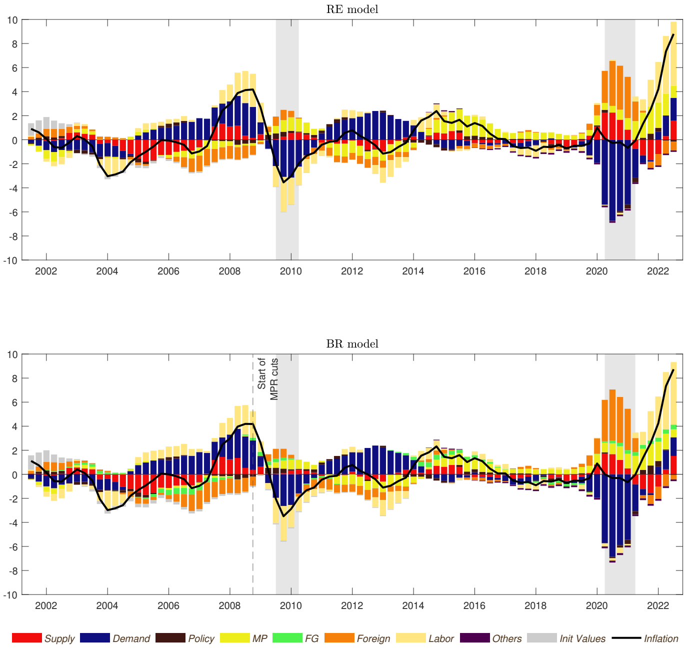

Figure 9: Historical Shock Decomposition - Headline CPI,'RE' (top panel) and 'BR III' (bottom panel)

Finally, Figure (11) depicts the historic shock decomposition for the one-year-ahead expected monetary policy rate. The top graph plots the households' expectations, whereas the lower graph plots the aggregate model's expectations. They clearly show, how households, given their cognitive discounting, barely - if at all - perceive expected deviations generated by future monetary policy announcements. The aggregate model's expectations include the actual effect of these shocks, accounting, in particular, for the views of all types of agents within the model.

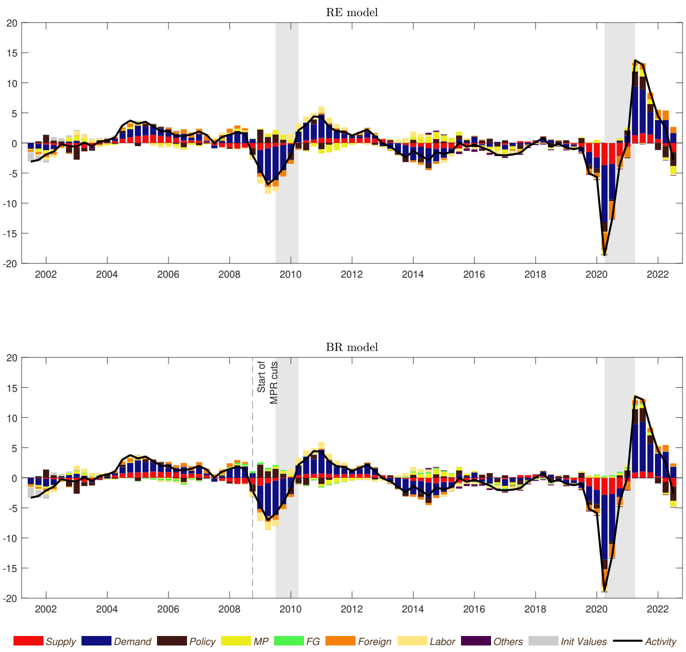

Figure 10: Historical Shock Decomposition - Output Growth,'RE' (top panel) and 'BR III' (bottom panel)

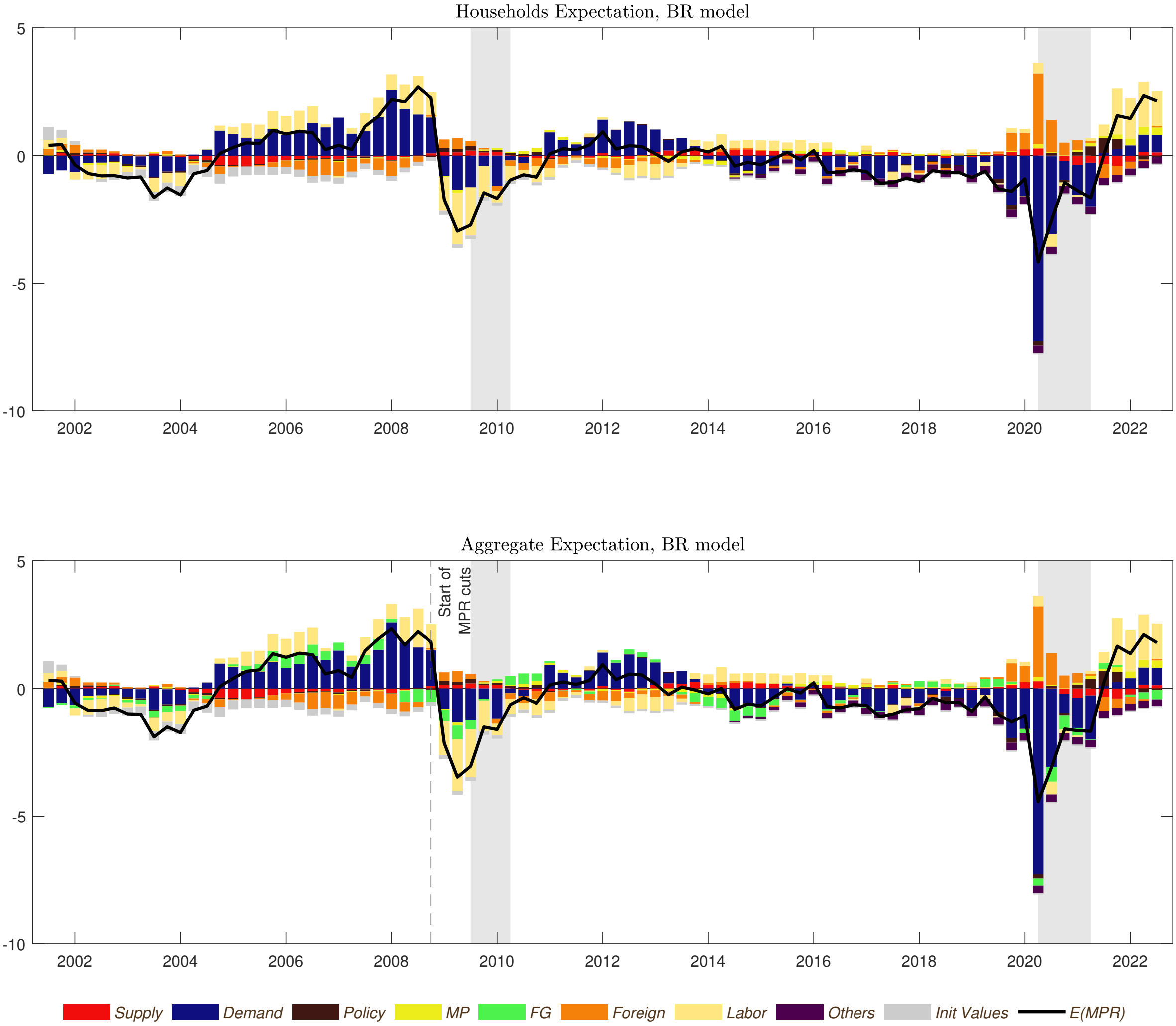

Figure 11: Historical Shock Decomposition - Expected MPR

magnitude is smaller; see Figure (10).

