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The Inverted Leading Indicator Property and Redistribution Effect of the Interest Rate*

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Abstract

The interest rate at which US firms borrow funds has two features: (*i*) it moves in a countercyclical fashion and (*ii*) it is an inverted leading indicator of real economic activity: low interest rates today forecast future booms in GDP, consumption, investment, and employment. We show that a Kiyotaki-Moore model accounts for both properties when interest-rate movements are driven, in a significant way, by self-fulfilling belief shocks that redistribute income away from lenders and to borrowers during booms. The credit-based nature of such self-fulfilling equilibria is shown to be essential: the dynamic correlation between current loanable funds rate and future aggregate economic activity depends critically on the property that the interest rate is state-contingent. Bayesian estimation of our benchmark DSGE model on US data shows that the model driven by redistribution shocks results in a better fit to the data than both standard RBC models and Kiyotaki-Moore type models with unique equilibrium.

Keywords:

Endogenous Collateral Constraints, State-Contingent Interest Rate, Redistribution Shocks, Multiple Equilibria

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JEL codes: E21, E22, E32, E44, E63.

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1 Introduction

The inverted leading indicator property of the borrowing cost is a long-standing puzzle. In US data, low real interest rates are associated with both current and future investment (and output) booms. However, standard real business-cycle (RBC thereafter) models deliver the opposite relationship: high investment and output are associated with a high interest rate (see King and Watson, 1996). The reason behind such counterfactual predictions is rather simple. In such models the real interest rate is dictated by the marginal product of capital, which is proportional to the output-to-capital ratio. Given that output is more cyclical than the capital stock, high output thus always implies a high interest rate regardless of the source of shocks.[1]

In this paper, we tackle this long-standing puzzle by introducing a credit market that channels funds from lenders to borrowers. Due to borrowing constraints *à la* Kiyotaki and Moore (1997) - KM thereafter - the credit market friction creates a wedge between credit supply and credit demand. However, this wedge by itself is not sufficient for the loanable funds rate to be countercyclical because in equilibrium credit demand still depends on the rate of return to capital: the cost of borrowing is still dictated by the benefit of borrowing and investing, that is, by the marginal product of capital, so that high credit demand (associated with high capital returns) results in high interest rates and vice versa. Our main theoretical finding is that if the loan is such that the interest rate is not pre-determined, or set when the loan is negotiated, but instead is state-contingent and responds to changes in aggregate economic conditions when the loan payment is due, then the credit market features an interesting property: when the demand for loans increases, the supply of loans increases by more in response to the higher credit demand, so that the equilibrium interest rate falls instead of rising. The subsequent economic boom validates the inverted leading indicator property of the real interest rate. This also suggests that the low-interest-rate-based economic boom can be self-fulfilling: in the absence of any fundamental shocks, the very anticipation by borrowers of a lower expected interest rate can stimulate credit demand and aggregate investment, resulting in an economic boom and fulfilling the initial optimistic expectations. Conversely, expectations of a high interest rate can trigger a recession and an interest rate hike in the credit market, as if a higher credit risk had materialized and reduced loanable funds even though it is in fact not the case.

The fact that the borrowing cost faced by US firms is countercyclical has far-reaching macroeconomic consequences. When the borrowing cost is low, financing investment is easier and the economy booms. Figures 1 and 2 report the impulse response functions (IRFs thereafter), at quarterly frequency, of real land price, the inverse relative price of capital, real consumption, real investment, real business debt, hours worked, real GDP, and real borrowing interest rate faced by corporate and noncorporate firms. Those IRFs are obtained from vector autoregressive (VAR) models, using Cholesky decomposition and ordering first either land price (Figure 1) or investment (Figure 2).[2] Both figures make clear that all variables are procyclical, except the debtor interest rate. When there is a positive shock to either land price or investment, the interest rate stays below trend for several quarters while all variables boom. To the extent that both credit demand (by firms) and credit supply (by investors and financial intermediaries) are procyclical, this evidence suggests that changes in the supply of loanable funds dominate those in the demand for loans.

[1] Solutions to such a puzzle are so scarce that, in fact, we know of only one in flexible-price settings: the two-sector RBC model of Boldrin, Christiano and Fisher (2001). Alternatively, King and Watson (1996) argue that sticky-price models are promising to address the puzzle they document. Backus, Kehoe and Kydland (1994) develop a two-country RBC model to address a similar puzzle arising from international trade data.

[2] The first source of shocks is consistent with the collateral channel documented, among others, by Chaney, Sraer and Thesmar (2012) while the second embodies the keynesian notion of investment booms and busts.

While data clearly shows that the borrowing cost is countercyclical, standard RBC models counterfactually predict that the interest rate is procyclical, as noticed above.[3] Since there is no credit market in the standard one-sector RBC model, one might wonder whether or not theoretical predictions agree with empirical evidence in meaningful extensions of the textbook model.

In this paper, we consider various versions of dynamic models that incorporate a credit market and endogenous collateral constraints following the seminal contribution of KM, whose setting has become a workhorse of DSGE theory with financial frictions. Our main contribution is to show that the loanable funds rate is countercyclical only in versions of the model such that the unique steady state is indeterminate, which in turn happens if loan repayments are state-contingent. In other words, collateralized lending with predetermined interest rate delivers a procyclical interest rate that is at odds with data while, in sharp contrast, collateralized loans with state-contingent interest rate accord with empirical evidence. A striking implication of our results is therefore that self-fulfilling swings, and in particular fluctuations in real economic activity caused by interest-rate movements that redistribute income between lenders and borrowers, are an important driver behind actual business cycles both in theory and in the data.

Our focus on credit markets that feature collateral requirements is dictated by the fact that they are a prominent feature of loans in many economies around the world, both in developed and in developing countries. It is well understood both in practice and in theory that contractual agreements involving some form of collateral brought by borrowers mitigate the consequences of asymmetric information in debtor-creditor relationships (see for example the textbook by Tirole, 2006, chapter 4). In particular, because collateralized borrowing reduces default risk, conventional wisdom holds that financial institutions that rely more on secured debt - and less on unsecured debt - should be less prone to financial crisis.[4] This paper shows, however, that such conventional wisdom is not necessarily correct: even collateralized lending can itself be a source of self-fulfilling credit cycles and financial instability. This finding is thus surprising for two reasons: (*i*) it is against the common view that secured borrowing is safer and thus promotes macroeconomic stability; (*ii*) it is a salient feature of KM-type models.

Collateralized borrowing hinges on market values, yet such market values are endogenous to the economy and out of control by competitive creditors and debtors. Thus, intuition tells us that endogenous collateral constraints may subject the economy to speculation and self-fulfilling financial crisis. When the market value of collateral is above trend, for example, the practice of collateralized borrowing stimulates, instead of curtailing, credit lending, fueling the asset boom. Conversely, when the market value of collateral is below trend, collateralized borrowing restricts credit lending instead of relaxing it, exacerbating the crisis in a downturn. Hence, the market value of collateral generates an externality that serves not only to amplify and propagate business cycle shocks, but may also make expected changes in asset prices self-fulfilling, creating business-cycle movements even without any fundamental shocks to the economy. Of course, the amplification and propagation mechanism of collateralized borrowing through such an externality has long been noticed in the literature, and the seminal contribution by KM precisely emphasized such a mechanism. However, this literature shows that the KM constraint alone is not sufficient for generating the anticipated propagation mechanism (Kocherlakota, 2000, Cordoba and Ripoll, 2004, Pintus and Wen, 2013) and self-fulfilling business cycles, unless additional features or frictions such as fixed cost of production or transaction are added in conjunction with collateralized borrowing to generate self-fulfilling business cycles (see e.g. Benhabib and Wang, 2013, Liu and Wang,

[3] Of course, such a negative correlation between the market cost of borrowing and aggregate variables is at the heart of countercyclical policies, which aim at lowering the nominal interest rate in recessions so as to boost investment. Our results suggest such monetary policies - that set the nominal short term rate - may not be the full story behind countercyclical real interest rate movements.

[4] For recent theoretical models that shows the inherent instability of financial institutions under uncollateralized lending practices, see Gu, Mattesini, Monnet, and Wright (2013), Azariadis, Kaas, and Wen (2015).

Figure 1: IRFs from VAR model with land price ordered first - one standard deviation shock (±2 standard-error bands)

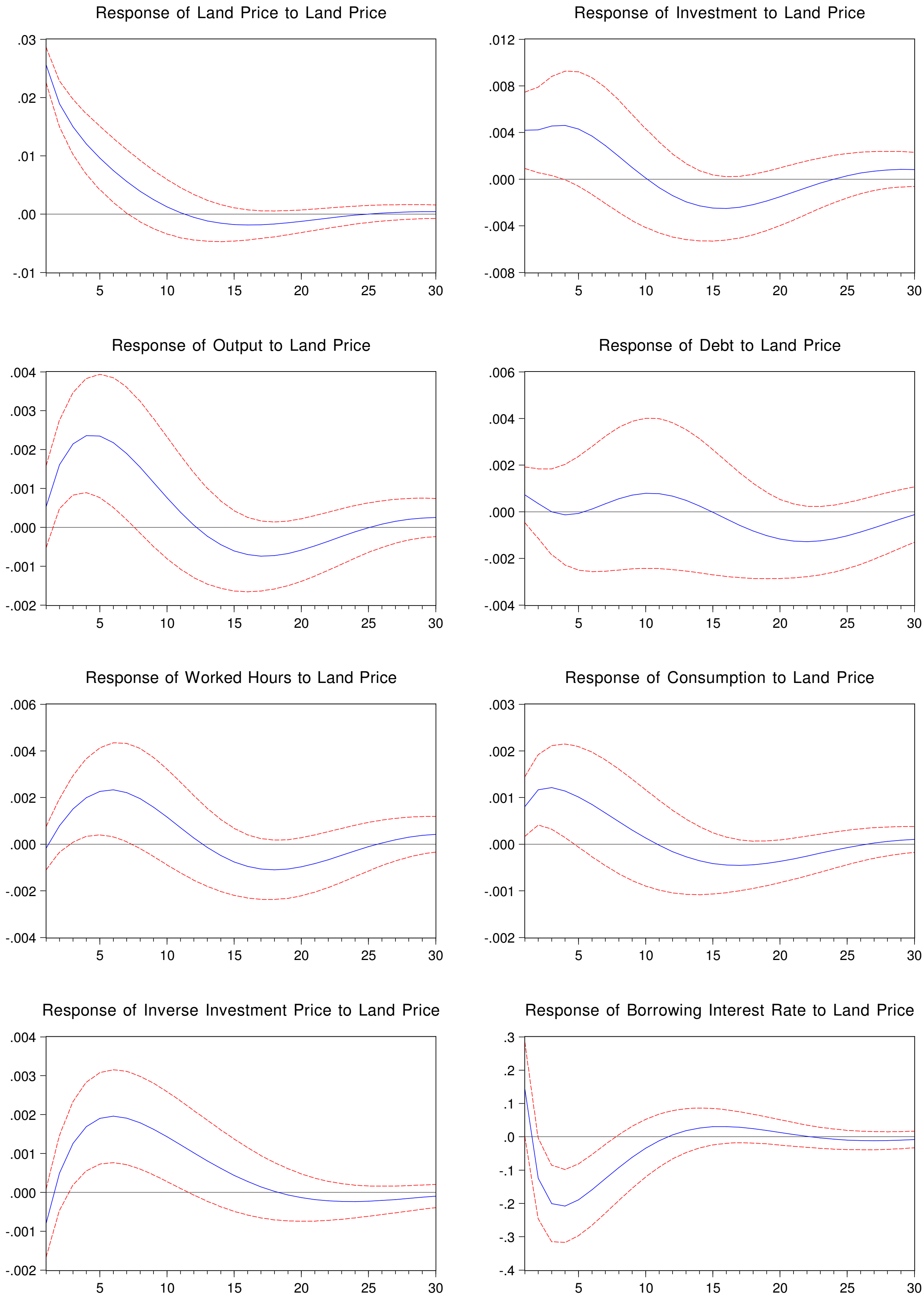
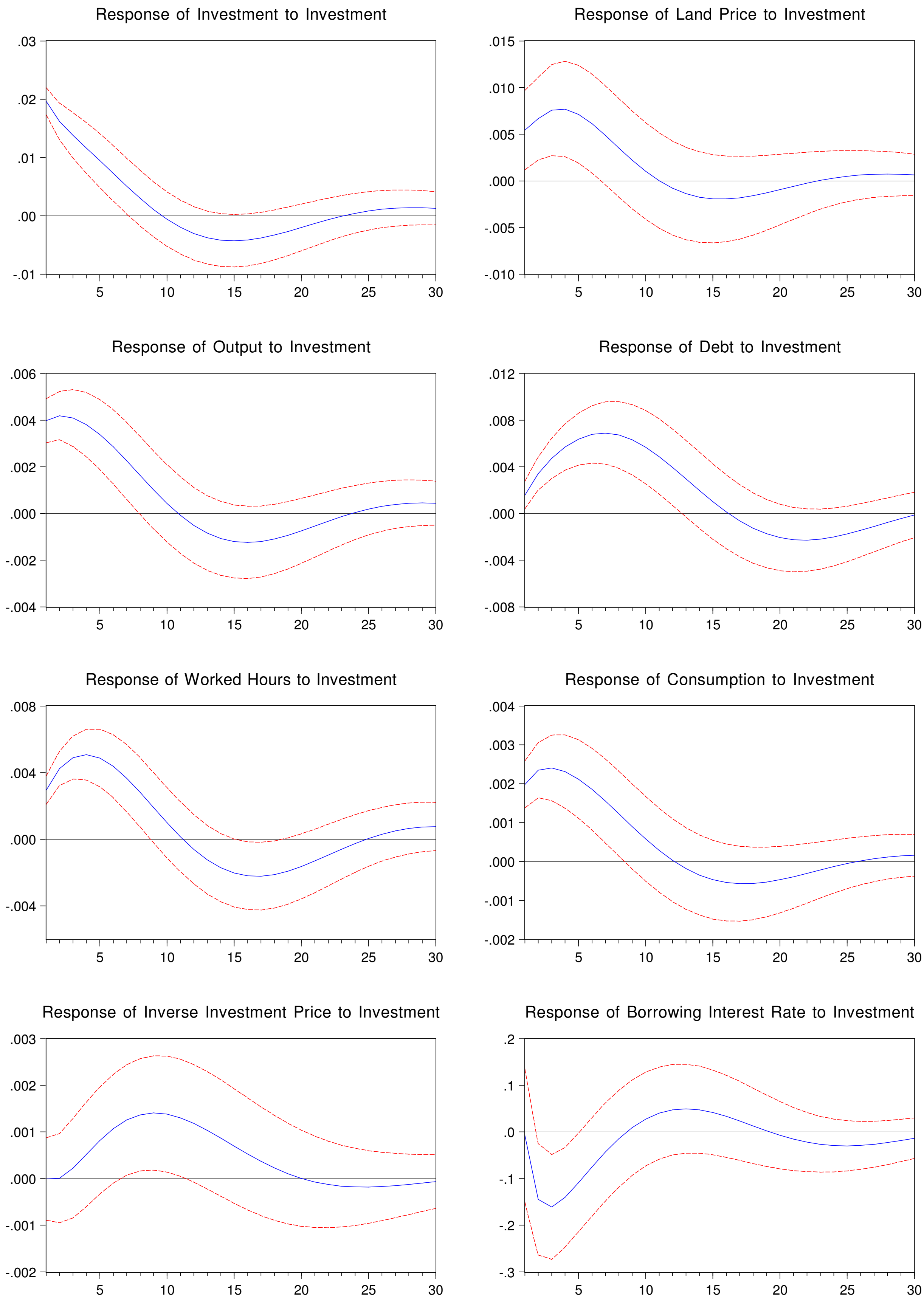


Figure 2: IRFs from VAR model with investment ordered first - one standard deviation shock (±2 standard-error bands)



2014).

The contribution of this paper to this large and growing literature is twofold. On the theory side, we show that borrowing constraints of the KM type are sufficient to generate self-fulfilling business cycles in asset prices and aggregate output, even in simple versions of the original model with realistic parameter values, provided interest payments are allowed to be state-contingent, as opposed to being predetermined as implicitly assumed in the existing literature. The intuition is straightforward: under a predetermined interest rate, simply relaxing the borrowing constraint via a higher value of the collateral does not by itself generate a higher demand for loans if the loan interest rate is expected to rise. Hence, once the credit market is in an equilibrium, an expectation of a higher asset value cannot be self-fulfilling unless the loanable funds rate is countercyclical. Therefore, key to our results is to relax the assumption that the interest rate on loan interest rate is predetermined. Vickery (2008) documents that US firms have been relying to a large extent on variable-rate borrowing over the last four decades. Although less important since the 2007-08 financial crisis, adjustable-rate mortgages have been a major source of financing for US households over the same time period (see Moench, Vickery, and Aragon, 2010). We show in this paper that collateralized loans with state-contingent interest rate produce belief-driven financial volatility, as they generate self-fulfilling equilibria for virtually all plausible parameter values.

On the empirical side, we perform a Bayesian estimation of the full-fledged model on US data 1975-2010 and we show that self-fulfilling redistribution shocks are important, as their presence affect not only the dynamics of the interest rate but also the propagation of fundamental financial shocks that have been stressed by previous quantitative studies. In addition, our estimation results establish that data overwhelmingly favor the (indeterminate) model with state-contingent interest rate over the traditional predetermined-interest rate (determinate) model à la KM, and that the former produces the S-shaped inverted leading indicator property of the real interest rate found in the data while the latter does not.

Regarding our theoretical contribution, we show that while loans with state-contingent interest rate lead to self-fulfilling, multiple equilibria near the steady state, loans with predetermined (or constant) interest rate do not. Multiplicity arises in our model because of an *aggregate credit-demand externality*: equilibria with lower interest rate imply lower debt repayment, making larger loan amounts affordable, which in turn imply larger investment demand and higher asset prices that benefit the lenders and encourage them to issue more loans to push down the interest rate. Intuitively, everything else equal, the expectation of a higher price of collateral is unable to induce a higher demand for loans unless the interest rate on loan payment is simultaneously lowered, which nonetheless cannot happen in a fixed-rate environment, thus preventing the original optimistic expectation of an asset boom to be self-fulfilling. In summary, self-fulfilling shocks that redistribute income away from lenders and benefit borrowers in booms are key in our model. The occurrence of self-fulfilling equilibria is shown to be very pervasive both in the simple model and in the full-fledged quantitative model that we consider next, as it happens for virtually all parameter values. The technical reason why indeterminacy is so pervasive is easy to grasp, if not trivial. Essentially, moving from the fixed-interest rate economy to the state-contingent interest rate economy involves moving the time index of the interest one period ahead. Therefore, when the loan interest rate is predetermined, shocks that occur in period t do not affect the interest payment due in the same period, in contrast with what happens in the state-contingent interest rate economy. More formally, this means that both economies share identical steady states and identical eigenvalues at their linearizations, but the economy with state-contingent interest rate has one more jump variable - since the loan interest rate is no longer predetermined - compared to the fixed-interest rate economy, which obviously leads to one-dimensional indeterminacy. Not surprisingly, multiplicity generates endogenous persistence of i.i.d. shocks and it is associated with different impulse responses to fundamental shocks as well as with a new role for redistributions shocks through the borrowing cost in triggering volatility of the asset price and other aggregates.

This stark distinction between fixed-interest rate economies that are immune from self-fulfilling equilibria and state-contingent interest rate economies that are highly prone to self-fulfilling disturbances has eluded the literature, largely because most contributions assume that the interest rate is either exogenous (as in KM and more recently Mendoza, 2010, among others) or predetermined (as in Iacoviello, 2005, Iacoviello and Neri, 2010, Liu, Wang and Zha, 2013, Guerrieri and Iacoviello, 2013, Justiniano, Primiceri and Tambalotti, 2015a,b, among others). We argue that our results point at expectation-driven movements as a potential empirically relevant force behind credit booms and busts, since loans with state-contingent interest rate are a widespread form of borrowing in the US economy. This mechanism is tightly related to the recent work by Benhabib, Wang and Wen (2015), who show in otherwise standard RBC models that self-fulfilling equilibria arise naturally when producers make production decisions based on expected demand and consumers make consumption decision based on expected labor income, yet production takes place before goods markets clear and before real wages are realized. We add to their contribution by showing in a dynamic model that a similar insight applies to credit markets where lenders make loans based on expected collateral value of the borrowers and the borrowers make borrowing decisions based on expected interested payment, yet the volume of loans are negotiated in advance based on state-contingent interest rate, that is, when the interest rate on loan payments is allowed to fluctuate according to changes in credit market conditions. In such a natural environment with rational expectations, we show that credit-led boom-bust cycles can become self-fulfilling as outlined above: suppose the lender anticipates an investment boom with higher collateral value and thus unleashes more loans into the credit market, then a lowered interest rate would induce more demand for loans, which enables the borrowers to finance more investment and, consequently, increases their collateral value, thus fulfilling the lender's original optimistic expectations.

As a first step towards addressing the question of whether or not indeterminacy and redistribution shocks matter in quantitative terms, we extend the more elaborated model of Liu, Wang and Zha (2013) in which there is a unique steady state that is determinate. We show that, just as in our simple model, determinacy is due to the assumption that the loan repayment is predetermined in the bond market formulation used by those authors. When the interest rate is assumed to be fixed or predetermined, a pecuniary externality (of the sort analyzed in Bianchi, 2011, and the references therein) is not sufficient for generating self-fulfilling asset price and investment fluctuations because the demand for credit depends not only on borrower's collateral value but also on the anticipated interest rate because of debt repayments. However, allowing loans with state-contingent interest rate leads to indeterminacy for virtually all plausible parameter values also in Liu, Wang and Zha (2013) since the borrowing cost falls in booms, which enables borrowers to borrow and invest more even though the price of the collateralizable asset may be fixed. We perform a Bayesian estimation of the extended quantitative model. The novelty of our estimation procedure is that we use our constructed measure of US firms' borrowing cost, that we compute using data from both Flow of Funds and NIPA accounts, on top of the US data 1975-2010 used by in Liu, Wang and Zha (2013). We estimate both the determinate model that obtains when the fraction of fixed-interest rate loans in the economy is large enough, and the indeterminate model (using the technique proposed in Farmer, Khramov, and Nicoló, 2015) when the fraction of loans with state-contingent interest rate in the economy is not too small. Our main findings are as follows. First, adding interest rate data alters results reported by Liu, Wang and Zha (2013) in the sense that housing demand shocks are found to be less important while risk-premium shocks turn out to be more important to explain the variances of output, investment, and worked hours. More generally, we show that the occurrence of self-fulfilling equilibria drastically changes the propagation of fundamental shocks and the variance decomposition of output, investment, credit, and labor hours along US business and credit cycles. We also show that the indeterminate model with self-fulfilling redistribution shocks has a much better fit than the determinate model: the latter is overwhelmingly rejected against the former. This is, to our knowledge, the first set of evidence showing why redistribution shocks between lenders and borrowers matter quantitatively in a DSGE model with financial frictions. Finally, our empirical results show that he data favor redistribution shocks that are quite persistent.

In policy terms, the main implication of our results is that asset-backed credit markets are likely to experience boom-bust patterns driven by expectations when loans have a large state-contingent interest rate component, as in the US or the UK. Conversely, fixed-interest rate loans that are common practice in many continental Europe countries are an efficient tool to rule out self-fulfilling equilibria. Therefore, how the fraction of loans with state-contingent interest rate evolves over time should be a key indicator for monetary/prudential authorities.

Related Literature: Our analysis relates to the growing literature about debt deflation and redistribution (e.g. Calza, Monacelli and Stracca, 2013, Gomes, Jermann and Schmid, 2014, Auclert, 2016, Kaplan, Moll and Violante, 2016). Our analysis adds to this growing literature, first by focusing on firms' real interest rate exposure and by addressing the inverted leading indicator puzzle, and second by estimating the quantitative importance of redistribution shocks. Our results show that even if monetary policy is able to perfectly anchor inflation, shocks that redistribute income between lenders and borrowers may still occur as long as credit instruments allow for floating debt repayment. Financial innovation is an obvious force behind the development of such instruments and a contribution of this paper is to show that the associated redistributive effects are quite important for the business cycle, both in theory and empirically. Our results are also arguably reminiscent of earlier and famous views about how capitalist economies work. In particular, the main mechanism that is formalized in this paper can be viewed as the outcome of combining Keynes' idea of "animal spirits" as important drivers of investment decisions, on the one hand, and Minsky's views on financial instability driven by debt accumulation, on the other. This paper connects, of course, to other recent strands of research. We very much follow Backus, Kehoe and Kydland (1994) (see also, more recently, Gomme, Kydland and Rupert, 2001, and Kydland, Rupert and Šustek, 2015) by considering how the model matches not only contemporaneous correlations in the data but also dynamic lead-lag relationships, in our case between the borrowing cost and aggregate variables. In so doing, we provide a theoretical interpretation of the leading indicator property of interest rates pointed out by King and Watson (1996), that we also document for US firms borrowing cost. There is by now a large literature, to which this paper also belongs, about whether credit cycles are mostly explained by fundamental shocks, expectation - self-fulfilling - shocks or a combination of the two, which remains an unsettled issue and calls for further evidence both to understand the mechanisms at work and to guide sound policy. As part of the ongoing research agenda that tries to address this issue, a large literature has developed, building upon the seminal contributions of Bernanke and Gertler (1989) and KM.[5] On the one hand, a robust result that several attempts to fit DSGE models with fundamental disturbances to data share is that financial shocks are important (Kiyotaki, Michaelides and Nikolov, 2011, Liu, Wang and Zha, 2013, Justiniano, Primiceri and Tombalotti, 2015a, among others). More precisely, land demand shocks, and to a lesser extent leverage shocks, are key drivers that help account for business-cycle data. In line with such

[5]This strand of literature has shown how endogenous borrowing constraints amplify shocks and generate excess-volatility that would not materialize absent credit markets. Early papers include Carlstrom and Fuerst (1997), Krishnamurthy (2003), Cooley, Marimon, and Quadrini (2004), Iacoviello (2005), Campbell and Hercowitz (2006), Boháček and Rodríguez Mendizábal (2007), Christiano, Motto, and Rostagno (2010) among many others.

an approach, Pintus and Wen (2013) have provided quantitative results showing how simple variants of KM's setting indeed produce significant and robust amplification of productivity and financial shocks that is line with evidence on credit booms, thus addressing early criticism about the plausibility of the collateral channel (e.g. Kocherlakota, 2000, Cordoba and Ripoll, 2004). On the other hand, in addition to amplifying fundamental shocks, endogenous borrowing constraints have been shown to originate multiple equilibria, as the early numerical examples in Cordoba and Ripoll (2004) have revealed in a simple RBC setup. In this approach, the emphasis is on self-fulfilling shocks as a possible driver of credit cycles. Building on these early examples, Benhabib and Wang (2013) and Liu and Wang (2014) have further examined how various forms of fixed costs - and the associated increasing returns - make indeterminacy and self-fulfilling business cycles more likely than the model without fixed cost analyzed by Cordoba and Ripoll (2004).[6] In contrast with Benhabib and Wang (2013) and Liu and Wang (2014), we do not introduce fixed costs. Multiplicity is shown to be very pervasive both in our basic model and in the extended quantitative model that we consider next, as it happens for virtually all parameter values. This is in sharp contrast with Benhabib and Wang (2013) and Liu and Wang (2014), who show that the indeterminacy parameter region such is rather small. In addition, the novelty of our paper, compared to earlier studies, is to provide estimation results about the quantitative importance of self-fulfilling shocks in US data.

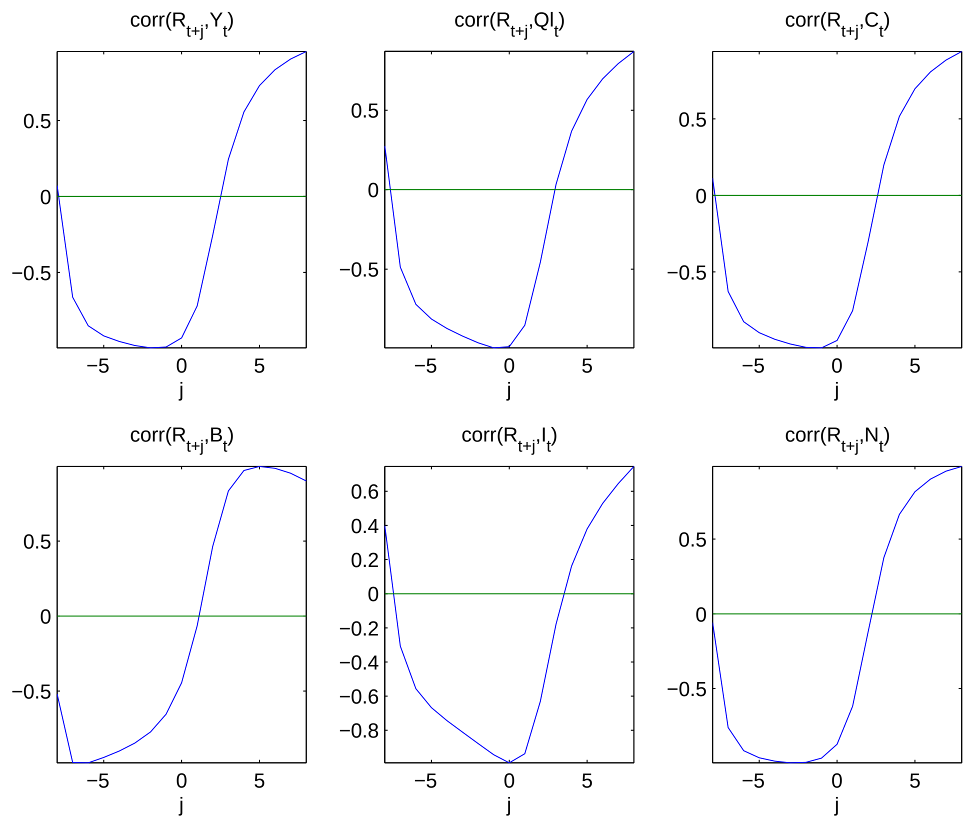
In what follows, Section 2 reports some empirical motivation of the paper. Section 3 presents a basic setup with loans that are collateralized and have state-contingent interest rate and it shows that such model generates global indeterminacy and self-fulfilling equilibria for virtually all parameter values. Section 4 shows that local indeterminacy is robustly pervasive by considering extensions of the basic model that we use to conduct our estimation analysis and to show that redistribution shocks matter. Section 5 concludes the paper with remarks for future research, and an Appendix gathers proofs.

2 Empirical Motivation: Lead-Lag Correlations from Aggregate Data

We first present some stylized facts about the dynamic relationships between macroeconomic variables at quarterly frequency. More precisely, we report the lead-lag correlations of all variables with the interest rate, which we construct from the time series generated by the impulse responses in Figures 1 and 2. In all figures of this section, all variables are real, with R denoting the interest rate, Ql land price, C consumption, B corporate and noncorporate nonfinancial firms' debt, I capital investment, N working hours. The dynamic correlations that we obtain are therefore conditional on either a land price shock (Figure 3) or an investment shock (Figure 4). The most striking feature in both Figure 3 and Figure 4 is that the empirical dynamic correlations of the interest rate with all other variables have an S-shaped pattern. While King and Watson (1996) reported a similar pattern for the rate on three month Treasury bills, which is a policy instrument, our VAR results extend their findings to a measure of market borrowing cost faced by US firms. Consistent with the IRFs reported above, the contemporaneous correlations of the interest rate with virtually all variables are negative. So as to get a first sense of how empirically relevant the settings developed and estimated in the next sections are, in the next two figures we report the dynamic correlations that are predicted by our two competing models. More specifically, the question we now ask is whether the determinate model with predetermined loan interest rate, the indeterminate model with state-contingent loan interest rate, or both replicate the lead-lag

[6] More recently, He, Wright and Zhu (2015) have shown that bubbly and cyclical patterns driven by expectations arise in search environments subject to KM constraints. In addition, labor and credit market frictions interact to create indeterminacy in the model of Kaas, Pintus, and Ray (2016).

Figure 3: Empirical dynamic correlations from VAR with land price ordered first



correlations reported in Figures 3-4. The response is that the latter does while the former does not.

Figure 5 reports the theoretical lead-lag correlations that are produced by the determinate model with predetermined loan interest rate, when a positive shock to household's land demand hits and triggers a boom. Dynamic correlations in Figure 6 arise in the indeterminate model with loans that have state-contingent interest rate, when a negative shock to the interest rate redistributes income from lenders to borrowers.

Inspection of Figures 5 and 6 clearly shows that while the determinate model does not produce the S-shape pattern that is a feature of the data in view of Figures 3 and 4, the indeterminate model is more successful in that respect.[7] This is because while both models predict that credit demand and credit supply go up in booms, they reach opposite conclusions regarding the net effect of those changes. The determinate model predicts that the interest rate is procyclical, which suggests that changes in the rate that is charged in the credit market are mainly determined by a rise of credit demand during good times. In contrast, the loan interest rate is countercyclical in the indeterminate model, which means that supply changes dominate demand changes so that the interest rate falls during booms. The evidence from both VAR models and dynamic correlations reported in this section suggests that the indeterminate model with state-contingent loan interest rate is more in line with the data than the determinate model with predetermined interest rate. In particular, the indeterminate model not only correctly predicts that contemporaneous correlations between the interest and macroeconomic variables are negative but also that low levels of borrowing cost predicts future booms. We examine more formally those aspects in the following sections, which develop and estimate both models, where we show that the self-fulfilling model does a good job along other dimensions as well.

[7] We have checked that similar conclusions are reached under other sources of shocks.

Figure 4: Empirical dynamic correlations from VAR with investment ordered first

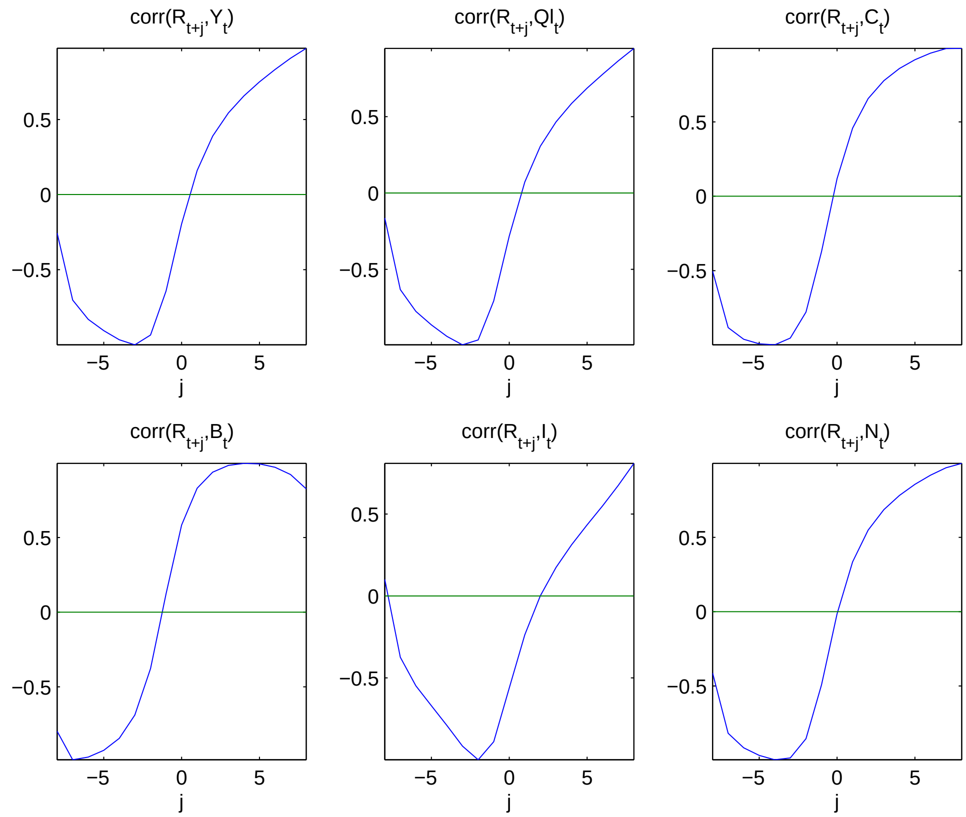


Figure 5: Theoretical dynamic correlations from determinate model with land price shock (95 % confidence bands)