We end this section by considering several IRFs for the main macro-variables and, again, for our two main model versions, the ‘RE’ (blue lines) and the ‘BR II’ (red lines). Figure (12) depicts the effects of a conventional monetary policy (CMP) shock, while Figure (14) depicts the effects of a transitory technology shock. Again, dynamics do not differ much from each other, stressing that this strategy for introducing forward guidance shocks into an already working model which suffers the forward guidance puzzle is not only effective, but constitutes a barely disruptive strategy. This is a very much valued feature as changes in the interpretation of past events may be difficult to communicate.

IRFs corresponding to a preference shock and to a foreign interest rate are shown in the appendix; see Figures (19) and (20) respectively. for these cases, some more substantial differences appear.

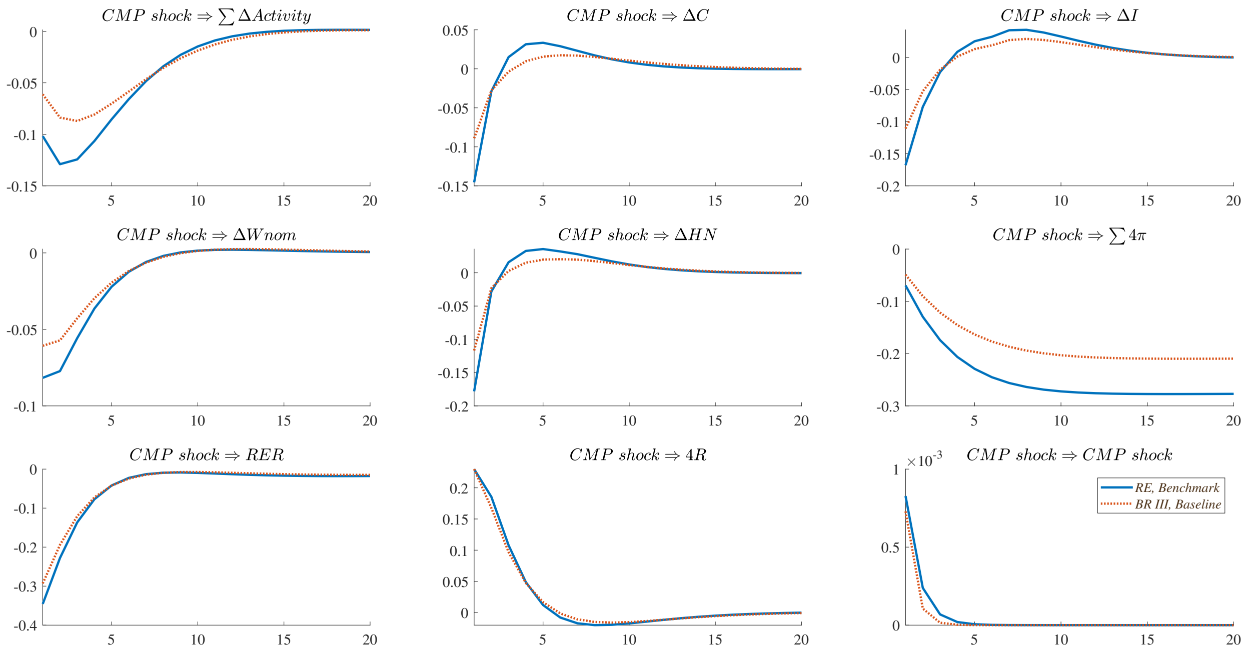

Figure 12: IRFs to a Monetary Policy Shock.

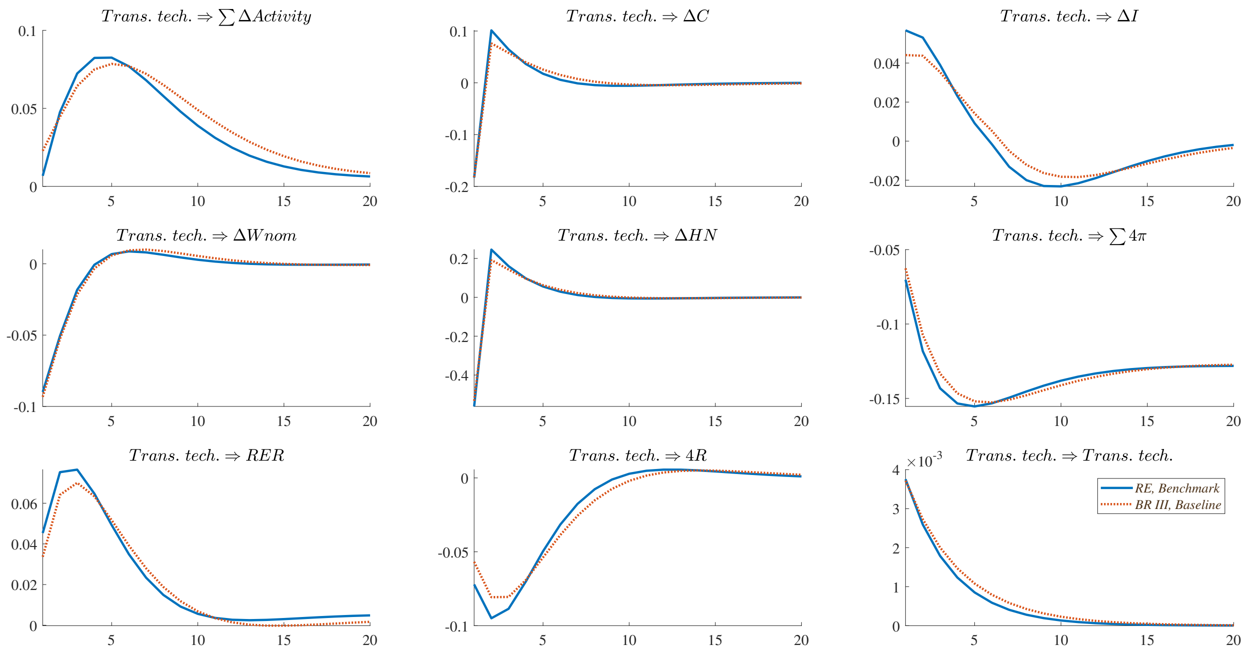

Figure 13: IRFs to a Transitory Technology Shock.

5.4 Extending cognitive discounting and the use of data on expectations

In this sub-section we extend cognitive discounting to the whole model. That is, we present a version that features cognitive discounting not only for the future events generated by monetary policy announcements but for all future events. This version, which nests that of Gabaix (2020), allows for agents to entertain two different degrees of cognitive discounting depending on whether the shock that triggers an expected future deviation from steady state was a forward guidance shock or not.

Let us first describe how to implement this specification. We begin by considering again two models as in section (3.1), a DSGE model M featuring forward guidance shocks and a model $M^\star$ equal to M but without those shocks. The idea now is that when a non-forward guidance shock hits, agents also discount the expected deviations from steady state it generates. This can be easily achieved by assuming that agents' behavioral expectations in model M are given by

$$E_t^{BR}[x_{t+k} - \bar{x}] = m_{fg}^k(E_t[x_{t+k}|M] - E_t[x_{t+k}|M^\star]) + m^k(E_t[x_{t+k}|M^\star] - \bar{x}) \qquad (11)$$

Then, when a forward guidance shock hits the economy, agents' expectations collapse to $m_{fg}^k(E_t[x_{t+k}|M]-\bar{x})$, and when a non forward guidance shock hits, they collapse to $m^k(E_t[x_{t+k}|M^\star]-\bar{x})$. That is, m_{fg} captures the discounting associated to forward guidance triggered events due to cognitive and, say, certainty reasons, while m captures the cognitive considerations proposed by the behavioral approach in Gabaix (2020).

Table (9) reports the results. As already anticipated, while the estimated values for the cognitive discount factors associated to forward guidance remain similar to those of our baseline version, the cognitive discount factors associated to the rest of the events are virtually 1.[38] This reinforces the idea that future events triggered by forward guidance shocks should not be treated as events generated by non-forward guidance shocks.