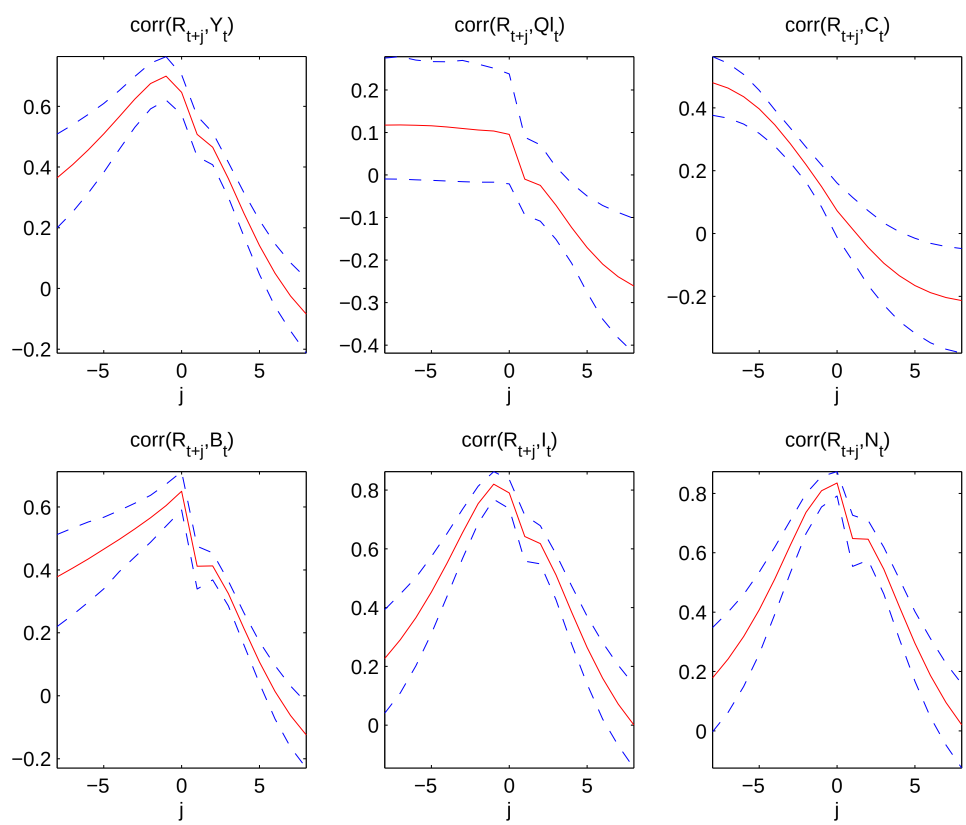
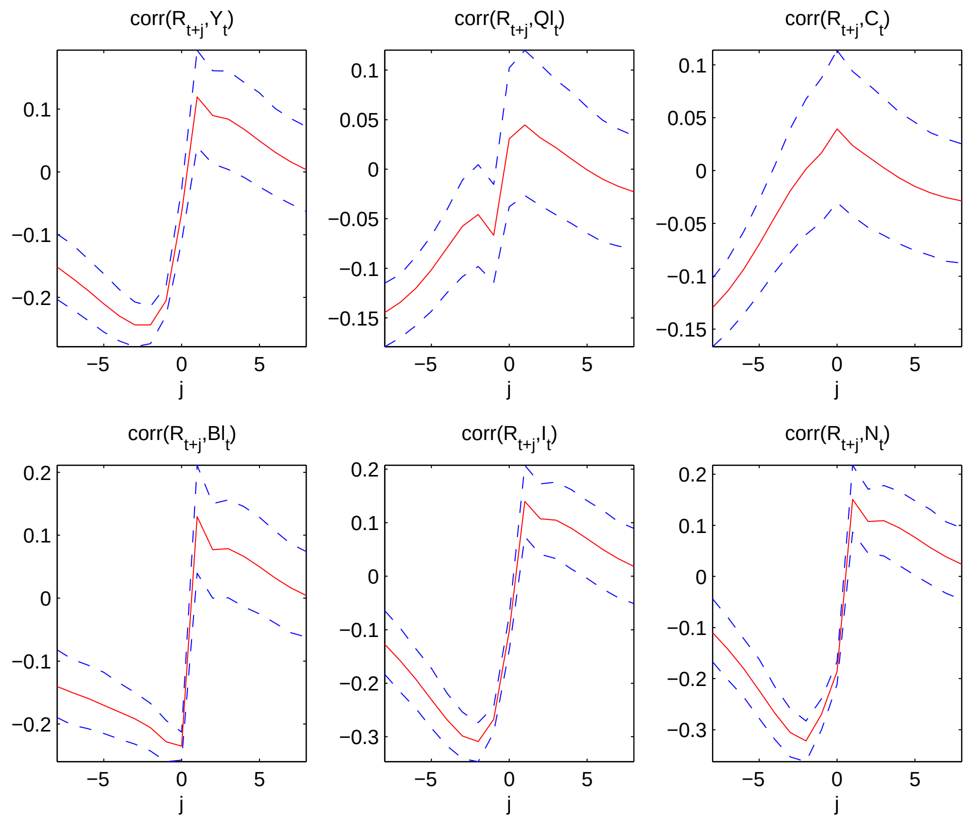


Figure 6: Theoretical dynamic correlations from indeterminate model with redistribution shock (95 % confidence bands)



3 A Simple Model with State-Contingent Interest Rate

In this section we use a simple version of our model to show that incorporating loans with state-contingent interest rate leads to steady-state indeterminacy for virtually all parameter values. We have two objectives in mind. First, to derive global self-fulfilling equilibria analytically and, second, to provide an intuitive account of why self-fulfilling equilibria are pervasive in such a framework.

There are two types of infinitely-long lived agents in the economy, lenders and borrowers. Lenders do not produce, but provide loans to borrowers. In this sense, lenders serve the role of banks or financial intermediaries in the economy. The type of credit provided by lenders are one-period loans that can be used to finance consumption and land investment. Lenders derive utilities from consumption and land,[8] do not accumulate fixed capital, and use interest income from payment on previous loans to finance current consumption and land investment. The budget constraint of a representative lender is given by:

$$\tilde{C}_t + Q_t(\tilde{L}_{t+1} - \tilde{L}_t) + B^l_{t+1} \leq R_t B^l_t \tag{1}$$

where $\tilde{C}_t$ denotes consumption, $\tilde{L}_t$ the amount of land owned by the lender in the beginning of period t, Q_t the relative price of land, B^l_{t+1} the amount of new loans (credit lending) generated in period t, and R_t the gross real interest rate. The instantaneous utility function of the lender is given by:

$$U_L = \tilde{C}_t + \psi \tilde{L}_t, \quad \psi > 0 \tag{2}$$

[8] As in Iacoviello (2005), the lender's asset demand comes from utility attached to land.

and the time discounting factor is $\tilde{\beta} \in (0, 1)$.

Borrowers can produce goods using land[9], using the technology given by:

$$Y_t = AL_t \tag{3}$$

where A is TFP, L_t denotes the amount of land owned by the borrower, and K_t denotes capital stock. The total amount of land is in fixed supply, that is:

$$L_t + \tilde{L}_t = \bar{L}. \tag{4}$$

A representative borrower in each period needs to finance consumption C_t, land investment $L_{t+1} - L_t$, and loan interest rate $R_t B_t^l$, where $\delta \in (0, 1)$ is the depreciation rate of capital. The budget constraint of the borrower is given by:

$$C_t + Q_t(L_{t+1} - L_t) + R_t B_t^l \leq B_{t+1}^l + AL_t \tag{5}$$

An important feature of the budget constraint is that the debt repayment is not predetermined in period t, as the endogenous interest rate adjusts to fundamental and possibly self-fulfilling shocks. The per-period utility function of the representative borrower is given by:

$$U_B = \log C_t \tag{6}$$

and her discount factor is $\beta \in (0, 1)$. Borrowers are assumed to be less patient than lenders, that is, their time discounting factor satisfies $\beta < \tilde{\beta}$.

The *ex-ante* borrowing constraint faced by the borrower is

$$\mathbb{E}_t R_{t+1} B_{t+1}^l \leq \theta \mathbb{E}_t Q_{t+1} L_{t+1} \tag{7}$$

where $\theta > 0$ is the loan repayment-to-value ratio. The borrowing constraint imposes that the amount of debt in the beginning of the next period cannot exceed a fraction θ (≤ 1) of the collateral value of assets owned by the borrower next period. The rationale for this constraint is that, due to lack of contractual enforceability, the lender has incentives to lend today only if the loan is secured by the value of the collateral that will be realized tomorrow. Therefore, the lender has to forecast in period t both the debt obligations that will be redeemed and the market value of collateral that will prevail in $t + 1$. In contrast with KM, who assume a fixed interest rate, the fact that the interest rate is variable is a key feature for our results.[10]

The model just described turns out to have closed-form solutions. More specifically, assuming $A = 1$ and $\theta = 1$, the first-order conditions of the lender immediately imply that the land price are constant over time, $Q = \beta/(1 - \tilde{\beta})$, while expected interest rate is constant too, that is $\mathbb{E}_t R_{t+1} = \tilde{\beta}^{-1}$.[11] In addition, the binding credit constraint gives $B_{t+1}^l = \tilde{\beta} Q L_{t+1}$, which once plugged into the borrower's budget constraint gives:

$$C_t + Q(1 - \tilde{\beta})L_{t+1} = X_t L_t \tag{8}$$

where $X_t \equiv 1 + Q(1 - \tilde{\beta} R_t)$ represents the borrower's return on land net of interest payment. It is then easy to show that, due to logarithmic utility, the borrower's consumption and land demand have closed-form solutions that

[9] Capital and elastic labor supply will be introduced in Section 4.

[10] As long as what matters in the borrowing constraint is the amount of outstanding debt, it is possible to relax the assumption that debt matures after one period while keeping our main results unchanged.

[11] In addition, a unique steady state exists provided that $\psi = \beta/\tilde{\beta} < 1$.

are given by $C_t = (1-\beta)X_t L_t$ and $L_{t+1} = X_t L_t$. On the other hand, lender's first-order condition boils down to $\mathbb{E}_t R_{t+1} = \tilde{\beta}^{-1}$. It follows that self-fulfilling equilibria are simply constructed as solutions to $L_{t+1} = [1 + Q(1 - \tilde{\beta} R_t)]L_t$ and $\tilde{\beta} R_t = 1 + \varepsilon_t$, where the innovation ε_t is any i.i.d. random variable with zero mean, given initial value $L_0 > 0$. In this simple setup, sunspot innovations ε_t originate from forecasting errors on the interest rate, which can be for example interpreted as redistribution shocks that move resources away from lenders and towards borrowers in booms. This means that such a simple economy with variable (state-contingent) interest rate can be globally indeterminate so that interest rate expectations are self-fulfilling. In the full-fledged model of Section 4, sunspot innovations could in principle affect any other jump variables such as investment or consumption for example.[12]

Before moving on to the intuition of why self-fulfilling equilibria arise in the basic model, it is interesting to contrast the above results with what happens in the economy with predetermined-interest rate loans. By this we mean that the borrower's budget and credit constraints are now:

$$C_t + Q(L_{t+1} - L_t) + R_{t-1} B_t^l \leq B_{t+1}^l + L_t \tag{9}$$

$$R_t B_{t+1}^l \leq Q L_{t+1} \tag{10}$$

while the lender's budget constraint is:

$$\tilde{C}_t + Q(\tilde{L}_{t+1} - \tilde{L}_t) + B_{t+1}^l \leq R_{t-1} B_t^l \tag{11}$$

so that the interest repayment due in period t is now predetermined while the interest rate that enters the credit constraint is variable but now known in period t. It is then easy to show that the interest rate is constant over time, that is, $R_t = \tilde{\beta}^{-1}$, so that $X_t = 1$ at all dates and the economy is forever in steady state, absent fundamental shocks, hence not subject to self-fulfilling shocks.

A useful way to shed light on the intuition of why self-fulfilling equilibria arise is to derive credit demand and credit supply. Credit demand is simply:

$$B_{t+1}^d = \tilde{\beta} Q L_{t+1} \tag{12}$$

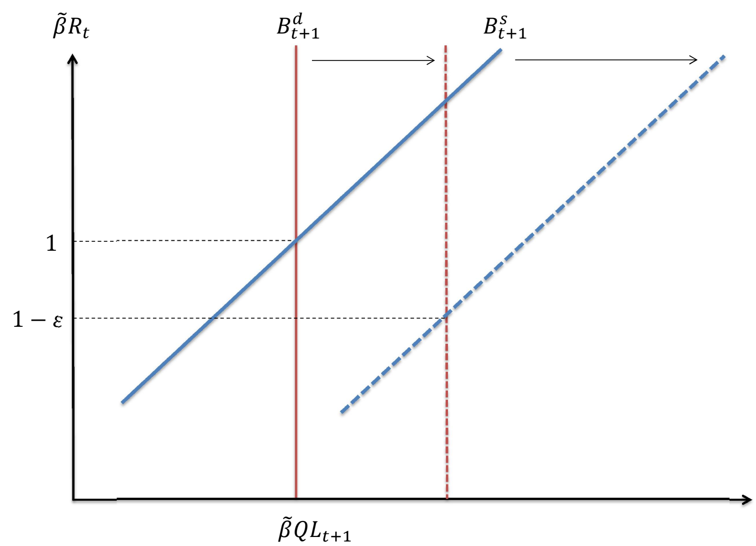
while credit supply is given by:

$$B_{t+1}^s = Q L_{t+1} - \beta X_t L_t \tag{13}$$

and both are conveniently depicted in Figure 7. Now suppose that the borrower expects the interest rate to go down. Then the borrower increases consumption and land investment L_{t+1} so that credit demand shifts rightward in Figure 7. In addition to being a shifter of credit demand through the collateral channel - see (12) - L_{t+1} is also a shifter of credit supply through land reallocation to the borrower - see (13). As can be seen from Figure 7, the net effect is a fall of the interest rate. This is because in view of equations (12) and (13), the credit supply curve shifts to the right by more than the credit demand curve when L_{t+1} goes up: when the borrower's land demand goes up by ΔL_{t+1}, the lender's land holdings go down by the same amount since land is in fixed supply, which means that the lender's savings in the form of lending goes up by $Q\Delta L_{t+1}$. On the other hand, borrower's credit demand goes up by $\tilde{\beta} Q \Delta L_{t+1}$, that is, by a little less since the loan-to-value ratio is smaller than one. The bottom line is that the interest rate goes

[12] Notice that since land price is fixed, the existence of self-fulfilling equilibria is not related to the pecuniary externality (through asset price) that has been stressed by the existing literature. In addition, output is split between borrower and lender, so that any change in borrower's consumption crowds out lender's, that is, $\tilde{C}_t = L_t - C_t$. What matters most is how income is distributed between lenders and borrowers, which in turn depends on loan interest rate that is state-contingent and subject to self-fulfilling changes.

Figure 7: Both credit demand B^d and credit supply B^s shift rightward when the borrower expects a fall in interest rate and invests more in land so that L_{t+1} goes up, resulting in a self-fulfilling fall in R_t.



down and the initial expectation is fulfilled. In other words, the interest rate is countercyclical in the indeterminate model.[13] In contrast, the economy with predetermined interest rate stays in steady state forever, absent fundamental shocks, because the interest rate is constant through time and there is no reallocation of land that can trigger shifts in credit supply or demand. It turns out that self-fulfilling equilibria are also ruled out in the simple economy with predetermined interest rate even if we allow the land price to move over time, typically in a procyclical fashion, and despite the associated pecuniary externality.[14]

4 A Full-Fledged Model with State-Contingent Interest Rate

This section extends the simple setup of Section 3 to a full-fledged DSGE model with realistic parameter values and multiple fundamental shocks. To do so we introduce loans with state-contingent interest rate in the medium-scale model of Liu et al. (2013), that originally deals with predetermined-interest rate loans. Such an extended setup is useful in quantitatively assessing whether or not indeterminacy and self-fulfilling shocks are relevant and we show that they are. More precisely, we perform a Bayesian estimation of both the determinate and the indeterminate models. To estimate the latter, we follow the approach developed in Farmer et al. (2015). Redistribution shocks are shown to be quantitatively important, as their presence alter significantly the propagation of other shocks, including land demand shocks, to explain US business and credit cycles. In addition the determinate model is rejected against the indeterminate model according to the Bayes factor criterion.

[13] Appendix 6.1 shows that global self-fulfilling equilibria survive when, more realistically, both fixed and state-contingent interest rate loans are used, provided that the constant share of variable-rate loans is larger than 0.5.

[14] A previous draft of this paper, Pintus, Wen and Xing, 2016, also derives the existence of local indeterminacy in a generalized version of the model with a risk-averse lender.

4.1 Determinate Economy with Predetermined Interest Rate

So as to make clear how and why loans with state-contingent interest rate modify the analysis, we first expose briefly the original model of Liu et al. (2013) in which the debt repayment is predetermined and the steady state is determinate, using the same notation as in their paper, including the end-of-period convention for stock variables.

Household: The infinitely-long lived representative household consume and supply both labor and credit in each period. They take decisions that maximize lifetime utility, defined as:

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t A_t (\ln(C_{ht} - \gamma_h C_{ht-1}) + \varphi_t \ln L_{ht} - \psi_t N_{ht}) \right] \tag{14}$$

where C_{ht} is consumption, L_{ht} is the land stock, and N_{ht} represents labor hours. Parameter $\beta \in (0,1)$ denotes the discount factor and consumption habits are measured by parameter $\gamma_h \in (0,1)$. Preferences are subject to three shocks, as follows. An intertemporal preference shock, which can be also thought as a risk premium shock, is denoted by $A_t = A_{t-1}(1+\lambda_{at})$, with $\ln \lambda_{at} = \rho_a \ln \lambda_{at-1} + (1-\rho_a)\ln \bar{\lambda}_a + \sigma_a \varepsilon_{a,t}$, $\bar{\lambda}_a > 0$, $\rho_a \in (-1,1)$, and ε_{at} is i.i.d. and normally distributed with mean zero and unit variance so that $\sigma_a > 0$ is the standard deviation of the innovation. In addition, a shock to land utility is denoted by ϕ_t such that $\ln \varphi_t = \rho_\varphi \ln \varphi_{t-1} + (1-\rho_\varphi)\ln \bar{\varphi} + \sigma_\varphi \varepsilon_{\varphi t}$, $\bar{\varphi} > 0$, $\rho_\varphi \in (-1,1)$, and $\varepsilon_{\varphi t}$ is i.i.d. and normally distributed with mean zero and unit variance so that $\sigma_\varphi > 0$ denotes the innovation's standard deviation. Finally, a labor supply shock is denoted by ψ_t such that $\ln \psi_t = \rho_\psi \ln \psi_{t-1} + (1-\rho_\psi)\ln \bar{\psi} + \sigma_\psi \varepsilon_{\psi_t}$, $\bar{\psi} > 0$, $\rho_\psi \in (-1,1)$, and ε_{ψ_t} is i.i.d. and normally distributed with mean zero and unit variance while $\sigma_\psi > 0$ is the innovation's standard deviation.

Households are subject to their budget constraint:

$$C_{ht} + q_{lt}(L_{ht} - L_{ht-1}) + \frac{S_t}{R_t} \leq w_t N_{ht} + S_{t-1} \tag{15}$$

where q_{lt} is the relative land price in terms of the produced good, R_t is the debtor gross interest rate, w_t is the real wage, and S_t denotes the quantity of uncontingent bonds that each pays one consumption unit in period $t+1$.

Defining μ_{ht} as the Lagrange multiplier attached to (15), it is straightforward to derive the following first-order conditions with respect to consumption demand, labor demand, land demand and credit supply:

$$\mu_{ht} = A_t \left(\frac{1}{C_{ht} - \gamma_h C_{ht-1}} - \mathbb{E}_t \left[\frac{\beta \gamma_h}{C_{ht+1} - \gamma_h C_{ht}} (1 + \lambda_{at+1}) \right] \right) \tag{16}$$

$$w_t = \frac{A_t \psi_t}{\mu_{ht}} \tag{17}$$

$$q_{lt} = \beta \mathbb{E}_t \left[\frac{\mu_{ht+1}}{\mu_{ht}} q_{lt+1} \right] + \frac{A_t \varphi_t}{\mu_{ht} L_{ht}} \tag{18}$$

$$1 = \beta \mathbb{E}_t \left[\frac{\mu_{ht+1}}{\mu_{ht}} \right] R_t \tag{19}$$

Entrepreneur: The representative entrepreneur is also infinite-long lived and runs the productive technology that uses capital, labor and land and delivers a good that can be either consumed or used for investment. Her consumption, investment and borrowing decisions maximize lifetime utility, as defined by:

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \ln(C_{et} - \gamma_e C_{et-1}) \right] \tag{20}$$

where C_{et} is consumption and the habit parameter $\gamma_e \in (0,1)$. Entrepreneur operate under four types of constraints. (i) a technological constraint:

$$Y_t = Z_t (L_{et-1}^{\phi} K_{t-1}^{1-\phi})^{\alpha} N_{et}^{1-\alpha} \tag{21}$$

where Y_t is output produced out of capital K_{t-1}, labor N_{et} and land L_{et-1}, with $\alpha \in (0,1)$ and $\phi \in (0,1)$. Total factor productivity Z_t is stochastic and subject to a temporary component ν_{zt} and a permanent component Z_t^p, with $Z_t = \nu_{zt} Z_t^p$, $Z^p = Z_{t-1}^p \lambda_{zt}$, $\ln \lambda_{zt} = \rho_z \ln \lambda_{zt-1} + (1-\rho_z)\bar{\lambda}_z + \sigma_z \varepsilon_{zt}$, $\ln \nu_{zt} = \rho_{\nu_z} \ln \nu_{zt-1} + \sigma_{\nu_z} \varepsilon_{\nu_z t}$. It follows that $\bar{\lambda}_z$ denotes the growth rate of productivity, parameters ρ_z and ρ_{ν_z} belong to $(0,1)$, parameters $\sigma_z > 0$ and $\sigma_{\nu_z} > 0$ denote standard deviations, while ε_{zt} and $\varepsilon_{\nu_z t}$ are i.i.d. and normally distributed with zero mean and unit variance.
(ii) a capital accumulation constraint:

$$K_t = (1-\delta)K_{t-1} + \left(1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2\right) I_t \tag{22}$$

where I_t denotes investment, $\bar{\lambda}_I$ is the steady-state growth rate of investment, and $\Omega > 0$ measures the cost of adjusting the investment flow.
(iii) a budget constraint:

$$C_{et} + q_{lt}(L_{et} - L_{et-1}) + B_{t-1} = Y_t - \frac{I_t}{Q_t} - w_t N_{et} + \frac{B_t}{R_t} \tag{23}$$

where B_t denotes uncontingent debt that matures in period t, Q_t denotes stochastic investment-specific technological change, with $Q_t = Q_t^p \nu_{qt}$. The permanent component Q_t^p follows an autoregressive process, that is, $Q^p = Q_{t-1}^p \lambda_{qt}$, $\ln \lambda_{qt} = \rho_q \ln \lambda_{qt-1} + (1-\rho_q)\bar{\lambda}_q + \sigma_q \varepsilon_{qt}$, $\ln \nu_{qt} = \rho_{\nu_q} \ln \nu_{qt-1} + \sigma_{\nu_q} \varepsilon_{\nu_q t}$. Parameter $\bar{\lambda}_q$ denotes the growth rate of Q_t^p, parameters ρ_q and ρ_{ν_q} belong to $(0,1)$, parameters $\sigma_q > 0$ and $\sigma_{\nu_q} > 0$ denote standard deviations, while ε_{qt} and $\varepsilon_{\nu_q t}$ are i.i.d. and normally distributed with zero mean and unit variance.
(iv) an endogenous collateral requirement:

$$B_t \leq \theta_t \mathbb{E}_t[q_{lt+1} L_{et} + q_{kt+1} K_t] \tag{24}$$

where q_{kt+1} is tomorrow's shadow price of capital expressed in units of the produced good, and θ_t denotes stochastic loan-to-value ratio, with $\ln \theta_t = \rho_\theta \ln \theta_{t-1} + (1-\rho_\theta)\ln \bar{\theta} + \sigma_\theta \varepsilon_{\theta t}$, $\bar{\theta} > 0$ is the steady-state value of the loan-to-value ratio, $\rho_\theta \in (-1,1)$, and $\varepsilon_{\theta t}$ is i.i.d. and normally distributed with mean zero and unit variance while $\sigma_\theta > 0$ is the innovation's standard deviation.

Defining μ_{et}, μ_{kt}, μ_{bt} as the respective Lagrange multipliers of (22), (23), and (24), it follows that relative price of capital in terms of the consumption good satisfies $q_{kt} = \frac{\mu_{kt}}{\mu_{et}}$ and the first-order conditions with respect to demands for consumption, labor, investment, capital, land and credit are:

$$\mu_{et} = \frac{1}{C_{et} - \gamma_e C_{et-1}} - \mathbb{E}_t \left[\frac{\beta \gamma_e}{C_{et+1} - \gamma_e C_{et}} \right] \tag{25}$$

$$w_t = (1-\alpha)Y_t/N_{et} \tag{26}$$

$$q_{kt} = \frac{\mu_{kt}}{\mu_{et}} \tag{27}$$

$$\frac{1}{Q_t} = q_{kt}\left(1 - \frac{\Omega}{2}\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)^2 - \Omega\left(\frac{I_t}{I_{t-1}} - \bar{\lambda}_I\right)\frac{I_t}{I_{t-1}}\right) + \beta\Omega\mathbb{E}_t\left[\frac{\mu_{et+1}}{\mu_{et}}q_{kt+1}\left(\frac{I_{t+1}}{I_t} - \bar{\lambda}_I\right)\left(\frac{I_{t+1}}{I_t}\right)^2\right] \tag{28}$$

$$q_{kt} = \mathbb{E}_t\left[\beta\frac{\mu_{et+1}}{\mu_{et}}\left((1-\phi)\alpha\frac{Y_{t+1}}{K_t} + q_{kt+1}(1-\delta)\right) + \frac{\mu_{bt}}{\mu_{et}}\theta_t q_{kt+1}\right] \tag{29}$$

$$q_{lt} = \beta\frac{\mu_{et+1}}{\mu_{et}}\left(\phi\alpha\frac{Y_{t+1}}{L_{et}} + q_{lt+1}\right) + \frac{\mu_{bt}}{\mu_{et}}\theta_t q_{lt+1} \tag{30}$$

$$1 = \mathbb{E}_t\left[\beta\frac{\mu_{et+1}}{\mu_{et}} + \frac{\mu_{bt}}{\mu_{et}}\right]R_t \tag{31}$$

Finally, in all period t the market clearing conditions are $Y_t = C_t + \frac{I_t}{Q_t}$ for the goods market, where $C_t = C_{ht} + C_{et}$ denotes aggregate consumption, $N_{et} = N_{ht}$ for the labor market, $L_{ht} + L_{et} = \bar{L}$ for the land market, where land is in fixed supply given by parameter $\bar{L} > 0$, and finally $B_t = S_t$ for the credit market.

The stationary version of the model, its linearization at the unique steady state and the calibration strategy are given in Appendix 6.2.1.

4.2 Indeterminate Economy with State-Contingent Interest Rate

As easily seen, the bond formulation used by Liu et al. (2013) is equivalent to one with a loan market. We switch to the latter and then move the time index of the interest rate one period ahead, in order to introduce loans with state-contingent interest rate. Consider the situation where the borrower repays $R_t B^l_{t-1} \equiv B_{t-1}$ and gets loanable fund $B^l_t \equiv B_t/R_{t+1}$ in period t, which means he will have to repay $R_{t+1}B^l_t \equiv B_t$ in period $t+1$. All conditions can now be expressed in terms of the amount borrowed B^l and moving from the fixed-rate economy in Section 4.1 to the variable-rate economy implies the following changes in equations:

(15)→

$$C_{ht} + q_{lt}(L_{ht} - L_{ht-1}) + S^l_t \leq w_t N_{ht} + R_t S^l_{t-1} \tag{32}$$

(19)→

$$1 = \beta\mathbb{E}_t\left[\frac{\mu_{ht+1}}{\mu_{ht}}R_{t+1}\right] \tag{33}$$

(23)→

$$C_{et} + q_{lt}(L_{et} - L_{et-1}) + R_t B^l_{t-1} = Y_t - \frac{I_t}{Q_t} - w_t N_{et} + B^l_t \tag{34}$$

(24)→

$$\mathbb{E}_t[R_{t+1}]B^l_t \leq \theta_t \mathbb{E}_t[q_{lt+1}L_{et} + q_{kt+1}K_t] \tag{35}$$

(31)→

$$1 = \mathbb{E}_t\left[\left(\beta\frac{\mu_{et+1}}{\mu_{et}} + \frac{\mu_{bt}}{\mu_{et}}\right)R_{t+1}\right] \tag{36}$$

Table 1: Parameter values

Structural parameters	g_γ	λ_q	γ_h	γ_e	Ω	$\bar{L}$	α		
	1.004221	1.012126	0.4976	0.6584	0.1753	1	0.3		
Targeted steady state values	$\frac{I}{K}$	$\frac{K}{Y}$	$\frac{q_l L_e}{Y}$	$\frac{q_l L_h}{Y}$	N	θ			
	0.052325	4.6194	2.6	5.8011	0.25	0.75			
Shock parameters	ρ_a	ρ_z	ρ_{ν_z}	ρ_q	ρ_{ν_q}	ρ_ψ	ρ_θ	ρ_φ	
	0.9055	0.4263	0.0095	0.5620	0.2949	0.9829	0.9804	0.9997	
	σ_a	σ_z	σ_{ν_z}	σ_q	σ_{ν_q}	σ_ψ	σ_θ	σ_φ	σ_{red}
	0.1013	0.0042	0.0037	0.0042	0.0029	0.0073	0.0112	0.0462	0.0462

It is straightforward to show that the fixed-rate and variable-rate economies have the same steady state. In addition, the linearized system for the variable-rate economy obtains from that of the fixed-rate economy by replacing $\hat{R}_t$ with $\hat{R}_{t+1}$, $\hat{B}_{t-1}$ with $\hat{R}_t + \hat{B}^l_{t-1}$ and $\hat{B}_t$ with $\hat{R}_{t+1} + \hat{B}^l_t$. The resulting linearized system appears in Appendix 6.2.2.

4.3 Comparing Propagation in Determinate and Indeterminate Economies

We calibrate the model following Liu et al. (2013) to match some key ratios and use their posterior means for the other deep parameters. More details about the calibration strategy are given in Appendix 6.2.1. Parameter values are set according to Table 1.

Determinate Economy: Since it is the most important shock in Liu et al. (2013), we activate only the (fundamental) land demand shock while all other shocks are shut down in the determinate economy with fixed-interest rate loans. Figure 8 reports the corresponding IRFs while Table 2 reports moment statistics. A noticeable and surprising feature of Figure 8 is that although the shock to the lender's utility for land is positive, which implies that households are willing to hold more land, it turns out that land is reallocated to the entrepreneur at impact, as explained in Liu et al. (2013). This happens because land price goes up, which relaxes the entrepreneur's credit constraint and generates a boom that initially reallocates land to the borrower. Because the shock to land utility is very persistent (see Table 1), the response of land price and other aggregates are also very persistent. In addition, the interest rate is procyclical while the land price looks strongly countercyclical in Figure 8, which is confirmed by Table 2 and is at odds with evidence reported in Section 2.

Indeterminate Economy: There is one-dimensional indeterminacy in the economy with state-contingent loan interest rate and we assume that self-fulfilling innovations affect redistribution flows between lenders and borrowers (though similar qualitative results obtain if, for instance, either the land price or investment reacts to extrinsic uncertainty instead). We first investigate what happens in the indeterminate economy when redistribution shocks are inactive while a land demand shock hits. Figure 9 reports the IRFs to a land demand shock and Table 3 reports moment statistics. In Figure 9, a positive land demand shock generates an expansion, similar to what happens in fixed-interest rate economy (see Figure 8). Second, we shut down all fundamental shocks and feed the model with a redistribution shock only. Figure 10 reports the IRFs to a negative shock to loan interest rate and Table 4 reports moment statistics. The main features of Figure 10 are that indeterminacy generates persistence endogenously, since the shock has zero autocorrelation, and a higher level of volatility of output, investment and worked hours compared to Figure 8 (given the same standard deviations for both shocks' innovations). Land price, credit, consumption and labor are procyclical while and the interest rate is countercyclical, which accords with evidence reported in Section

Figure 8: IRFs to a positive land demand shock in the - determinate - economy with fixed interest rate ($\rho_\varphi = 0.9997$, $\sigma_\varphi = 0.0462$)

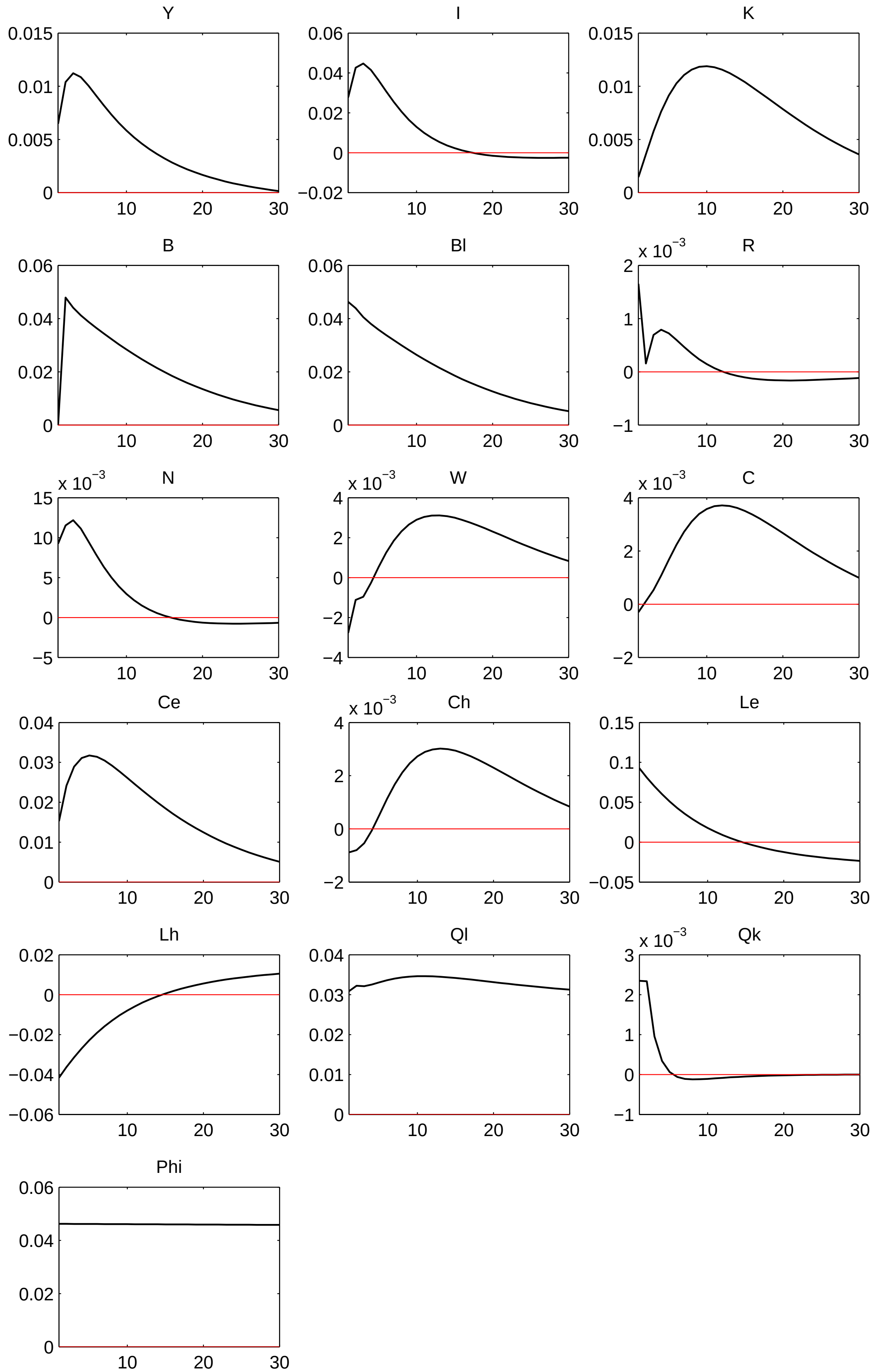


Table 2: Moments under positive land demand shock in the - determinate - economy with fixed interest rate ($\rho_\varphi = 0.9997$, $\sigma_\varphi = 0.0462$)

Variable (log)	S.D. relative to output (%)	CORR with output	ACF1	ACF2	ACF3	ACF4	ACF5
Y	100	1	0.9815	0.9424	0.8974	0.8527	0.8113
I	253.5463	0.8403	0.9478	0.8394	0.7156	0.5954	0.4881
K	129.4317	0.8322	0.9958	0.9841	0.966	0.9427	0.9156
B	324.038	0.8729	0.9412	0.8815	0.8258	0.7725	0.7239
R	5.6797	0.4798	0.5321	0.6048	0.5555	0.4464	0.3431
N	65.2197	0.6661	0.9299	0.8089	0.666	0.5279	0.4066
w	74.5977	0.7581	0.9933	0.988	0.9798	0.9702	0.9603
C	77.5277	0.825	0.9987	0.9955	0.9904	0.9837	0.9758
C_e	274.0718	0.8797	0.9856	0.9537	0.9118	0.8647	0.8159
C_h	74.0065	0.7748	0.9984	0.9948	0.9894	0.9828	0.9755
L_e	2445.2123	0.8033	0.9954	0.9911	0.9871	0.9833	0.9801
L_h	1095.9218	-0.8033	0.9954	0.9911	0.9871	0.9833	0.9801
q_l	2277.1502	-0.6026	0.9994	0.9989	0.9983	0.9977	0.9971
q_k	8.3326	0.3343	0.6876	0.2773	0.0763	-0.0239	-0.0594

2. Comparing Figures 8 and 10 suggests that self-fulfilling redistribution shocks could potentially be as quantitatively important as land demand shocks in explaining booms and busts in the credit market and real production activities. This is what we examine next in the estimation section of the paper.

4.4 Bayesian Estimation of Determinate and Indeterminate Models with Hybrid Interest Rate

This section addresses the following questions: are indeterminacy and redistribution shocks important to explain to US business cycles and do they affect the propagation of other fundamental shocks? Our estimation results, reported below, unambiguously yield "yes" and "yes" as the answers. For comparison purpose, we use Bayesian techniques and all estimation results reported below are based on the dataset made available by Liu et al. (2013) - obtained through the Econometrica website referenced in the published version of that paper, to which we add our interest rate data.

Our estimation strategy is as follows. It is obvious that the determinate and indeterminate models are both unrealistic in the sense that the firm sector as a whole is expected to use a combination of fixed-interest rate and variable-interest rate loans at any point in time.[15] We therefore estimate hybrid versions of the model with a fixed fraction - say, $\omega \in (0, 1)$ - of loans with state-contingent interest rate. It is not difficult to show numerically that such an hybrid model has a determinate steady-state if and only if $\omega < 0.5$ while the steady state is indeterminate if and only if $\omega > 0.5$, just as in the simple model of Section 3 in which it can be proved analytically (see Appendix 6.1). Of course, the versions simulated in Section 4.3 correspond to extreme cases, such that either $\omega = 0$ (see Section 4.1) or $\omega = 1$ (see Section 4.2). We therefore estimate the determinate model under the restriction that $\omega \in (0, 0.5)$ and

[15] To our knowledge, there exists no comprehensive measure of how prevalent variable-interest rate loans to US firms are. Historically, floating-rate debt was introduced in the US in 1974 (see Allen and Gale, 1994, page 19). Since then it has been increasingly used by companies to borrow funds, with a pronounced acceleration in the 1980s and 1990s when non-bank investors like mutual funds and insurance companies massively entered the market as buyers, followed by collateralized loan obligations structures and hedge funds in the 2000s. Modern forms of floating-rate loans are investment-grade corporate floaters and sub-investment-grade bank loans (also referred to as senior secured loans, leveraged loans, or syndicated loans), which are both classified as senior collateralized debt in the borrowing firm's capital structure. Although this is only indicative, we notice that, at least since 2000, the market size for floating-rate loans has been exceeding that of high-yield (usually fixed-rate and unsecured) bonds. As of December 2014, the former exceeds \$1.9 trillion while the latter represents slightly more than \$1.3 trillion (source: Crédit Suisse and Loan Pricing Corporation). In periods of low yields, bank loans are particularly attractive to investors and recommended by many portfolio management firms. See for example http://www.loomissayles.com/internet/internetdata.nsf/id/8yaj9c/$file/bankloans-lookingbeyondinterestrateexpectations.pdf.