Following a growing trend in the estimation of macro models, we further estimate the model adding data on expectations as observables and contrast those estimations with our main results. For this, we use professional forecasters' expectations (PFE) on future interest rates and inflation one and two years ahead. Unfortunately, households and/or firms expectations are not available. The data corresponds to the median answer from the Economic Expectations Survey, run by the Central Bank of Chile, and we use the available data for the same sample period we run the previous estimations, from 2001Q3 until 2017Q2.

Our behavioral model features heterogeneous expectations - except for 'BR I', which has a unique common CD factor - requiring us to make an assumption about which model expectations should be matched to the data. We consider three alternatives: one that matches observed forecasts to households' expectations (HH), one that matches them to firms' expectations (FF), and one that matches them to an ad-hoc "professsional froecaster" who has its own cognitive

[38] All priors for cognitive discount parameters are set to a $beta(0.5, 0.25)$ distribution.

discount parameter (PF). We run several versions, considering both models with cognitive discounting only for forward guidance triggered expected future events - our base specifications - and for full cognitive discount versions as above.

As some works have found, e.g. Mueller et al. (2020), we find that by matching households' or firms' expectations to PFE data drives the corresponding cognitive discount parameter's estimate close to 1. However, those versions are dominated, in term of marginal data density, by the one in which PFE data is imputed to an ad-hoc "professional forecaster." In addition, assuming that PFE represents households' or firms' expectations creates other problems, such as rendering the investment technology shock the only explanation for investment dynamics in our model. Moreover, it seems that the estimated models do not solve the forward guidance puzzle (although matching households' expectations to PFE data, does help mitigate its power as it contains the Euler equation).

CD factor	Details	Prior	full-CD I			full-CD III		
			mean	5%	95%	mean	5%	95%
M_C^{fg}	Common CD factor	$beta(0.5, 0.25)$	0.56	0.50	0.63	-	-	-
M_{HH}^{fg}	Ricardian Households/Unions	$beta(0.5, 0.25)$	-	-	-	0.33	0.02	0.62
M_{FF}^{fg}	Firms and Mutual funds	$beta(0.5, 0.25)$	-	-	-	0.49	0.41	0.58
M_{CC}^{fg}	Copper firm	$beta(0.5, 0.25)$	-	-	-	0.89	0.74	0.99
M_C	Common CD factor	$beta(0.5, 0.25)$	0.97	0.96	0.98	-	-	-
M_{HH}	CD Households/Unions	$beta(0.5, 0.25)$	-	-	-	0.92	0.87	0.97
M_{FF}	CD Firms and MF	$beta(0.5, 0.25)$	-	-	-	0.99	0.98	0.99
M_{CC}	CD Copper firm	$beta(0.5, 0.25)$	-	-	-	0.78	0.53	0.99
Laplace approximation			-3050.3			-3023.64		
Marginal data density			-3057.07			-3022.6		

Table 9: Cognitive discount estimates for full cognitive discounting versions. ^{fg} denotes discount factors associated to forward guidance triggered future events.

Finally, Figure (14) shows how the dynamics of both our baseline model and the one featuring full cognitive discounting are very similar to each other. This is again to be expected as the estimated cognitive discount parameters of non-forward guidance triggered expected future deviations are close to unity, and thus very close to the baseline scenario. The graph follows the spirit of Figure (2) in Del Negro et al. (2023) and shows - though because of the endogenous reaction of the Taylor rule not as clearly - how cognitive discounting copes with the forward guidance puzzle.

6 Conclusions

After being central for monetary policy during the effective lower bound period following the financial crisis, forward guidance continues to be used by central banks as rates are increased to curb inflation. Yet, and notwithstanding the inability of standard monetary DSGE models

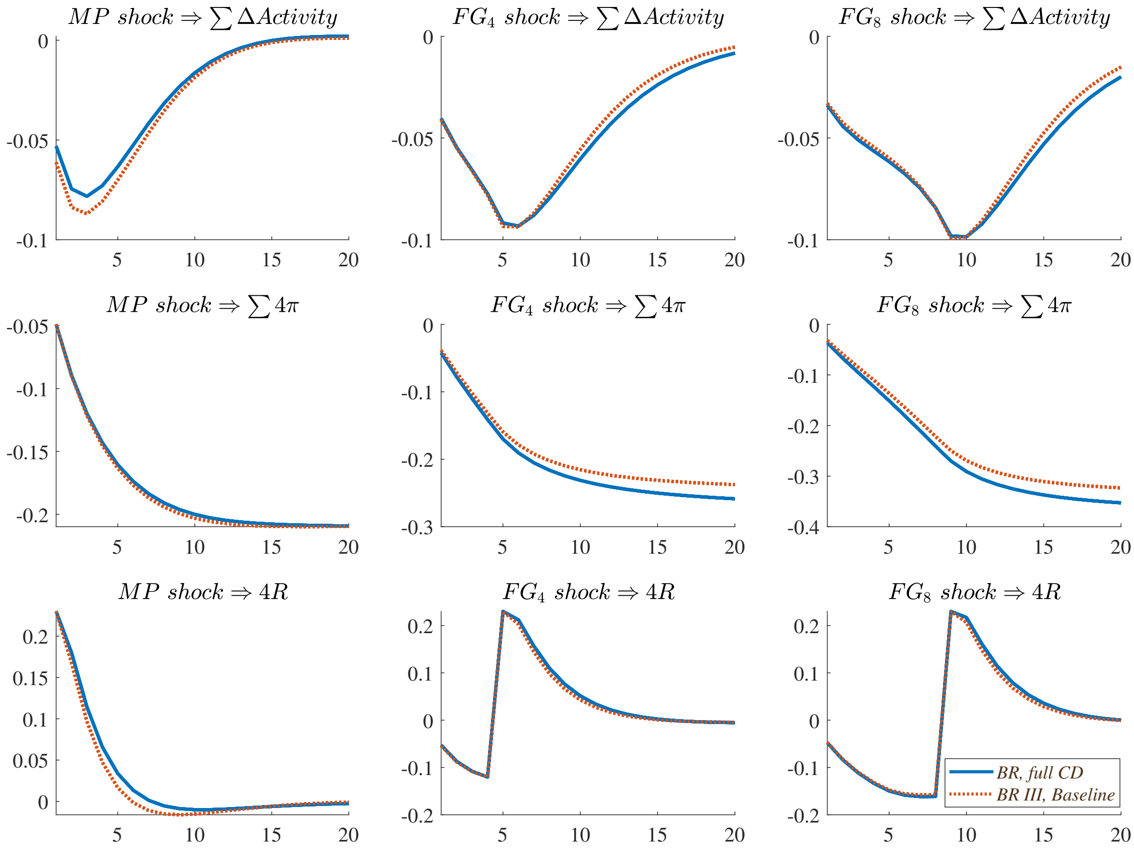

Figure 14: IRFs to different monetary shocks.

to accommodate this type of policies, empirical tests of the literature's several proposals to circumvent this limitation remain scarce.

In this context, we introduce cognitive discounting, a behavioral approach proposed by Gabaix (2020), into a full-fledged monetary DSGE model and test its ability to cope with the forward guidance puzzle. We find that crucial for its successful implementation is endowing agents with a specific discount factor for expectations deviations triggered by future monetary policy announcements. This is achieved - in a linear(ized) model - by introducing of a novel shock-dependent focal point. The idea behind is that the nature of forward guidance shocks is different from that of the other shocks in the model, as they have effects before they materialize and agents might have uncertainty concerns among other considerations. The data appears to agree with this idea as it favors a higher degree of discounting for the forward guidance-generated future events than for the rest.

The estimation assumes system priors, which play a major role in disciplining our behavioral model. They guide the IRFs of conventional monetary policy and forward guidance shocks to be close to each other, and are responsible for the estimation of the strong discounting of future effects of forward guidance. Using data on expectations we find that professional forecasters' expectations are consistent with rational ones and, therefore, unrepresentative of households and firms.

The behavioral model adjusts significantly better to the data and it does so by estimating roughly similar structural parameters to those of the original model under rational expectations. As such, this strategy for introducing forward guidance into a standard monetary model constitutes a rather non-disruptive alternative.

Though cognitive discounting as a whole is found to help improve the model's fit to the data, forward guidance shocks together with their specific cognitive discount factors are the ones responsible for most of that improvement, accounting for about 90%.

Perhaps an important message of this paper is that there is still much to learn about how to implement cognitive discounting in practice. Though a very promising hypothesis, as most deviations from rational expectations, it allows for some flexibility in its formulation that needs to be systematically and carefully explored.

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Appendix

A Complementary results

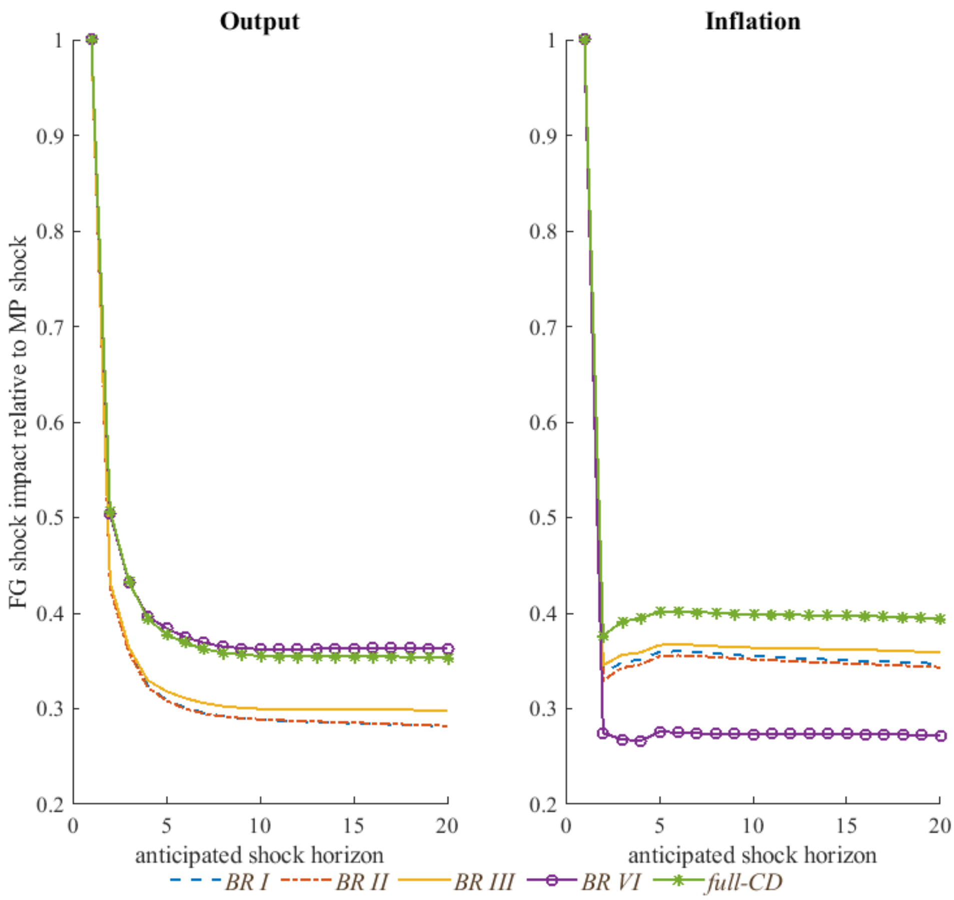

Figure 15: Forward guidance relative impact; main versions.

The graphs plots the impact on activity and inflation of a FG shock about the real interest rate - keeping it unchanged until it is changed at an increasing horizon - relative to the impact of a conventional monetary policy shock of the same magnitude.

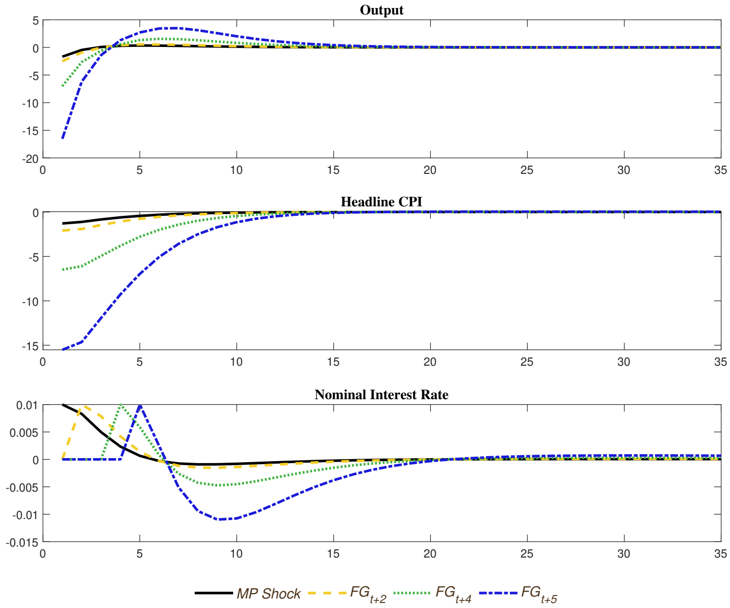

Figure 16: Conventional Monetary Policy and FG shocks in X-MAS under rational expectations.

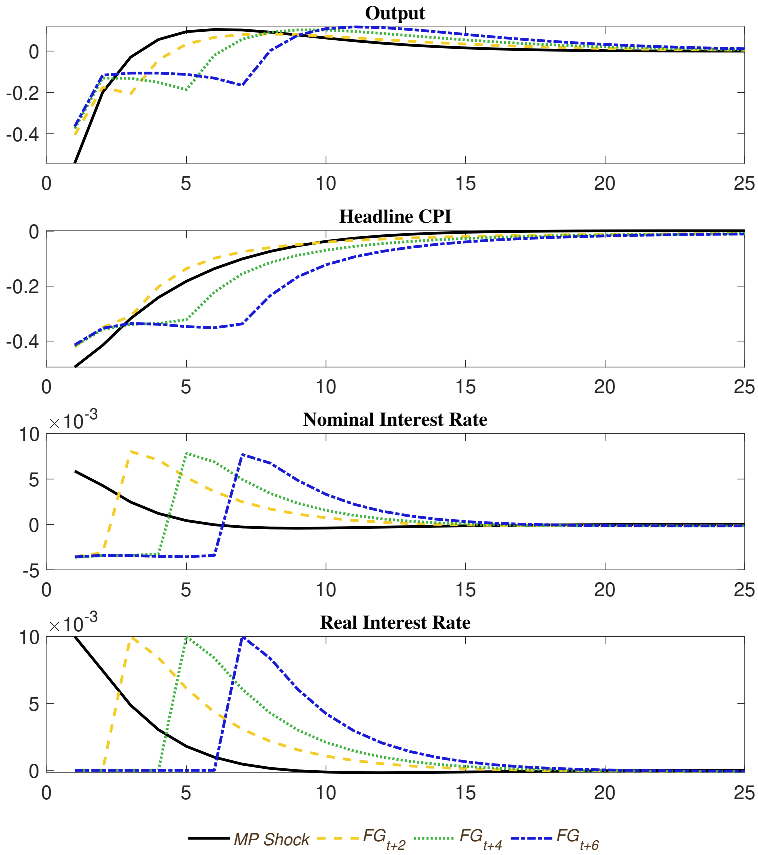

Figure 17: Real interest rate and real rate FG shocks in behavioral X-MAS model; BR III.