Figure 9: IRFs to a positive land demand shock in the - indeterminate - economy with state-contingent interest rate ($\rho_\varphi = 0.9997$, $\sigma_\varphi = 0.0462$)

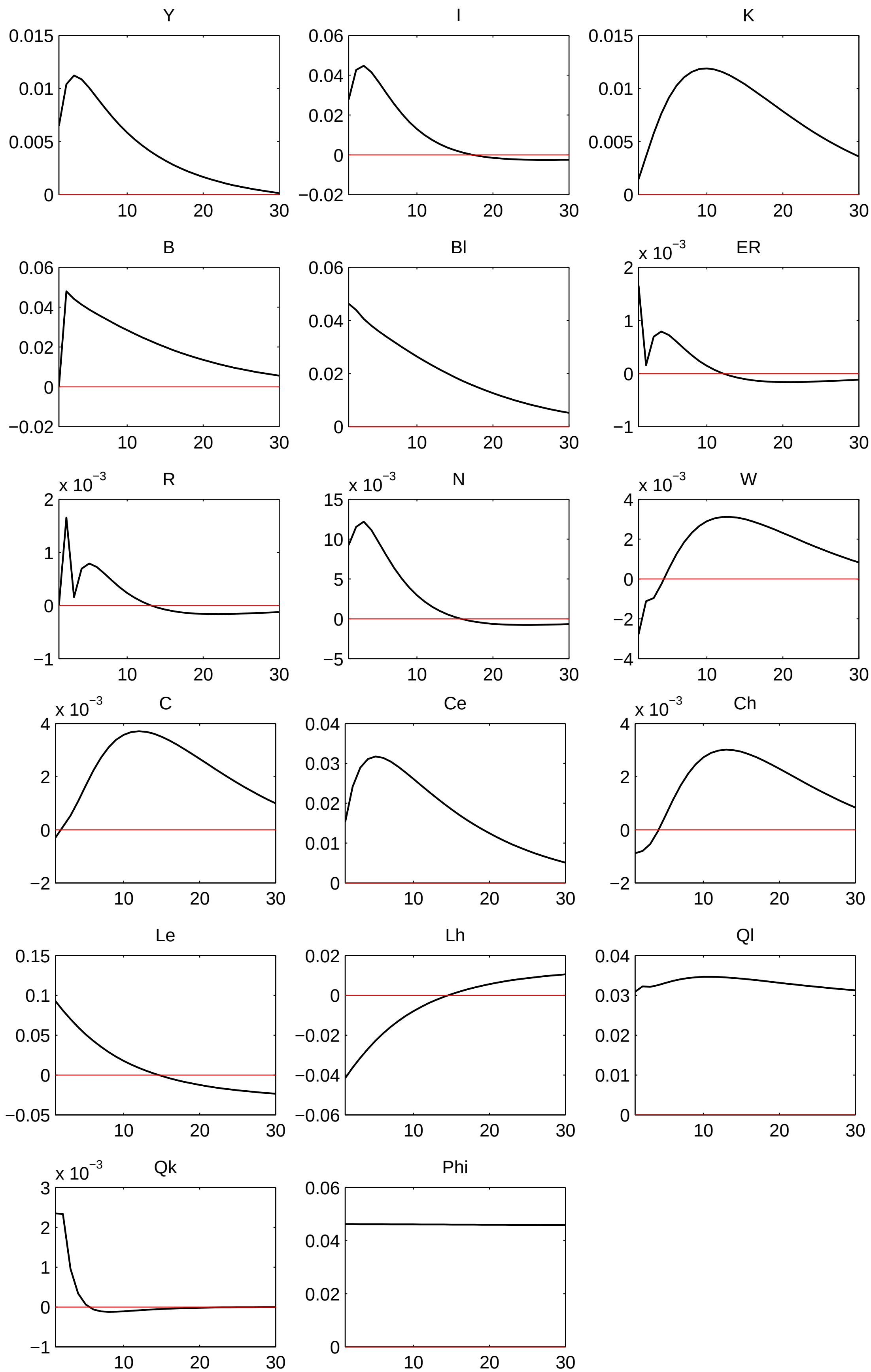


Figure 10: IRFs to a redistribution shock in the - indeterminate - economy with state-contingent interest rate (zero autocorrelation, $\sigma_{red} = 0.0462$)

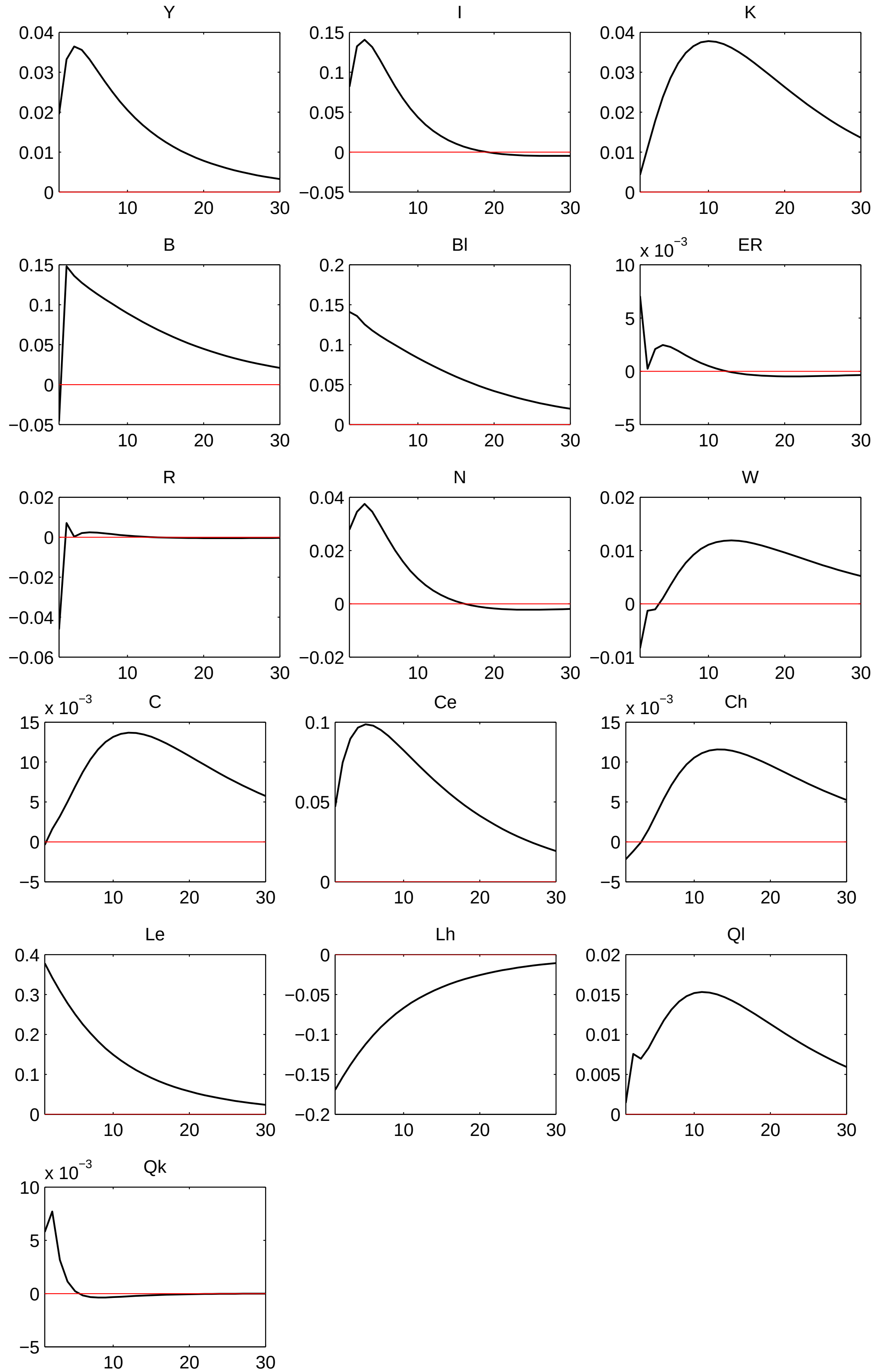


Table 3: Moments under positive land demand shock in the - indeterminate - economy with state-contingent interest rate ($\rho_\varphi = 0.9997$, $\sigma_\varphi = 0.0462$)

Variable (log)	S.D. relative to output (%)	CORR with output	ACF1	ACF2	ACF3	ACF4	ACF5
Y	100	1	0.9821	0.9443	0.9007	0.8574	0.8171
I	251.7177	0.8396	0.9487	0.8422	0.7203	0.602	0.4961
K	129.8306	0.8344	0.9959	0.9846	0.9669	0.9442	0.9178
B	325.3979	0.8614	0.9402	0.8828	0.8279	0.7746	0.7259
R	5.544	0.52	0.5475	0.617	0.566	0.4561	0.3518
N	64.7279	0.6631	0.9309	0.8115	0.6705	0.5341	0.4141
w	74.8738	0.7624	0.9936	0.9884	0.9804	0.971	0.9615
C	77.856	0.8286	0.9988	0.9956	0.9906	0.9841	0.9765
C_e	273.7372	0.8789	0.9861	0.9552	0.9145	0.8688	0.8213
C_h	74.2978	0.7787	0.9984	0.9949	0.9897	0.9833	0.9761
L_e	2454.9207	0.8032	0.9958	0.9917	0.988	0.9844	0.9814
L_h	1100.273	-0.8032	0.9958	0.9917	0.988	0.9844	0.9814
q_l	2289.2229	-0.6053	0.9994	0.9989	0.9983	0.9977	0.9971
q_k	8.1954	0.329	0.6864	0.2781	0.0779	-0.0223	-0.0579

Table 4: Moments under redistribution shock in the - indeterminate - economy with state-contingent interest rate (zero autocorrelation, $\sigma_{red} = 0.0462$)

Variable (log)	S.D. relative to output (%)	CORR with output	ACF1	ACF2	ACF3	ACF4	ACF5
Y	100	1	0.9685	0.8998	0.8201	0.741	0.6675
I	319.7803	0.9231	0.9469	0.8333	0.7028	0.576	0.4626
K	149.0911	0.8021	0.9947	0.9798	0.9567	0.9271	0.8924
B	410.4521	0.9441	0.8874	0.829	0.7734	0.7179	0.6688
R	45.6358	-0.0657	-0.1092	0.0151	-0.0197	-0.0586	-0.0492
N	84.0383	0.8803	0.9334	0.8181	0.6784	0.5422	0.4219
w	47.6029	0.5466	0.9694	0.9502	0.9168	0.8752	0.8307
C	54.4377	0.694	0.9953	0.9825	0.9623	0.9355	0.9035
C_e	339.0278	0.9641	0.9847	0.9506	0.9058	0.8554	0.803
C_h	45.9859	0.5839	0.9933	0.9771	0.9522	0.9206	0.884
L_e	863.3324	0.962	0.9046	0.8131	0.7284	0.6503	0.5833
L_h	386.9377	-0.962	0.9046	0.8131	0.7284	0.6503	0.5833
q_l	61.2425	0.7862	0.9925	0.9795	0.961	0.9363	0.9063
q_k	10.1782	0.4464	0.7109	0.2854	0.0778	-0.0244	-0.0609

the indeterminate model using the restriction $\omega \in (0.5, 1)$. All estimations are performed with the Dynare software (see http://www.dynare.org/) using 6 MCMC chains, each with $60,000$ draws and acceptance rate between 0.25 and 0.33.

The simulation results reported in Section 4.3 already contain some information that can be used to form some guess about what estimating the model should deliver. First, because redistribution shocks generate a procyclical land price and a countercyclical interest rate, which is line with the data, the contribution of indeterminacy is expected to be quantitatively significant. In contrast, because land demand shocks have opposite effects in the indeterminate economy, it could well be that their contribution appears to be reduced in the variable-interest rate economy. These observations turn out to accord with the estimation results that we report next.

Estimated Parameters:

As a benchmark, we first estimate the determinate model, which is essentially an extended version of Liu et al.'s (2013) with: (i) an additional parameter - the share of loans with state-contingent interest rate (ω) - and (ii) an additional observed data - the borrowing cost (R) - that is used in the estimation procedure. Table 5 reports the estimated parameters, which differ substantially from the ones found by Liu et al.'s (2013, Tables 1 and 2). In particular, the fraction of loans with state-contingent interest rate ω is estimated to be around 10%, a rather low value, while the level of investment adjustment cost is larger. In addition, all shocks are estimated to be more persistent in Table 5, compared to Liu et al.'s (2013, Table 2), expect for the land demand shock and for the TFP permanent shock. As for the standard deviations of shocks, they are of similar magnitudes in our estimation, except for the land demand shock and investment-specific permanent shock which are less volatile, and for the investment-specific temporary shock which is more volatile. Table 6 reports the estimated parameters obtained from the indeterminate model. It is important to stress that on top of the fundamental shocks that are present in the determinate model - as in Liu et al. (2013), the indeterminate model is also subject to self-fulfilling redistribution shocks. We follow the literature by assuming that such self-fulfilling shocks are both i.i.d. and orthogonal to fundamental shocks (as in, e.g., Farmer, Khramov, and Nicoló, 2015).[16] The share ω is poorly identified in the indeterminate economy, but its estimated value is close to 0.7, in line with the time series constructed by Vickery (2008).[17] Comparing Tables 5 and 6 reveals some differences. Most notably, in the indeterminate model the patience shock has a largest autocorrelation, TFP shocks are more persistent than investment-specific disturbances, while land demand shock are moderately persistent and less so than labor supply shocks. In addition, estimated standard deviations differ between both models, with that of land demand shock much higher in the indeterminate model.

In light of these changes, one expects patience shocks to become more important and land demand shocks to be less active in the indeterminate economy, compared to what happens in the determinate model, which is confirmed in the variance decomposition that we discuss next.

Variance Decomposition:

Our metric to assess the importance of each shock at business-cycle frequency is the conditional variance decomposition at various horizons (quarters), as in Liu et al. (2013). In fact, Table 7 (see also Figure 11) shows that the variance decomposition that obtains in our hybrid version of the determinate model estimated using also interest-rate data delivers results that are quite different from those in Liu et al. (2013). More precisely, the land demand shock's

[16] The i.i.d. assumption is relaxed in Section 4.5.

[17] It is not difficult to see that our hybrid economy's moments depend on ω only in the determinacy regime. In a nutshell, this happens because ω affects the set of unstable eigenvalues and the linear saddle-path solution used to solve the determinate model, and this is why ω is identified when estimating the determinate model. In contrast, as long as it is larger than 0.5, ω does not matter in the indeterminate regime and, therefore, is not identified in that case.

Table 5: Estimated parameters of determinate model with hybrid interest rate

parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
ω	beta	0.167	0.1179	0.0904	0.1059	0.0148	0.1863
γ_h	beta	0.333	0.2357	0.5432	0.5437	0.4919	0.5973
γ_e	beta	0.333	0.2357	0.6373	0.614	0.4168	0.8484
Ω	gamma	2	2	0.264	0.2776	0.1929	0.3541
$100(g_\gamma - 1)$	gamma	0.618	0.453	0.0136	0.0292	0.0013	0.0571
$100(\lambda_q - 1)$	gamma	0.618	0.453	0.087	0.1666	0.009	0.3231
ρ_a	beta	0.333	0.2357	0.967	0.9634	0.9475	0.98
ρ_z	beta	0.333	0.2357	0.3555	0.3537	0.2849	0.422
ρ_{ν_z}	beta	0.333	0.2357	0.5605	0.5364	0.3892	0.6795
ρ_q	beta	0.333	0.2357	0.9926	0.9898	0.98	0.9995
ρ_{ν_q}	beta	0.333	0.2357	0.9799	0.9767	0.9619	0.9921
ρ_φ	beta	0.333	0.2357	0.9989	0.9985	0.9973	0.9998
ρ_ψ	beta	0.333	0.2357	0.9884	0.9856	0.9759	0.9962
ρ_θ	beta	0.333	0.2357	0.9931	0.9919	0.9884	0.9954
σ_a	inverse gamma	0.01	∞	0.1064	0.1285	0.0847	0.1703
σ_z	inverse gamma	0.01	∞	0.0056	0.0057	0.005	0.0064
σ_{ν_z}	inverse gamma	0.01	∞	0.0035	0.0035	0.0028	0.0043
σ_q	inverse gamma	0.01	∞	0.0015	0.0016	0.0013	0.0018
σ_{ν_q}	inverse gamma	0.01	∞	0.0072	0.0074	0.0066	0.0081
σ_φ	inverse gamma	0.01	∞	0.0381	0.0401	0.0333	0.0466
σ_ψ	inverse gamma	0.01	∞	0.0089	0.009	0.0078	0.0102
σ_θ	inverse gamma	0.01	∞	0.0122	0.0123	0.0112	0.0136

contribution to the variance of output, investment and worked hours is more or less halved compared to what Liu et al. (2013) found. In addition, shocks to risk-premium (that is, patience), TFP and investment-biased technology are much more important. Focusing now on the variance of land price, Table 7 shows that the contribution of land demand shocks is reduced by about a third while that of patience shocks is multiplied five-fold compared to results in Liu et al. (2013). In that sense, estimating ω and using data on R in estimation add new findings compared to Liu et al. (2013), as seen from Table 7.

Another set of new results come from the variance decomposition that arises in the indeterminate economy with redistribution shocks, and that is reported in Table 8 and Figure 12, which tells an altogether very different story. In a nutshell, risk-premium shocks play a much more important role in explaining the variances of all variables in the indeterminate model than in the determinate model. For example, they contribute between 30% and 50% to the variances of output, investment and credit. In comparison, the contribution of land demand shocks is lower. For example, a striking feature reported in Table 8 is that while patience shocks explain more than 90% of the land price's variance, the contribution of land demand shocks explains less than 8%. Both Tables 7 and 8 show that productivity and investment-specific shocks are not important to account for movements in output and investment, in contrast with earlier results in the business-cycle literature (e.g. Greenwood, Hercowitz, Huffman, 1997, Justiniano, Primiceri, Tambalotti, 2011). The contributions of each fundamental shock to consumption movements are not very different in each regime.

A surprising feature in Table 8 and Figure 12 is that redistribution shocks do not contribute to the variances of aggregates, except for that of the interest rate. One might be tempted to infer from such an observation that those

Table 6: Estimated parameters of indeterminate model with hybrid interest rate

parameters	prior			posterior			
	distribution	mean	s.d.	mode	mean	low	high
ω	beta	0.167	0.1179	0.6923	0.6905	0.519	0.8349
γ_h	beta	0.333	0.2357	0.5307	0.5306	0.4754	0.5871
γ_e	beta	0.333	0.2357	0.6037	0.5827	0.3388	0.8068
Ω	gamma	2	2	0.1753	0.183	0.137	0.2265
$100(g_\gamma - 1)$	gamma	0.618	0.453	0.3516	0.3401	0.2338	0.4324
$100(\lambda_q - 1)$	gamma	0.618	0.453	1.1996	1.1977	1.0619	1.3287
ρ_a	beta	0.333	0.2357	0.9995	0.9992	0.9986	1
ρ_z	beta	0.333	0.2357	0.7205	0.7064	0.6022	0.8047
ρ_{ν_z}	beta	0.333	0.2357	0.892	0.8855	0.85	0.9203
ρ_q	beta	0.333	0.2357	0.5895	0.5856	0.4838	0.6913
ρ_{ν_q}	beta	0.333	0.2357	0.3931	0.4156	0.1414	0.697
ρ_φ	beta	0.333	0.2357	0.9285	0.9211	0.8975	0.9448
ρ_ψ	beta	0.333	0.2357	0.9934	0.9919	0.9854	0.9987
ρ_θ	beta	0.333	0.2357	0.9885	0.9881	0.9832	0.9933
σ_a	inverse gamma	0.01	∞	0.041	0.0598	0.0168	0.1063
σ_z	inverse gamma	0.01	∞	0.0024	0.0025	0.0018	0.0032
σ_{ν_z}	inverse gamma	0.01	∞	0.0063	0.0064	0.0057	0.007
σ_q	inverse gamma	0.01	∞	0.0039	0.004	0.0032	0.0048
σ_{ν_q}	inverse gamma	0.01	∞	0.0033	0.0033	0.0026	0.004
σ_φ	inverse gamma	0.01	∞	0.2072	0.2262	0.1563	0.2924
σ_ψ	inverse gamma	0.01	∞	0.0085	0.0087	0.0075	0.0098
σ_θ	inverse gamma	0.01	∞	0.0124	0.0126	0.0113	0.0138
σ_{red}	inverse gamma	0.01	∞	0.0018	0.0018	0.0014	0.0021

shocks are irrelevant in the estimation procedure and hence should be dropped. This turns out to be untrue, as we now argue in view of both models' fit.

A natural question to ask at this stage is which model does better fit the data. To that aim, Table 9 reports the marginal data density, using Geweke's criterion. The four models for which the data density is reported are Liu et al. (2013)'s original version with ω set to 0 (second column in Table 9), the hybrid version with ω estimated to have a mean about 0.1 (third column), the pure indeterminate model with ω set to 1 (fourth column) and its hybrid version with ω's estimated mean to be around 0.7 (fifth column). Table 9 shows that while the hybrid determinate model is preferred to the pure determinate model, they are both overwhelmingly rejected against the hybrid indeterminate model: if the prior distribution over models is agnostic, the posterior probability of the determinate models is essentially zero. On the other hand, while the data does not strongly discriminate between the determinate and the pure indeterminate models, the posterior probability of the hybrid indeterminate model is essentially one with identical priors across all models. In summary, the data strongly favors the hybrid indeterminate model with redistribution shocks.[18]

[18] We have also estimated the hybrid indeterminate model without redistribution shocks and such a setting turns out to have a lower fit compared to that of the same model with redistribution shocks. This suggests that the latter play a role in fitting better the data. In addition, unreported results show that hitting any other jump variable with self-fulfilling shocks results in a worse fit.

Table 7: Variance decomposition in determinate model with hybrid interest rate (in %)

Horizon	ε_a	ε_z	ε_{ν_z}	ε_q	ε_{ν_q}	ε_φ	ε_ψ	ε_θ
Output (Y)								
1	17.3	5.24	0.03	27.5	5.08	12.53	23.76	8.56
4	18.72	0.84	2	28.86	1.53	13.79	23.82	10.44
8	18.2	0.46	1.68	32.43	0.95	12.05	25.47	8.76
16	16.27	0.31	1.25	38.15	0.63	9.13	28.08	6.2
24	14.47	0.25	1.03	42	0.51	7.44	29.3	5.01
Consumption (C)								
1	1.98	38.32	27.78	0.36	16.66	0.26	14.54	0.1
4	2.04	36.29	7.45	0.89	16.51	0.12	36.44	0.25
8	1.35	20.93	3.66	13.24	11.39	1.39	46.31	1.74
16	3.7	7.09	1.73	38.2	4.33	2.86	39.48	2.62
24	4.12	3.92	1.12	49.59	2.4	2.28	34.7	1.87
Investment (I)								
1	24.57	0.07	4.39	33.01	0.36	15.4	11.96	10.23
4	25.37	1.63	3.42	31.31	0.06	15.78	11.28	11.17
8	26.18	2.34	2.53	32.56	0.11	14.61	11.86	9.82
16	26.5	2.53	2.2	33.42	0.22	13.35	13.05	8.73
24	26.24	2.5	2.16	33.13	0.25	13.11	13.63	8.98
Credit (B^l)								
1	16.28	0	1.67	3.14	5.94	27.06	4.73	41.18
4	16.37	0.12	1.88	4.63	5.97	25.69	4.6	40.74
8	16.82	0.17	2.03	8.35	5.3	23.67	4.96	38.69
16	16.92	0.13	1.89	17.46	4.08	19.87	5.63	34.01
24	16.16	0.11	1.66	25.69	3.37	16.98	5.97	30.06
Labor (N)								
1	20.04	0.52	0.79	26.65	0.03	14.51	27.53	9.92
4	19.38	1.13	2.25	25.64	0.18	12.9	30.36	8.16
8	18.46	2.03	1.69	23.73	0.3	11.39	35.63	6.76
16	16.34	2.13	1.39	20.57	0.41	9.6	43.8	5.75
24	14.89	1.97	1.29	19.07	0.4	8.87	47.7	5.82
Wage (w)								
1	14.7	8.18	8.4	11.95	18.64	10.65	20.2	7.28
4	7.25	24.92	3.49	5.77	29.85	3.54	22.78	2.41
8	5.78	20.93	2.61	26.83	21.73	3.87	13.14	5.11
16	9.18	6.42	1.64	61.91	6.87	4.87	3.53	5.58
24	8.71	3.35	1.08	73.98	3.58	3.53	2	3.77
Interest rate (R)								
1	0.49	25.32	16.28	0	7.3	17.66	0.17	32.78
4	2.51	23.33	18.52	4.68	6.21	16.02	0.8	27.92
8	1.98	20.06	14.11	14.16	5.3	17.17	2.82	24.41
16	6.16	19.72	12.75	14.43	5.44	16.12	2.95	22.43
24	12.15	17.09	11.07	17.6	4.78	14.47	2.78	20.06
Land price (q_l)								
1	26.05	0.2	0.06	0.23	1.61	66.47	5.32	0.06
4	24.61	0.71	0.03	0.11	1.85	67.95	4.7	0.04
8	23.65	0.68	0.12	1.1	1.42	68.02	4.95	0.06
16	21.45	0.39	0.17	4.6	0.84	66.99	5.49	0.07
24	19.11	0.27	0.15	7.29	0.58	66.86	5.68	0.07
Capital price (q_k)								
1	18.8	0	19.03	32.76	2.7	10.23	11.61	4.86
4	20.25	2.23	13.47	28.6	1.67	13.68	10.49	9.61
8	20.24	2.3	13.49	28.56	1.67	13.67	10.46	9.61
16	20.24	2.3	13.45	28.55	1.67	13.7	10.45	9.65
24	20.24	2.3	13.45	28.55	1.66	13.7	10.45	9.65

Table 8: Variance decomposition in indeterminate model with hybrid interest rate (in %)

Horizon	ε_a	ε_z	ε_{ν_z}	ε_q	ε_{ν_q}	ε_φ	ε_ψ	ε_θ	ε_{red}
				Output (Y)					
1	36.16	4.86	0.01	9.64	0.01	19.81	20.07	9.17	0.26
4	42.31	2.24	3.91	5.51	0.01	13.87	20.02	11.79	0.33
8	44.41	1.49	4.47	4.17	0.03	9.87	23.99	11.25	0.33
16	43.6	1.08	4.11	3.36	0.03	7.3	30.89	9.33	0.3
24	41.26	0.94	3.67	2.96	0.03	7.13	35.7	8.03	0.27
				Consumption (C)					
1	0.31	3.19	73.38	3.76	3.85	0.86	14.48	0.17	0
4	0.75	10.59	31.54	16	1.24	0.7	38.91	0.25	0.02
8	6.83	11.91	12.51	18.88	0.49	0.85	46.6	1.84	0.09
16	16.51	7.75	7.33	13.01	0.19	1.18	50.32	3.54	0.16
24	18.65	5.62	6.33	9.8	0.13	0.85	55.27	3.17	0.16
				Investment (I)					
1	38.91	2.33	9.93	5.62	0.4	23.18	9.21	10.17	0.26
4	46.25	0.66	10.87	2.2	0.12	17.65	9.06	12.87	0.33
8	50.09	0.71	10.19	1.52	0.12	13.97	10.3	12.76	0.34
16	50.46	1.22	9.27	1.61	0.14	13.45	11.79	11.75	0.32
24	49.3	1.28	8.99	1.64	0.13	14.47	12.43	11.46	0.31
				Credit (B^l)					
1	53.95	0.17	0.86	3.46	0.3	5.17	2.47	33.22	0.39
4	54.94	0.46	0.93	4.56	0.17	2.88	2.45	33.23	0.39
8	55.68	0.75	1.27	4.98	0.11	1.77	2.73	32.34	0.37
16	56.54	0.83	1.72	4.65	0.08	2	3.33	30.5	0.34
24	56.93	0.78	1.81	4.25	0.07	3.07	3.82	28.96	0.31
				Labor (N)					
1	38.04	2.52	2.5	4.48	0.59	20.84	21.11	9.64	0.27
4	39.65	0.83	7.42	1.52	0.19	15.79	25.13	9.2	0.28
8	39.3	0.92	6.93	1.19	0.17	11.73	31.4	8.09	0.26
16	34.37	1.36	5.7	1.39	0.16	10.58	39.54	6.69	0.22
24	30.77	1.32	5.2	1.35	0.14	10.51	44.03	6.48	0.2
				Wage (w)					
1	29.48	0	23.97	0.11	6.25	16.15	16.36	7.47	0.21
4	12.88	7.35	22.86	19.41	2.79	10.43	21.41	2.79	0.07
8	12.97	16.06	11.54	31.68	1.39	6.52	13.12	6.59	0.12
16	29.11	12.68	9.55	23.92	0.6	5.7	5.71	12.47	0.26
24	36.81	10.33	10.01	20	0.45	4.42	4.39	13.28	0.3
				Interest rate (R)					
1	0	0	0	0	0	0	0	0	100
4	21.46	17.44	4.63	7.03	1.08	8.05	0.64	22.78	16.88
8	22.94	16.29	4.03	5.79	0.89	12.74	2.41	21.72	13.18
16	22.86	17.44	4.49	6.97	0.86	12.39	2.59	20.33	12.08
24	26.65	16.2	5.11	6.85	0.77	12.14	2.4	18.94	10.94
				Land price (q_l)					
1	89.63	0	0.34	0.07	0.2	7.55	2.21	0	0
4	90.96	0.15	0.23	0.58	0.07	5.93	1.98	0.1	0
8	91.51	0.32	0.13	0.82	0.03	4.82	2.14	0.22	0.01
16	92.89	0.29	0.19	0.66	0.02	3.17	2.46	0.31	0.01
24	94.01	0.21	0.19	0.5	0.01	2.21	2.6	0.26	0.01
				Capital price (q_k)					
1	19.33	5.52	22.47	8.37	7.91	24.97	7.94	3.39	0.1
4	27.47	3.82	19.22	6.14	5.24	22.89	7.12	7.89	0.19
8	27.35	3.95	19.13	6.3	5.24	22.88	7.08	7.87	0.19
16	27.36	3.95	19.11	6.28	5.23	22.92	7.07	7.89	0.19
24	27.36	3.95	19.11	6.28	5.22	22.92	7.07	7.89	0.19

Figure 11: Variance decomposition in determinate model with hybrid interest rate (in %, at different horizons)

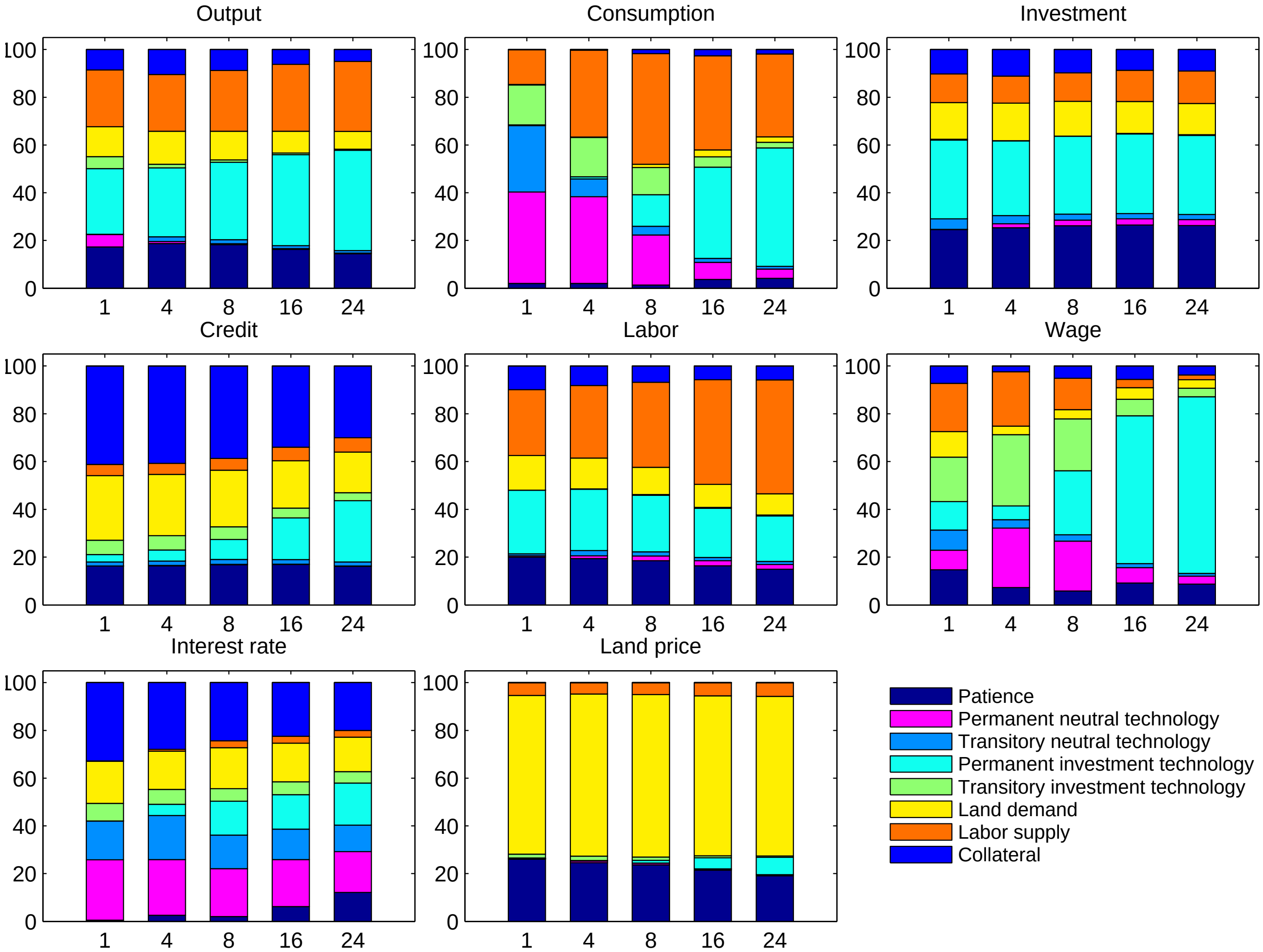


Table 9: Model Fit

	LWZ Model	Hybrid LWZ Model	Indet. Model	Hybrid Indet. Model
Log marginal data density	2879.372221	2879.622297	2896.814187	2910.562874
Model posterior probability	10^{-14}	10^{-14}	10^{-6}	1

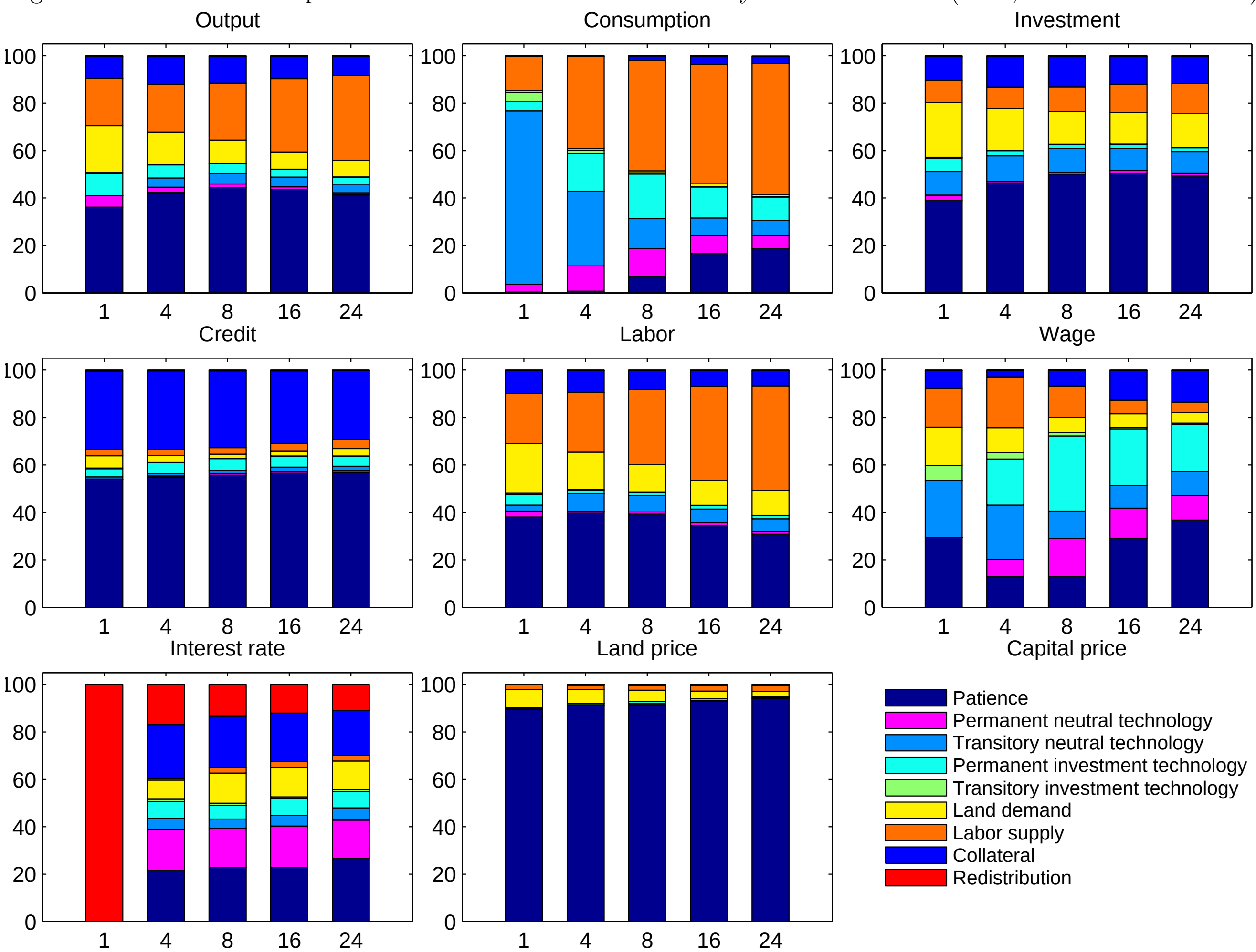
We use Geweke's definition of Log marginal data density for all estimated models. LWZ Model: Liu et al. (2013) with ω set to 0. Hybrid LWZ Model: Liu et al. (2013) with ω estimated to have mean be around 0.1. Indet. Model: indeterminate model with ω set to 1. Hybrid Indet. Model: indeterminate model with ω estimated to have mean around 0.7.