	$E_t(R_{t+4})$								$E_t(\pi_{t+4})$							
	Baseline				Benchmark				Baseline				Benchmark			
	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞
Supply	1.32	0.87	1.70	2.36	3.49	2.64	3.36	3.91	3.44	2.69	3.26	3.37	4.94	3.64	4.34	4.45
Demand	53.37	55.71	55.95	54.85	65.31	71.63	68.88	67.58	40.82	42.33	41.40	41.30	47.28	48.60	46.66	46.53
Labor	4.60	3.81	3.12	3.01	3.35	2.63	2.17	2.11	7.71	5.98	5.39	5.35	4.70	3.19	3.04	3.02
Foreign	34.27	31.02	29.07	29.29	27.39	22.52	23.43	23.62	40.36	39.90	40.21	40.17	31.42	32.42	33.98	33.95
Policy	0.30	0.24	0.21	0.20	0.34	0.27	0.23	0.22	0.68	1.17	1.17	1.16	0.65	1.40	1.46	1.45
Interest Rate	0.32	0.20	0.39	0.37	0.11	0.28	0.53	0.52	5.75	5.97	5.85	5.81	10.98	10.73	10.20	10.14
Forward Guidance	5.82	8.13	8.44	8.24	–	–	–	–	1.20	1.93	2.49	2.50	–	–	–	–
Other	0.01	0.02	1.11	1.67	0.01	0.03	1.40	2.04	0.03	0.17	0.22	0.33	0.02	0.02	0.31	0.45
	$E_t(R_{t+8})$								$E_t(\pi_{t+8})$							
	Baseline				Benchmark				Baseline				Benchmark			
	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞	t_1	t_4	t_{40}	∞
Supply	0.21	0.53	4.76	6.65	1.00	1.67	6.40	8.22	4.85	7.28	8.98	9.62	5.01	8.50	10.61	11.20
Demand	64.76	70.41	56.51	52.38	91.65	86.86	57.77	53.86	43.11	41.22	34.71	31.88	50.23	41.34	29.57	29.25
Labor	1.64	1.10	0.78	0.71	0.52	0.28	0.35	0.34	0.16	0.49	1.09	1.04	0.29	1.50	1.68	1.60
Foreign	16.81	11.58	22.43	24.27	4.57	7.94	26.90	27.38	35.81	34.28	43.10	42.71	30.76	36.83	47.59	46.74
Fiscal Policy	1.51	1.37	0.97	0.91	0.10	0.07	0.05	0.5	4.65	6.49	5.01	2.52	3.37	2.98	1.99	1.89
Interest Rate	0.83	1.23	0.98	0.86	1.89	2.26	1.49	1.32	6.76	6.39	4.41	4.13	10.22	8.50	5.50	5.23
Forward Guidance	15.47	14.59	9.35	8.56	–	–	–	–	7.75	8.80	6.58	6.37	–	–	–	–
Other	0.15	0.43	5.08	6.46	0.36	0.93	7.04	8.83	0.05	0.19	2.46	3.34	0.12	0.35	3.06	4.09

Table 10: Variance Decomposition - Expectation. Numbers express percentage contributions, columns - for each variable - add up to 100.

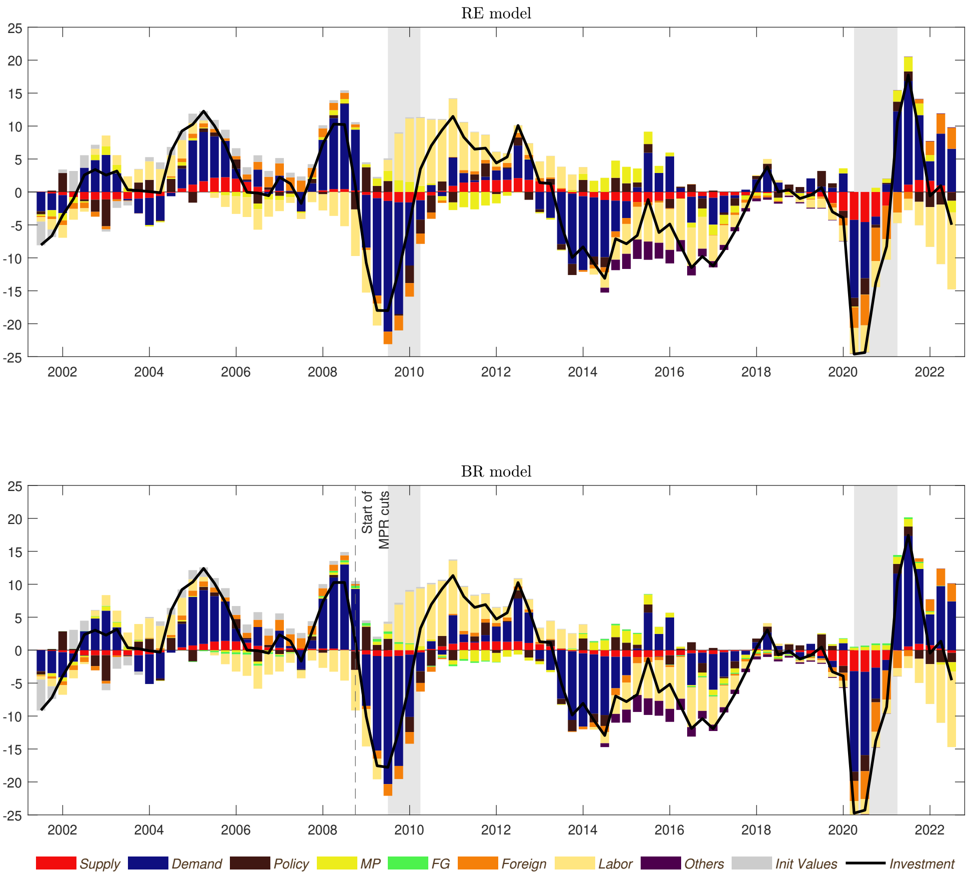

Figure 18: Historical Shock Decomposition - Investment Growth, 'XMAS RE' and 'XMAS BR MF II'

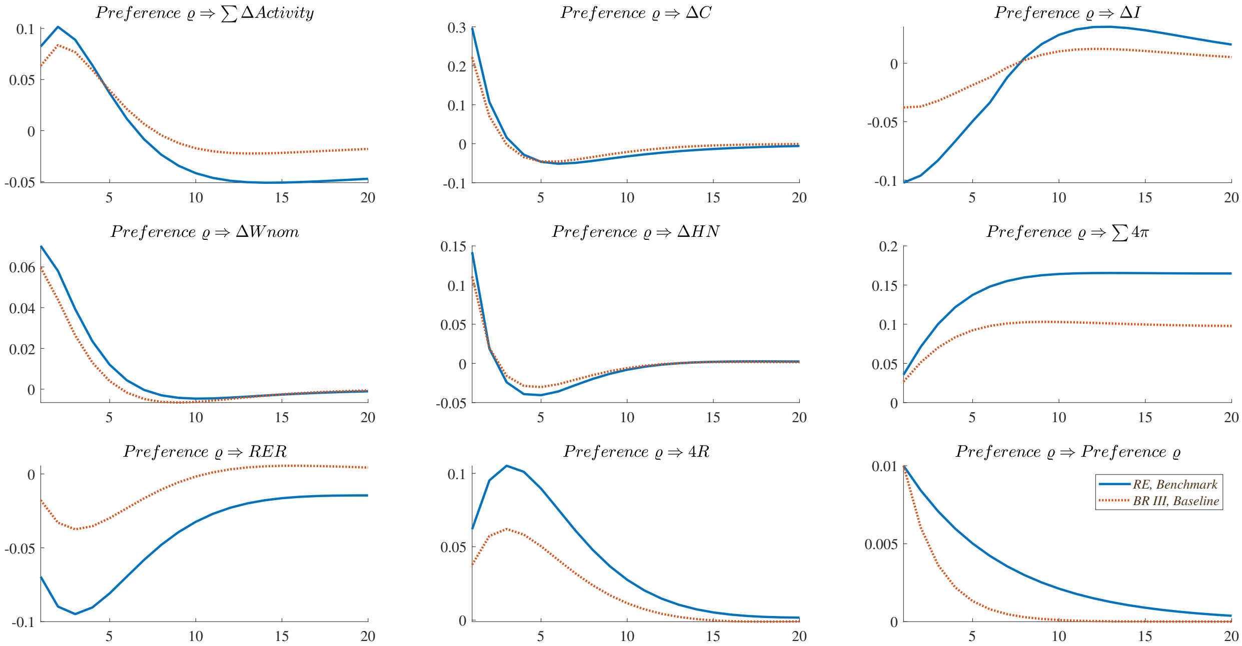

Figure 19: IRFs to a Preferences Shock.