4.5 Persistent Redistribution Shocks

One striking feature of the setting analyzed so far is that the interest rate response to redistribution shocks shows no persistence, as can be seen from Figure 10. As a consequence, redistribution shocks contribute little to the variance of the interest rate and nothing to the variances of other variables in the estimated model (see Table 8 and Figure 12). In this section, we show that data favor persistent shocks to the interest rate. To illustrate this point in an ad-hoc fashion, we reestimate the model under the assumption that redistribution shocks follow an AR(1) process.[19] The outcome is that the estimated autocorrelation parameter of redistribution is quite large (see Table 10). In such model,

[19]Strictly speaking, redistribution shocks are required to be i.i.d. in the indeterminate model with rational expectations. However, we view our AR(1) assumption as a convenient shortcut to proxy mechanisms that could generate persistent shocks to the interest rate but are outside of the model under scrutiny, as discussed below.

Figure 12: Variance decomposition in indeterminate model with hybrid interest rate (in %, at different horizons)



therefore, redistribution shocks have a persistent effect on the interest rate (see Figure 13) and it follows that their contribution in the variance decomposition is now far from negligible (see Figure 14). For example, after 8 quarters, the contribution of redistribution shocks to variance is about 35% for output, 27% for investment, 36% for worked hours, 23% for consumption, 19% of debt, 23% for interest rate, and 13% for land price.[20] Finally, the estimated model with persistent redistribution shocks has a much better fit than all the other models and, hence, a posterior probability that is essentially 1: its log marginal data density is about 2930, compared to about 2910 for the best model with i.i.d. redistribution shocks (see Table 9).

The results of this section show that data unambiguously favors interest rate shocks that are persistent. Although endogenizing such shocks is beyond the scope of this paper, this section shows that their persistence is key to account for the data and as such should be explained. Likely candidates to this task are disturbances from monetary policy, land use regulation, interest income tax and other credit market policies, to the extent that they affect the interest rate in a persistent way. In addition, deviations from rational expectations and learning, as well as sentiment shocks due to information frictions come also to mind. It remains to be seen which mechanism better helps account for data.

[20] A striking feature in Figure 14 is that, compared to Figure 12, land demand shocks emphasized by Liu et al. (2013) have now a larger contribution in the variance decomposition. In contrast, patience shocks contribute relatively less.

Figure 13: IRFs to a persistent redistribution shock in the - indeterminate - economy with state-contingent interest rate ($\rho_{red} = 0.99$, $\sigma_{red} = 0.0462$)

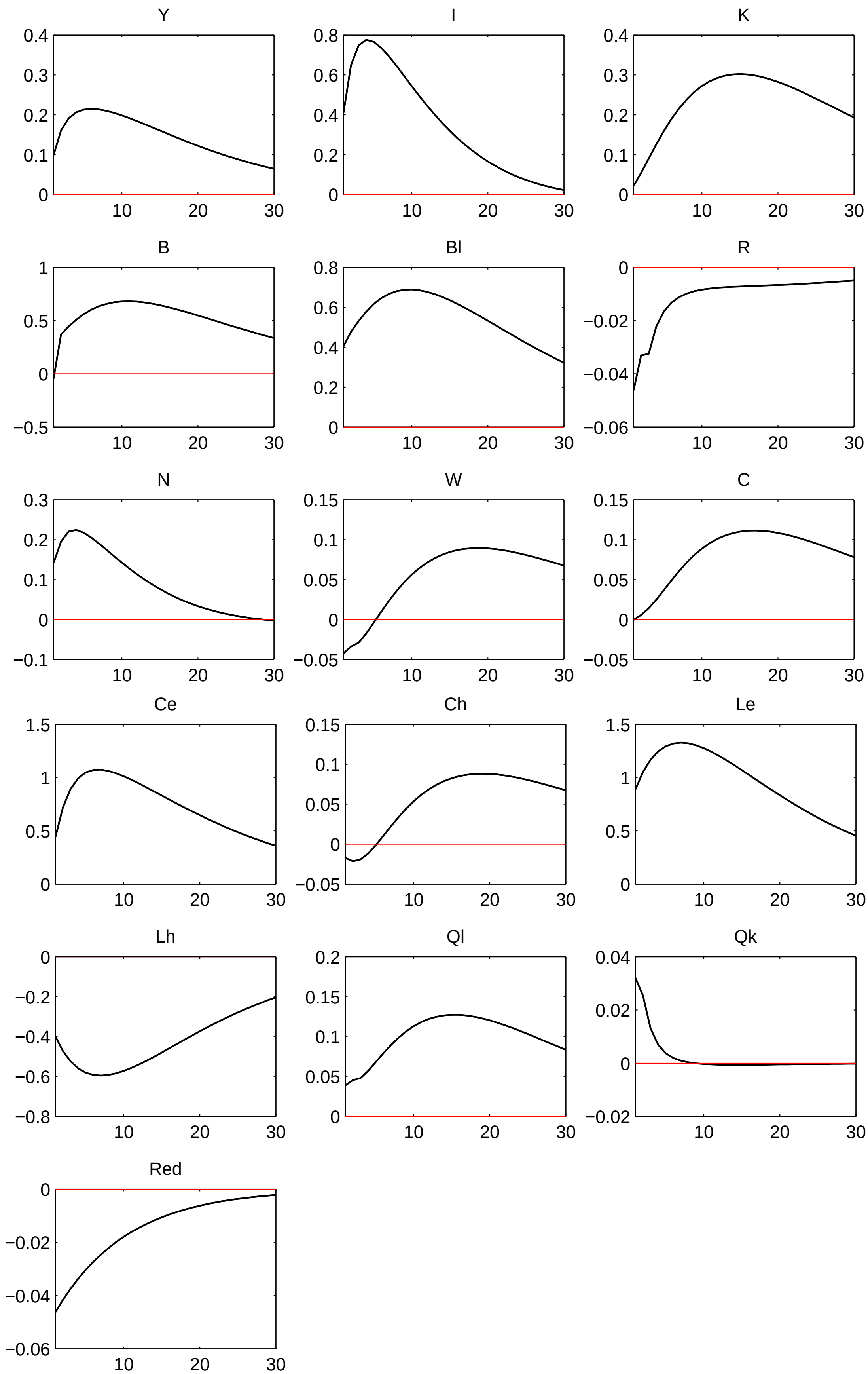


Figure 14: Variance decomposition in indeterminate model with persistent redistribution shocks (in %, at different horizons)

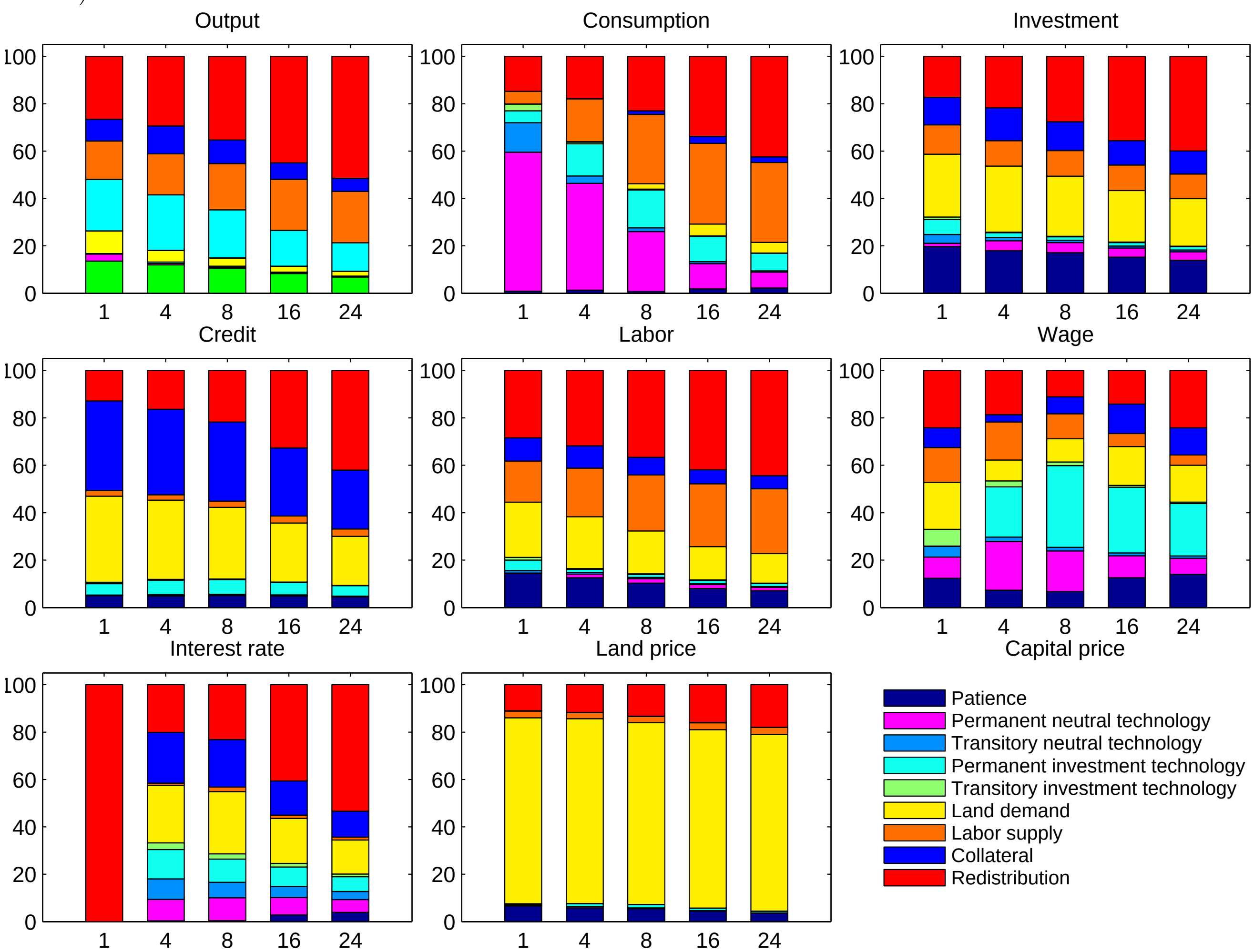


Table 10: Estimated parameters of indeterminate model with hybrid rate

	prior			posterior			
parameters	distribution	mean	s.d.	mode	mean	low	high
ω	beta	0.167	0.1179	0.6923	0.689	0.5162	0.8338
γ_h	beta	0.333	0.2357	0.6733	0.672	0.5918	0.7521
γ_e	beta	0.333	0.2357	0.1826	0.1911	0.0531	0.3216
Ω	gamma	2	2	0.0797	0.0863	0.0632	0.1093
$100(g_\gamma - 1)$	gamma	0.618	0.453	0.0234	0.0648	0.0059	0.1205
$100(\lambda_q - 1)$	gamma	0.618	0.453	1.1448	1.1461	1.0196	1.277
ρ_a	beta	0.333	0.2357	0.9335	0.9282	0.9071	0.9497
ρ_z	beta	0.333	0.2357	0.228	0.2304	0.1618	0.2964
ρ_{ν_z}	beta	0.333	0.2357	0.2992	0.3225	0.0921	0.5209
ρ_q	beta	0.333	0.2357	0.4732	0.509	0.4123	0.6032
ρ_{ν_q}	beta	0.333	0.2357	0.0449	0.1627	0	0.3209
ρ_φ	beta	0.333	0.2357	0.9997	0.9995	0.999	1
ρ_ψ	beta	0.333	0.2357	0.9853	0.9817	0.9703	0.9929
ρ_θ	beta	0.333	0.2357	0.9941	0.9925	0.989	0.9961
ρ_{red}	beta	0.333	0.2357	0.9964	0.9949	0.9923	0.9975
σ_a	inverse gamma	0.01	∞	0.1182	0.1905	0.0938	0.3021
σ_z	inverse gamma	0.01	∞	0.0062	0.0062	0.0055	0.007
σ_{ν_z}	inverse gamma	0.01	∞	0.0021	0.0022	0.0016	0.0028
σ_q	inverse gamma	0.01	∞	0.0046	0.0045	0.0038	0.0052
σ_{ν_q}	inverse gamma	0.01	∞	0.0029	0.0032	0.0026	0.0038
σ_φ	inverse gamma	0.01	∞	0.0426	0.0447	0.0394	0.0504
σ_ψ	inverse gamma	0.01	∞	0.0075	0.0079	0.0066	0.0091
σ_θ	inverse gamma	0.01	∞	0.0117	0.0118	0.0106	0.013
σ_{red}	inverse gamma	0.01	∞	0.0013	0.0014	0.0012	0.0016

5 Conclusion

The contribution of this paper is twofold. On the theory side, we have provided a model to explain the long-standing puzzle of the interest rate dynamics, which the vast majority of existing business-cycle models fail to explain: namely, that the real interest rate is countercyclical and, as an inverted leading indicator, forecasts the business cycle. In an extension of the KM model, we have shown that indeterminacy and self-fulfilling equilibria arise in standard versions of DSGE models with endogenous collateral constraints, provided that loans have state-contingent interest rate. The empirical part of the paper has given content to the claim that, far from being only a theoretical curiosity, the indeterminate model with self-fulfilling redistribution shocks accords with data in terms of goodness of fit.

We conjecture that our set of results could be of interest to understand the business-cycle consequences of household's debt and housing investment, in view of the fact that variable-interest rate loans (e.g. adjustable-rate mortgages) have been an important source of funding up to the 2007-08 crisis. The main mechanism that we emphasize in this paper could in particular have first-order effects on the monetary transmission channel, when embedded in particular in the setting developed by Kydland, Rupert and Šustek (2015), Garriga, Kydland and Šustek (2013). In relation to this, it is obvious that real interest rate movements arise also in the context of nominal debt contracts when inflation is not perfectly stabilized. In that sense all loans have state-contingent real interest rates. This is a second reason why embedding the mechanism of this paper in a framework with monetary policy, whether conventional or not, is worth pursuing. Our results also complement the recent analysis of Justiniano, Primiceri, and Tambalotti (2015b), who analyze the 2000s US trend in housing and credit markets in a very similar model and show that falling interest rates must be part of the story. We have further shown that countercyclical borrowing cost and redistribution shocks are important drivers of fluctuations at business-cycle frequency in output, investment and other aggregate variables. In our model, however, countercyclical interest rate results from self-fulfilling swings in borrowing cost that move both credit supply and credit demand endogenously. In addition, because collateralized lending with variable rates is standard practice in interbank credit markets, our results point at a potentially empirically relevant force that could explain sudden freezes in those markets that have been under the spotlight after the last financial crisis (see e.g. Gorton and Metrick, 2012). In particular, self-fulfilling redistribution shocks could well be an important driver of banking crisis that reinforce fundamental shocks (see Boissay, Collard and Smets, 2015, for an analysis of the latter).

Of course, some unrealistic aspects of the settings that we have used and estimated in this paper need to be fixed. At the top of the list, there is need for further work to incorporate debt maturity into standard macroeconomic models. Our analysis has also identified the persistence of redistribution shocks as a key ingredient to account for the data, which suggests that such feature is left to be explained by any empirically-tested theory. Finally, our models feature no policy instruments that could potentially either prevent ex-ante, or fight against the consequences of self-fulfilling market gyrations. We believe this calls for further research.

6 Appendix

6.1 Global Self-Fulfilling Equilibria with Both Predetermined and State-Contingent Interest Rate

This section shows that global self-fulfilling equilibria exist in the simple model of Section 3 provided that the proportion of loans with state-contingent interest rate in the economy is larger than 0.5. Suppose that a constant fraction $\omega \in [0,1]$ of total loans has a state-contingent interest rate while a fraction $1-\omega$ of total loans has a fixed interest rate. This means that the interest rate paid in period t is now $\mathcal{R}_t \equiv \omega R_t + (1-\omega)R_{t-1}$ and it follows that the lender's first order condition now reads $\mathbb{E}_t \mathcal{R}_{t+1} = \tilde{\beta}^{-1}$. Two cases occur depending on the value for ω. When $\omega < 0.5$, then the latter equality $\omega \mathbb{E}_t R_{t+1} + (1-\omega)R_t = \tilde{\beta}^{-1}$ can be solved forward for $R_t = \tilde{\beta}^{-1}$ so that the interest rate is constant and the economy stays in steady state for all t, exactly as in the case with $\omega = 0$. In other words, the steady state solution for the interest rate is determinate. When $\omega > 0.5$, however, this is no longer true and the steady state interest rate is indeterminate: $\omega \mathbb{E}_t R_{t+1} + (1-\omega)R_t = \tilde{\beta}^{-1}$ cannot be solved forward and there exist self-fulfilling equilibria such that $R_{t+1} = (\tilde{\beta}\omega)^{-1} - (1-\omega)\omega^{-1}R_t + \varepsilon_{t+1}$, where the innovation ε is i.i.d. with zero mean.

In addition, the intuition developed in Section 3 still applies to the case with $\omega > 0.5$. While the expression for credit demand $B^d_{t+1} = \tilde{\beta}QL_{t+1}$ does not change, credit supply is now $B^s_{t+1} = QL_{t+1} - \beta L_t[1 + \omega Q(1-\tilde{\beta}R_t)]$, which of course collapses to (13) in Section 3 when $\omega = 1$. The situation depicted in Figure 7 therefore applies just the same if $\omega > 0.5$: if the borrower expects a lower interest rate in period t, she invests more so that L_{t+1} goes up and the expectation of a falling loan interest rate is self-fulfilling because credit supply shifts rightward by more than credit demand.

6.2 Linearized Version of Full-Fledged Model

The purpose of this appendix is to report the stationary and linearized versions of the equations describing the competitive equilibrium with borrowing constraints in Section 4.

6.2.1 Model with Predetermined Interest Rate

This is the model described in Section 4.1.