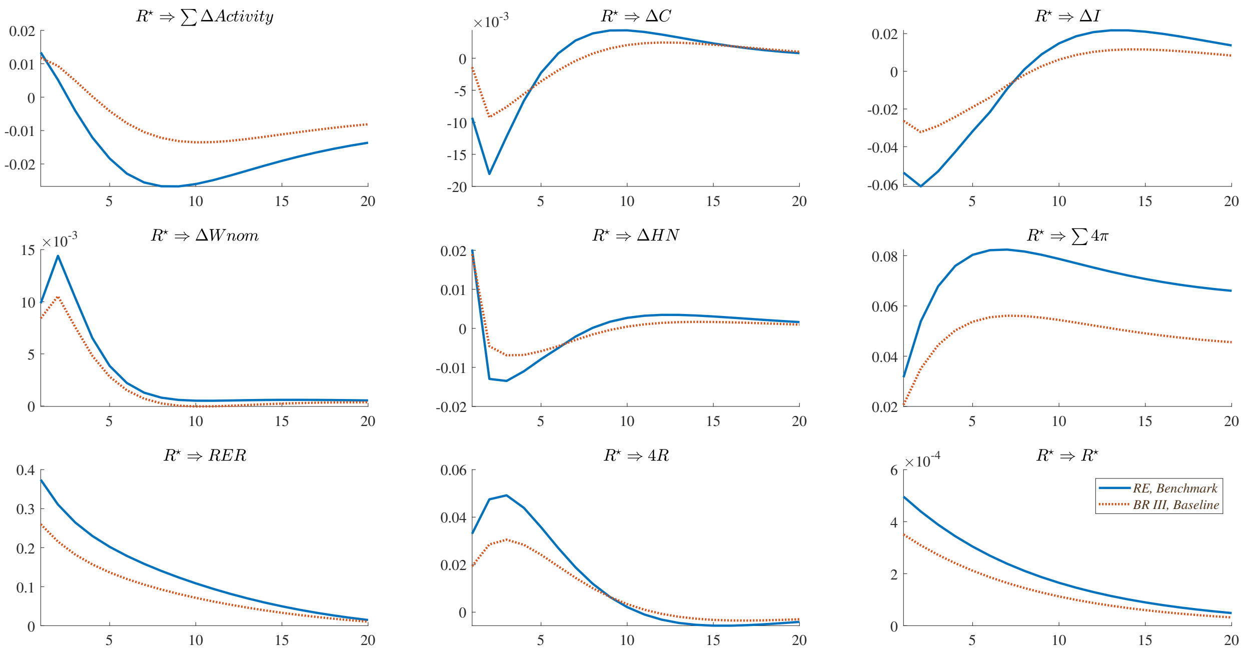

Figure 20: IRFs to a Foreign Monetary Shock.

B Introducing Cognitive Discounting in Dynare

Consider the following simplified Euler equation,

$$\frac{1}{c_t} = \beta E_t \left\{ \frac{r_t}{c_{t+1}} \right\}$$

In order to introduce cognitive discounting into this equation, one should proceed by, first, linearizing it and, then, by replacing the rational expectations operator (RE) with the one under the bounded rationality hypothesis (BR) that assumes cognitive discounting. That is,

1. linearizing we can write

$$-\left(\frac{c_t - c_{ss}}{c_{ss}^2}\right) = \frac{\beta}{c_{ss}}\left(r_t - r_{ss}\right) - \beta r_{ss}\left(\frac{c_{t+1} - c_{ss}}{c_{ss}^2}\right) \tag{12}$$

$\Rightarrow$

$$\hat{c}_t = E_t\left(\hat{c}_{t+1}\right) - \hat{r}_t \tag{13}$$

2. substituting BR for RE, where BR is defined as:

$$E_t^{BR}\left(x_{t+1}\right) = x_t^{pf} + m\left(E_t\left(x_{t+1}\right) - x_t^{pf}\right) = \left(1-m\right)x_t^{pf} + mE_t\left(x_{t+1}\right) \tag{14}$$

we get,

$$\hat{c}_t = E_t^{BR}\left(\hat{c}_{t+1}\right) - \hat{r}_t$$

$\Rightarrow$

$$\begin{aligned}
\hat{c}_t &= \frac{\left(1-m\right)c_t^{pf} + mE_t\left(c_{t+1}\right) - c_{ss}}{c_{ss}} - \hat{r}_t \\
&= \frac{1}{c_{ss}}\left(m\left[E_t\left(c_{t+1}\right) - c_t^{pf}\right] + \left(c_t^{pf} - c_{ss}\right)\right) - \hat{r}_t \\
&= mE_t\left(\hat{c}_{t+1}\right) + \left(1-m\right)\hat{c}_t^{pf} - \hat{r}_t
\end{aligned} \tag{15}$$

Alternatively, one can make use of the linearizing step in Dynare when solving a model upon a first-order linearization. This approach, clearly, has two valuable advantages, by avoiding linearizing equations, it dramatically simplifies the introduction of cognitive discounting and it eliminates the possibility of making errors in the linearization step. The idea is to replace rational expectations operator of forward looking variables in the model, say $x(+1)$, with auxiliary variables, e.g. x_{BR}, and, then, to define the latter in such a way that the Dynare linearization delivers the desired specification, e.g. equation (eq:BR$_o rig$).

How can one define the auxiliary variables? as the geometric - instead of the arithmetic - average between the RE operator and the assumed focal point,

$$E_t^{BR}\left(x_{t+1}\right) = x_{BR} = E_t\left(x_{t+1}\right)^m \left(x_t^{pf}\right)^{1-m}$$

In Dynare, we would write the above equation together with our Euler equation, but where we have

c_{BR} instead of $E_t(c_{t+1})$,[39]

$$-\left(\frac{c_t - c_{ss}}{c_{ss}^2}\right) = \frac{\beta}{c_{ss}}(r_t - r_{ss}) - \beta\frac{r_{ss}}{c_{ss}^2}(c_{BR} - c_{ss}) \Rightarrow \frac{c_t - c_{ss}}{c_{ss}} = \frac{c_{BR} - c_{ss}}{c_{ss}} - \frac{r_t - r_{ss}}{r_{ss}}$$

and

$$c_{BR} - c_{ss} = mE_t(c_{t+1} - c_{ss}) - (1-m)\left(c_t^{pf} - c_{ss}\right)$$

combining both equations we obtain

$$\frac{c_t - c_{ss}}{c_{ss}} = \frac{mE_t(c_{t+1} - c_{ss}) - (1-m)\left(c_t^{pf} - c_{ss}\right)}{c_{ss}} - \frac{r_t - r_{ss}}{r_{ss}}$$

or rearranging

$$\hat{c}_t = mE_t(\hat{c}_{t+1}) + (1-m)\hat{c}_t^{pf} - \hat{r}_t \tag{16}$$

which is the same equation as (15).

If a particular variable had 0 as its steady state value, then one could simply define,

$$E_t^{BR}(x_{t+1}) = x_{BR} = E_t(x_{t+1}+1)^m \left(x_t^{pf}+1\right)^{1-m} - 1$$

B.1 Generalizing shock-specific cognitive discount factors

In teh following section we describe how to introduce shock-specific cognitive discount factors into model that is to be solved upon a first-order linearization. Consider a non-linear model with three shocks, suchs as Gali's three equations model with a monetary policy shock (e), a preference shock (g), and a cost-push shock (u). We would like to write the model such that when one of this shocks hits and triggeres a deviation of expected future variables from the steady state/focal point, those deviations will be cognitively discounted with a shock-specific factor. The idea is that different shocks are percieved in different ways and, therefore, subject to diffferent degrees of discounting/attention/credibility/uncertainty. Following our implementation of forward guidance shocks in the X-MAS model, we proceed as follows:

- we consider four models, the original model with all shocks - the base model, call it M, and three auxiliary models M_e, M_g and, M_u which are equal to M except that they do not feature the shock with which they are indexed (e.g., M_e does not feature monetary policy shocks, but does have the preference and the cost-push shocks) - so that the model remains in steady state when that shock hits the base model.
- These auxiliary models will have the pourpose of yielding the focal point associated to each shock and to each cognitive discount parameter.

[39]Note that we assume that the steady state value for c_{BR} is c_{ss}, implying that the steady state value of c_t^{pf} is also c_{ss}. Furthermore, here, r_t is observable in t, if that were not the case, covariance terms would show up, however since we only care about a first order linearization those terms will ultimately disappear.

Expectations in model M, the base one would be gvien by

$$E_t^{BR,M}\left(x_{t+1}\right)=BRMx=E_t\left(x_{t+1}\right)^{m_e+m_g+m_u}\left(x_{t,e}^{pf}\right)^{m_e}\left(x_{t,g}^{pf}\right)^{m_g}\left(x_{t,u}^{pf}\right)^{m_u}$$

and in model, say, M_e

$$E_t^{BR,M_e}\left(x_{t+1}\right)=BRM_ex=E_t\left(x_{t+1}\right)^{m_g+m_u}\left(x_{t,g}^{pf}\right)^{m_g}\left(x_{t,u}^{pf}\right)^{m_u}$$

similarly for the other two auxiliary models. This is easily generalized to a model with n shocks. Assume those shocks were indexed by i, then we would have $n+1$ models, where

$$E_t^{BR,M}\left(x_{t+1}\right)=BRMx=E_t\left(x_{t+1}\right)^{\sum_{i=1}^{n}m_i}\prod_{i=1}^{n}\left(x_{t,i}^{pf}\right)^{m_i}$$

and for model M_i

$$E_t^{BR,M_i}\left(x_{t+1}\right)=BRM_ix=E_t\left(x_{t+1}\right)^{\sum_{j=1\wedge j\neq i}^{n}m_j}\prod_{j=1\wedge j\neq i}^{n}\left(x_{t,j}^{pf}\right)^{m_j}$$

C Mutual Funds

C.1 Ricardian Households

Households in this model decide on how much to work and how much to consume. But only Ricardian households can save and borrow. To that respect, they can buy and sell the shares of the introduced mutual fund, Q_t^R, which pay dividends D_t^R and they decide also how much of the investment good to purchase, (I_t^R), which determines their physical capital stock for next period (K_t^R), and receive dividends $\left(D_t^R\right)$ from the ownership of domestic firms as well as rents $\left(REN_t^{R*}\right)$ due to ownership of firms abroad (the latter are assumed to evolve stochastically according to $ren_t^{R*}=\overline{ren}^{R*}\xi_t^{ren}$, where $\overline{ren}^{R*}\geq 0$ and ξ_t^{ren} is an exogenous process). They pay a tax rate of τ_t^D on dividends and τ_t^K on capital income.

$$E_t\sum_{s=0}^{\infty}\beta^s\varrho_{t+s}\left[\frac{1}{1-\sigma}\left(\widehat{C}_{t+s}^R\right)^{1-\sigma}-n_{t+s}\ell_{t+s}^R\right],\tag{17}$$

They maximize their life-time utility (17), by choosing C_t^R, S_t^R, K_t^R and I_t^R, subject to the following period-by-period budget constraint:

$$\begin{aligned}(1+\tau_t^C)C_t^R+Q_t^SS_t^R&=rer_tREN_t^{R*}+\left(1-\tau_t^D\right)D_t^R+(1-\tau_t^L)W_th_tn_t+(1-n_t)UB_t+\\&\left(Q_{t-1}^S+D_{t-1}^{MF}\right)S_{t-1}^R+TR_t^R-T_t^R+K_{t-1}^R[r_t^K\bar{u}_t\left(1-\tau_t^K\right)+\\&\tau_t^Kp_t^I\left(\delta+\phi_{\bar{u}}\left(\bar{u}_t\right)\right)]p_t^I\left(I_t^R+K_{t-1}^R\phi_{\bar{u}}\left(\bar{u}_t\right)\right)\end{aligned}\tag{18}$$

We allow for the distinction between capital services (denoted as $K_t^{S,R}$) used in the production of goods, and physical units of capital (K_t^R), owned by the households, with a law of motion governed by the investment and depreciation rates. The former is defined as the productive potential of the available physical capital stock for a given utilization rate $\bar{u}_t$ chosen by the households, where

$$K_t^{S,R} = \bar{u}_t K_{t-1}^R \tag{19}$$

We follow **?** by introducing $\phi_{\bar{u}}\left(\bar{u}_t\right) K_{t-1}$, the investment goods used for private capital maintenance, as a part of the total private investment, alongside with the investment goods used for increasing the households physical capital. By assumption, these maintenance costs are deducted from capital taxation, and follow the same structure as in **?**:

$$\phi_{\bar{u}}\left(\bar{u}_t\right) = \frac{r^k}{\Phi_{\bar{u}}}\left(e^{\Phi_{\bar{u}}(\bar{u}_t - 1)} - 1\right) \tag{20}$$

Where the parameter $\Phi_{\bar{u}} \equiv \phi''_{\bar{u}}(1)/\phi'_{\bar{u}}(1) > 0$ governs the importance of these utilization costs. The physical capital stock evolves according to the law of motion:

$$K_t^R = (1-\delta)K_{t-1}^R + \left[1 - \phi_I\left(\frac{I_t^R}{I_{t-1}^R}\right)\right]\varpi_t I_t^R, \tag{21}$$

With depreciation rate $\delta \in (0,1]$, where ϖ_t is an investment shock that captures changes in the efficiency of the investment process **?**, I_t^R denotes capital augmenting investment expenditures, and $\phi_I\left(I_t^R/I_{t-1}^R\right) \equiv (\Phi_I/2)\left(I_t^R/I_{t-1}^R - a\right)^2$are convex investment adjustment costs with elasticity $\Phi_I = \phi''_I(a) \geq 0$.

The problem faced by Ricardian housholds can then be written as,

$$\mathcal{L}_t^R = E_t \sum_{s=0}^{\infty} \beta^s \varrho_{t+s} \left\{ \begin{array}{l} \frac{1}{1-\sigma}\left(\widehat{C}_{t+s}^R\right)^{1-\sigma} - n_{t+s}\Theta_{t+s}^R \kappa_{t+s} \frac{1}{1+\phi}\left(A_{t+s-1}^H\right)^{1-\sigma} h_{t+s}^{1+\phi} \\ +\Lambda_{t+s}^R \left[\begin{array}{l} (1-\tau_{t+s}^L)W_{t+s}h_{t+s}n_{t+s} + (1-n_{t+s})UB_{t+s} + \left(Q_{t+s}^S + D_{t+s}^{MF}\right)S_{t+s-1}^R + \\ TR_{t+s}^R - T_{t+s}^R - (1+\tau_{t+s}^C)C_{t+s}^R - Q_{t+s}^S S_{t+s}^R + K_{t-1}^R[r_t^K \bar{u}_t\left(1-\tau_t^K\right) + \\ \tau_t^K p_t^I\left(\delta + \phi_{\bar{u}}\left(\bar{u}_t\right)\right)] - p_t^I\left(I_t^R + K_{t-1}^R\phi_{\bar{u}}\left(\bar{u}_t\right)\right) + rer_t REN_t^{R*} + \left(1-\tau_t^D\right)D_t^R \end{array} \right] \end{array} \right\}$$

where Λ_t^R denotes the Lagrange multiplier associated with the budget constraint. The household does not decide the amount of hours or wages. That decision is left to a union, that maximizes a ponderated sum of the utilities of Ricardian and non-Ricardian households and decides the amount of hours, which is the same for every cohort and type of household. The corresponding first-order optimality conditions are,

$$
\begin{aligned}
C_t^R \quad &: \quad \Lambda_t^R = \frac{1}{(1+\tau_t^C)}\left(\widehat{C}_t^R\right)^{-\sigma}\left(\frac{\left(1-o_{\widehat{C}}\right)\widehat{C}_t^R}{C_t^R-\varsigma\check{C}_{t-1}^R}\right)^{\frac{1}{\eta_{\widehat{C}}}}, \\
S_t^R \quad &: \quad \Lambda_t^R = M_{HH}\beta E_t\left\{\frac{\varrho_{t+1}}{\varrho_t}\Lambda_{t+1}^R\frac{Q_{t+1}^S+D_{t+1}^{MF}}{Q_t^S}\right\}, \\
K_t^R \quad &: \quad q_t = M_{HH}E_t\left\{\bar{\chi}_{t,t+1}^R\left[\begin{array}{c} r_{t+1}^K\bar{u}_{t+1}\left(1-\tau_{t+1}^K\right)+q_{t+1}(1-\delta) \\ +p_{t+1}^I\left[\tau_{t+1}^K\delta-\phi_{\bar{u}}\left(\bar{u}_{t+1}\right)\left(1-\tau_{t+1}^K\right)\right]\end{array}\right]\right\}, \\
I_t^R \quad &: \quad \frac{p_t^I}{q_t} = \left\{1-\phi_I\left(\frac{I_t^R}{I_{t-1}^R}\right)-\phi_I'\left(\frac{I_t^R}{I_{t-1}^R}\right)\frac{I_t^R}{I_{t-1}^R}\right\}\varpi_t \\
&\qquad + M_{HH}E_t\left\{\bar{\chi}_{t,t+1}^R\frac{q_{t+1}}{q_t}\phi_I'\left(\frac{I_{t+1}^R}{I_t^R}\right)\left(\frac{I_{t+1}^R}{I_t^R}\right)^2\varpi_{t+1}\right\}, \\
\bar{u}_t \quad &: \quad r_t^K = p_t^I\phi_{\bar{u}}'\left(\bar{u}_t\right).
\end{aligned}
$$

we define, in addition, the stochastic discount factor $\bar{\chi}_{t,t+s}^R = \beta^s\frac{\varrho_{t+s}}{\varrho_t}\frac{\Lambda_{t+s}^R}{\Lambda_t^R}$.

C.2 Mutual Funds

The newly introduced mutual funds, in turn, take over the bond allocation decision from households in the original XMAS model. They are, then, in charge of purchasing domestic currency denominated government bonds (B_t^R) and trading foreign currency bonds (B_t^{R*}) with foreign agents, both being non-state contingent assets. r_t, r_t^* denote the gross real returns on B_{t-1}^R and B_{t-1}^{R*}, respectively, and let rer_t be the real exchange rate (i.e. the price of foreign consumption goods in terms of domestic consumption goods).

The mutual fund objective function is to maximize the present discounted value of dividends, where the discount factor is the aggregate stochastic discount factor of the Ricardian households, $\bar{\chi}_{t,t+s}^R = \beta^s\frac{\varrho_{t+s}}{\varrho_t}\frac{\Lambda_{t+s}^R}{\Lambda_t^R}$,

$$
E_t\sum_{s=0}^{\infty}\chi_{t,t+s}^R D_{t+s}^{MF} \tag{22}
$$

The period-by-period budget constraint of the Mutual Fund is then given by

$$
\begin{aligned}
D_t^{MF}S_{t-1}^R &= Q_t^S\left(S_t^R-S_{t-1}^R\right)+ \\
&\quad \left(r_tB_{t-1}^{MF}+r_t^*rer_tB_{t-1}^{MF*}\right)-\left(B_t^{MF}+rer_tB_t^{MF*}\right)
\end{aligned} \tag{23}
$$

The Mutual Fund chooses B_t^R and B_t^{R*} to maximize (22) subject to (23), taking r_t, r_t^*, rer_t, T_t^R, D_t^R

and $\check{C}_t^R$ as given. This intertemporal decision problem is associated with the following Lagrangian:

$$\mathcal{L}_t^{MF} = E_t \sum_{s=0}^{\infty} \bar{\chi}_{t,t+s}^R \left\{ D_{t+s}^{MF} + \Lambda_{t+s}^{MF} \left[\begin{array}{l} Q_{t+s}^S \left(S_{t+s}^R - S_{t+s-1}^R\right) + \\ \left(r_{t+s} B_{t+s-1}^{MF} + r_{t+s}^* rer_{t+s} B_{t+s-1}^{MF*}\right) - \left(B_{t+s}^{MF} + rer_{t+s} B_{t+s}^{MF*}\right) \\ -D_{t+s}^{MF} S_{t+s-1}^R \end{array} \right] \right\}$$

Where Λ_t^R denotes the Lagrange multiplier associated with the budget constraint and $\Lambda_t^R q_t$ denotes the multiplier associated with the law of motion for capital. The corresponding first-order optimality conditions are: [40]

$$B_t^R \quad : \quad 1 = M_{FF} E_t \left\{\bar{\chi}_{t,t+1}^R r_{t+1}\right\}, \tag{24}$$

$$B_t^{R*} \quad : \quad 1 = M_{FF} E_t \left\{\bar{\chi}_{t,t+1}^R \frac{rer_{t+1}}{rer_t} r_{t+1}^*\right\} \tag{25}$$

Notice that from (20) and (??), we can express the optimal utilization rate as a function with a standard deviation inversely proportional to $\Phi_{\bar{u}}$:

$$\bar{u}_t = 1 + \frac{\log\left(\frac{r_t^K}{r^K}\right) - \log\left(p_t^I\right)}{\Phi_{\bar{u}}} \tag{26}$$

The nominal interest rates are implicitly defined as

$$\begin{aligned} r_t &= R_{t-1} \left(\pi_t\right)^{-1}, \\ \pi_t &= \left(\frac{P_t}{P_{t-1}}\right) \frac{1+\tau_t^C}{1+\tau_{t-1}^C} \\ r_t^* &= R_{t-1}^* \xi_{t-1} \left(\pi_t^*\right)^{-1}, \\ \pi_t^* &= \frac{P_t^*}{P_{t-1}^*} \end{aligned}$$

Where π_t and π_t^* denote the gross inflation rates of the domestic and foreign consumption-based price indices, after tax in the domestic case. A debt elastic country premium (ξ_t) is given by:

$$\xi_t = \bar{\xi} \exp\left[-\psi\left(\frac{rer_t B_t^*}{p_t^Y Y_t} - \frac{rerb^*}{p^Y y}\right) + \frac{\zeta_t^O - \zeta^O}{\zeta^O} + \frac{\zeta_t^U - \zeta^U}{\zeta^U}\right], \qquad \psi > 0, \qquad \bar{\xi} \geq 1,$$

Where ζ_t^O and ζ_t^U are respectively observed and unobserved exogenous shocks to the country premium, and ψ denotes the elasticity of the premium to the country's net asset position **??**. The foreign nominal interest rate R_t^* evolves exogenously, whereas the domestic central bank sets R_t. The country net asset position(B_t^*), is composed of private$\left(B_t^{Pr*}\right)$ and government$\left(B_t^{G*}\right)$ net foreign asset holdings:

$$B_t^* = B_t^{Pr*} + B_t^{G*}$$

[40]Note that we use the fact that $S_t^R = 1 \; \forall t$, and the fact that the F.O.C. w.r.t. D_t^{MF} is $\Lambda_t^{MF} = 1$.

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