Stationary equilibrium:

Since there is technological progress, a steady state is defined in terms of detrended variables. Define $\tilde{X}_{1t} = \frac{X_{1t}}{\Gamma_t}$ where $\Gamma_t = (Z_t Q_t^{(1-\phi)\alpha})^{\frac{1}{1-(1-\phi)\alpha}}$, $X_1 \in \{Y, C_h, C_e, B, w, q_l\}$, define $\tilde{X}_{2t} = X_{2t}\Gamma_t$ where $X_2 \in \{\mu_e, \mu_b\}$, define $\tilde{X}_{3t} = \frac{X_{3t}}{Q_t \Gamma_t}$ where $X_3 \in \{I, K\}$ and define $\tilde{\mu}_{ht} = \frac{\mu_{ht}\Gamma_t}{A_t}$, $\tilde{q}_{kt} = q_{kt} Q_t$. The first-order and market clearing conditions in detrended variables are then:

$$\tilde{\mu}_{ht} = \frac{1}{\tilde{C}_{ht} - \gamma_h \tilde{C}_{ht-1}\Gamma_{t-1}/\Gamma_t} - \mathbb{E}_t \left[\frac{\beta\gamma_h}{\tilde{C}_{ht+1}\Gamma_{t+1}/\Gamma_t - \gamma_h \tilde{C}_{ht}} (1 + \lambda_{at+1}) \right] \tag{37}$$

$$\tilde{w}_t = \frac{\psi_t}{\tilde{\mu}_{ht}} \tag{38}$$

$$\tilde{q}_{lt} = \beta \mathbb{E}_t \left[\frac{\tilde{\mu}_{ht+1}}{\tilde{\mu}_{ht}} (1 + \lambda_{at+1}) \tilde{q}_{lt+1} \right] + \frac{\varphi_t}{\tilde{\mu}_{ht} L_{ht}} \tag{39}$$

$$1 = \beta \mathbb{E}_t \left[\frac{\tilde{\mu}_{ht+1}}{\tilde{\mu}_{ht}} \frac{\Gamma_t}{\Gamma_{t+1}} (1 + \lambda_{at+1}) \right] R_t \tag{40}$$

$$\tilde{\mu}_{et} = \frac{1}{\tilde{C}_{et} - \gamma_e \tilde{C}_{et-1}\Gamma_{t-1}/\Gamma_t} - \mathbb{E}_t \left[\frac{\beta\gamma_e}{\tilde{C}_{et+1}\Gamma_{t+1}/\Gamma_t - \gamma_e \tilde{C}_{et}} \right] \tag{41}$$

$$\tilde{w}_t = (1-\alpha)\tilde{Y}_t / N_{et} \tag{42}$$

$$\begin{aligned} 1 =& \tilde{q}_{kt} \left(1 - \frac{\Omega}{2} \left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}} \frac{Q_t \Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I \right)^2 - \Omega \left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}} \frac{Q_t \Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I \right) \frac{\tilde{I}_t}{\tilde{I}_{t-1}} \frac{Q_t \Gamma_t}{Q_{t-1}\Gamma_{t-1}} \right) \\ &+ \beta\Omega \mathbb{E}_t \left[\frac{\tilde{\mu}_{et+1}}{\tilde{\mu}_{et}} \frac{Q_t \Gamma_t}{Q_{t+1}\Gamma_{t+1}} \tilde{q}_{kt+1} \left(\frac{\tilde{I}_{t+1}}{\tilde{I}_t} \frac{Q_{t+1}\Gamma_{t+1}}{Q_t \Gamma_t} - \bar{\lambda}_I \right) \left(\frac{\tilde{I}_{t+1}}{\tilde{I}_t} \frac{Q_{t+1}\Gamma_{t+1}}{Q_t \Gamma_t} \right)^2 \right] \end{aligned} \tag{43}$$

$$\tilde{q}_{kt} = \mathbb{E}_t \left[\beta \frac{\tilde{\mu}_{et+1}}{\tilde{\mu}_{et}} \left(\alpha(1-\phi) \frac{\tilde{Y}_{t+1}}{\tilde{K}_t} + \tilde{q}_{kt+1} \frac{Q_t \Gamma_t}{Q_{t+1}\Gamma_{t+1}} (1-\delta) \right) + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}} \theta_t \tilde{q}_{kt+1} \frac{Q_t}{Q_{t+1}} \right] \tag{44}$$

$$\tilde{q}_{lt} = \mathbb{E}_t \left[\beta \frac{\tilde{\mu}_{et+1}}{\tilde{\mu}_{et}} \left(\alpha\phi \frac{\tilde{Y}_{t+1}}{\tilde{L}_{et}} + \tilde{q}_{lt+1} \right) + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}} \theta_t \tilde{q}_{lt+1} \frac{\Gamma_{t+1}}{\Gamma_t} \right] \tag{45}$$

$$1 = \mathbb{E}_t \left[\beta \frac{\tilde{\mu}_{et+1}}{\tilde{\mu}_{et}} \frac{\Gamma_t}{\Gamma_{t+1}} + \frac{\tilde{\mu}_{bt}}{\tilde{\mu}_{et}} \right] R_t \tag{46}$$

$$\tilde{Y}_t = \left(\frac{Q_t Z_t}{Q_{t-1} Z_{t-1}} \right)^{\frac{-(1-\phi)\alpha}{1-(1-\phi)\alpha}} L_{et-1}^{\phi\alpha} \tilde{K}_{t-1}^{(1-\phi)\alpha} N_{et}^{1-\alpha} \tag{47}$$

$$\tilde{K}_t = (1-\delta)\tilde{K}_{t-1} \frac{Q_{t-1}\Gamma_{t-1}}{Q_t \Gamma_t} + \left(1 - \frac{\Omega}{2} \left(\frac{\tilde{I}_t}{\tilde{I}_{t-1}} \frac{Q_t \Gamma_t}{Q_{t-1}\Gamma_{t-1}} - \bar{\lambda}_I \right)^2 \right) \tilde{I}_t \tag{48}$$

$$\tilde{Y}_t = \tilde{C}_{ht} + \tilde{C}_{et} + \tilde{I}_t \tag{49}$$

$$\bar{L} = L_{ht} + L_{et} \tag{50}$$

$$\alpha\tilde{Y}_t = \tilde{C}_{et} + \tilde{I}_t + \tilde{q}_{lt}(L_{et} - L_{et-1}) + \tilde{B}_{t-1}\frac{\Gamma_{t-1}}{\Gamma_t} - \frac{\tilde{B}_t}{R_t} \tag{51}$$

$$\tilde{B}_t = \theta_t \mathbb{E}_t \left[\tilde{q}_{lt+1}\frac{\Gamma_{t+1}}{\Gamma_t}L_{et} + \tilde{q}_{kt+1}\tilde{K}_t\frac{Q_t}{Q_{t+1}}\right] \tag{52}$$

For simplicity we can define

$$g_{zt} \equiv \frac{Z_t}{Z_{t-1}} = \frac{Z_t^p v_{zt}}{Z_{t-1}^p v_{zt-1}} = \lambda_{zt}\frac{v_{zt}}{v_{zt-1}} \tag{53}$$

$$g_{qt} \equiv \frac{Q_t}{Q_{t-1}} = \frac{Q_t^p v_{qt}}{Q_{t-1}^p v_{qt-1}} = \lambda_q\frac{v_{qt}}{v_{qt-1}} \tag{54}$$

$$g_{\gamma t} \equiv \frac{\Gamma_t}{\Gamma_{t-1}} = \left(g_{zt}g_{qt}^{(1-\phi)\alpha}\right)^{\frac{1}{1-(1-\phi)\alpha}} \tag{55}$$

Calibration Strategy:

We follow the calibration strategy used by Liu et al. (2013). First we have

$$\frac{1}{R} = \frac{\beta(1+\lambda_a)}{g_\gamma} \Leftrightarrow \lambda_a = \frac{g_\gamma}{\beta R} - 1 \tag{56}$$

$$\frac{\tilde{\mu}_b}{\tilde{\mu}_e} = \frac{\beta\lambda_a}{g_\gamma} \tag{57}$$

then we derive

$$\frac{\tilde{q}_l L_e}{\tilde{Y}} = \frac{\beta\alpha\phi}{1-\beta-\beta\lambda_a\theta} \Leftrightarrow \phi = \frac{1-\beta-\theta\beta\lambda_a}{\beta\alpha}\frac{\tilde{q}_l L_e}{\tilde{Y}} \tag{58}$$

On the other hand, define

$$\lambda_k = g_\gamma \lambda_q \tag{59}$$

it follows that the investment-capital ratio is

$$\frac{\tilde{I}}{\tilde{K}} = 1 - \frac{1-\delta}{\lambda_k} \Leftrightarrow \delta = 1 - \lambda_k\left(1 - \frac{\tilde{I}}{\tilde{K}}\right) \tag{60}$$

and the capital-output ratio is

$$\frac{\tilde{K}}{\tilde{Y}} = \frac{\beta\alpha(1-\phi)}{1-\frac{\beta}{\lambda_k}(\lambda_a\theta+1-\delta)} = \frac{\beta\alpha(1-\frac{1-\beta-\theta\beta\lambda_a}{\beta\alpha}\frac{\tilde{q}_l L_e}{\tilde{Y}})}{1-\frac{\beta}{\lambda_k}(\lambda_a\theta+1-\delta)} = \frac{\beta\left(\alpha+(1+\theta\lambda_a)\frac{\tilde{q}_l L_e}{\tilde{Y}}\right)-\frac{\tilde{q}_l L_e}{\tilde{Y}}}{1-\frac{\beta}{\lambda_k}(\lambda_a\theta+1-\delta)} \tag{61}$$

which gives the discount factor

$$\beta = \frac{\frac{\tilde{K}}{\tilde{Y}} + \frac{\tilde{q}_l L_e}{\tilde{Y}}}{\alpha + \frac{\tilde{q}_l L_e}{\tilde{Y}}(1+\theta\lambda_a) + \frac{\tilde{K}}{\tilde{Y}}\frac{1}{\lambda_k}(\lambda_a\theta+1-\delta)} \tag{62}$$

and the investment-output ratio

$$\frac{\tilde{I}}{\tilde{Y}} = \frac{\tilde{I}}{\tilde{K}}\frac{\tilde{K}}{\tilde{Y}} = \frac{\beta\alpha(1-\phi)(\lambda_k-(1-\delta))}{\lambda_k-\beta(\lambda_a\theta+1-\delta)} \tag{63}$$

Besides, the credit-to-output ratio is

$$\frac{\tilde{B}}{\tilde{Y}} = \theta\left(g_\gamma\frac{\tilde{q}_l L_e}{\tilde{Y}} + \frac{1}{\lambda_q}\frac{\tilde{K}}{\tilde{Y}}\right) \tag{64}$$

which gives the entrepreneur's consumption as a fraction of output

$$\frac{\tilde{C}_e}{\tilde{Y}} = \alpha - \frac{\tilde{I}}{\tilde{Y}} - \frac{1-\beta(1+\lambda_a)}{g_\gamma}\frac{\tilde{B}}{\tilde{Y}} \tag{65}$$

and the household's consumption-to-output ratio as well

$$\frac{\tilde{C}_h}{\tilde{Y}} = 1 - \frac{\tilde{C}_e}{\tilde{Y}} - \frac{\tilde{I}}{\tilde{Y}} \tag{66}$$

In addition

$$\frac{\tilde{q}_l L_h}{\tilde{C}_h} = \frac{\varphi(g_\gamma-\gamma_h)}{g_\gamma(1-g_\gamma/R)(1-\gamma_h/R)} \Leftrightarrow \varphi = \frac{\frac{\tilde{q}_l L_h}{\tilde{Y}}}{\frac{\tilde{C}_h}{\tilde{Y}}}\frac{g_\gamma(1-g_\gamma/R)(1-\gamma_h/R)}{(g_\gamma-\gamma_h)} \tag{67}$$

$$\frac{L_h}{L_e} = \frac{\varphi(g_\gamma-\gamma_h)(1-\beta-\beta\lambda_a\theta)}{\beta\alpha\phi g_\gamma(1-g_\gamma/R)(1-\gamma_h/R)}\frac{\tilde{C}_h}{\tilde{Y}} \tag{68}$$

and the steady-state quantity of labor is

$$N = \frac{(1-\alpha)g_\gamma(1-\gamma_h/R)}{\psi(g_\gamma-\gamma_h)}\frac{\tilde{Y}}{\tilde{C}_h} \Leftrightarrow \psi = \frac{(1-\alpha)g_\gamma(1-\gamma_h/R)}{N(g_\gamma-\gamma_h)}\frac{\tilde{Y}}{\tilde{C}_h} \tag{69}$$

Linearization:

Defining the following constant

$$\Omega_h = (g_\gamma - \beta(1+\lambda_a)\gamma_h)(g_\gamma-\gamma_h) \tag{70}$$

$$\Omega_e = (g_\gamma - \beta\gamma_e)(g_\gamma-\gamma_h) \tag{71}$$

then we dynamic linear system follows

$$\hat{\mu}_{ht}\Omega_h = -(g_\gamma^2+\beta\gamma_h^2(1+\lambda_a))\hat{C}_{ht} + g_\gamma\gamma_h(\hat{C}_{ht-1}-\hat{g}_{\gamma t}) - \beta\lambda_a\gamma_h(g_\gamma-\gamma_h)\hat{\lambda}_{at+1} + \beta(1+\lambda_a)g_\gamma\gamma_h(\hat{C}_{ht+1}+\hat{g}_{\gamma t+1}) \tag{72}$$

$$\hat{w}_t + \hat{\mu}_{ht} = \hat{\psi}_t \tag{73}$$

$$\hat{q}_{lt} + \hat{\mu}_{ht} = \beta(1+\lambda_a)\mathbb{E}_t[\hat{\mu}_{ht+1}+\hat{q}_{lt+1}] + (1-\beta(1+\lambda_a))(\hat{\varphi}_t - \hat{L}_{ht}) + \beta\lambda_a\mathbb{E}_t[\hat{\lambda}_{at+1}] \tag{74}$$

$$\hat{\mu}_{ht} - \hat{R}_t = \mathbb{E}_t\left[\hat{\mu}_{ht+1} + \frac{\lambda_a}{1+\lambda_a}\hat{\lambda}_{at+1} - \hat{g}_{\gamma t+1}\right] \tag{75}$$

$$\Omega_e\hat{\mu}_{et} = -(g_\gamma^2+\beta\gamma_e^2)\hat{C}_{et} + g_\gamma\gamma_e(\hat{C}_{et-1}-\hat{g}_{\gamma t}) + \beta g_\gamma\gamma_e\mathbb{E}_t[\hat{C}_{et+1}+\hat{g}_{\gamma t+1}] \tag{76}$$

$$\hat{w}_t = \hat{Y}_t - \hat{N}_t \tag{77}$$

$$\hat{q}_{kt} = (1+\beta)\Omega\lambda_k^2\hat{I}_t - \Omega\lambda_k^2\hat{I}_{t-1} + \Omega\lambda_k^2(\hat{g}_{\gamma t} + \hat{g}_{qt}) - \beta\Omega\lambda_k^2\mathbb{E}_t[\hat{I}_{t+1} + \hat{g}_{\gamma t+1} + \hat{g}_{qt+1}] \tag{78}$$

$$\begin{aligned}\hat{q}_{kt} + \hat{\mu}_{et} =& \frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\theta}{\lambda_q}(\hat{\mu}_{bt} + \hat{\theta}_t) + \frac{\beta(1-\delta)}{\lambda_k}\mathbb{E}_t[\hat{q}_{kt+1} - \hat{g}_{qt+1} - \hat{g}_{\gamma t+1}] \\ &+ \left(1 - \frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\theta}{\lambda_q}\right)\mathbb{E}_t[\hat{\mu}_{et+1}] + \frac{\tilde{\mu}_b}{\tilde{\mu}_e}\frac{\theta}{\lambda_q}\mathbb{E}_t[\hat{q}_{kt+1} - \hat{g}_{qt+1}] + \beta\alpha(1-\phi)\frac{\tilde{Y}}{\tilde{K}}\mathbb{E}_t[\hat{Y}_{t+1} - \hat{K}_t]\end{aligned} \tag{79}$$

$$\begin{aligned}\hat{q}_{lt} + \hat{\mu}_{et} =& \frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\theta(\hat{\theta}_t + \hat{\mu}_{bt}) + \left(1 - \frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\theta\right)\mathbb{E}_t[\hat{\mu}_{et+1}] + \frac{\tilde{\mu}_b}{\tilde{\mu}_e}g_\gamma\theta\mathbb{E}_t[\hat{q}_{lt+1} + \hat{g}_{\gamma t+1}] \\ &+ \beta\mathbb{E}_t[\hat{q}_{lt+1}] + (1 - \beta - \beta\lambda_a\theta)\mathbb{E}_t[\hat{Y}_{t+1} - \hat{L}_e]\end{aligned} \tag{80}$$

$$\hat{\mu}_{et} - \hat{R}_t = \frac{1}{1+\lambda_a}(\mathbb{E}_t[\hat{\mu}_{et+1} - \hat{g}_{\gamma t+1}] + \lambda_a\hat{\mu}_{bt}) \tag{81}$$

$$\hat{Y}_t = \alpha\phi\hat{L}_{et-1} + \alpha(1-\phi)\hat{K}_{t-1} + (1-\alpha)\hat{N}_t - \frac{(1-\phi)\alpha}{1-(1-\phi)\alpha}(\hat{g}_{zt} + \hat{g}_{qt}) \tag{82}$$

$$\hat{K}_t = \frac{1-\delta}{\lambda_k}(\hat{K}_{t-1} - \hat{g}_{\gamma t} - \hat{g}_{qt}) + \left(1 - \frac{1-\delta}{\lambda_k}\right)\hat{I}_t \tag{83}$$

$$\hat{Y}_t = \frac{\tilde{C}_h}{\tilde{Y}}\hat{C}_{ht} + \frac{C_e}{\tilde{Y}}\hat{C}_{et} + \frac{\tilde{I}}{\tilde{Y}}\hat{I}_t \tag{84}$$

$$0 = \frac{L_h}{\bar{L}}\hat{L}_{ht} + \frac{L_e}{\bar{L}}\hat{L}_{et} \tag{85}$$

$$\alpha\hat{Y}_t = \frac{\tilde{C}_e}{\tilde{Y}}\hat{C}_{et} + \frac{\tilde{I}}{\tilde{Y}}\hat{I}_t + \frac{\tilde{q}_l L_e}{\tilde{Y}}(\hat{L}_{et} - \hat{L}_{et-1}) + \frac{1}{g_\gamma}\frac{\tilde{B}}{\tilde{Y}}(\hat{B}_{t-1} - \hat{g}_{\gamma t}) - \frac{1}{R}\frac{\tilde{B}}{\tilde{Y}}(\hat{B}_t - \hat{R}_t) \tag{86}$$

$$\hat{B}_t = \hat{\theta}_t + g_\gamma\theta\frac{\tilde{q}_l L_e}{\tilde{B}}\mathbb{E}_t[\hat{q}_{lt+1} + \hat{L}_{et} + \hat{g}_{\gamma t+1}] + \left(1 - g_\gamma\theta\frac{\tilde{q}_l L_e}{\tilde{B}}\right)\mathbb{E}_t[\hat{q}_{kt+1} + \hat{K}_t + \hat{g}_{qt+1}] \tag{87}$$

$$\hat{g}_{zt} = \hat{\lambda}_{zt} + \hat{\nu}_{zt} - \hat{v}_{zt-1} \tag{88}$$

$$\hat{g}_{qt} = \hat{\lambda}_{qt} + \hat{\nu}_{qt} - \hat{v}_{zqt-1} \tag{89}$$

$$\hat{g}_{\gamma t} = \frac{1}{1-(1-\phi)\alpha}\hat{g}_{zt} + \frac{(1-\phi)\alpha}{1-(1-\phi)\alpha}\hat{g}_{qt} \tag{90}$$

$$\hat{\lambda}_{zt} = \rho_z\hat{\lambda}_{zt-1} + \hat{\varepsilon}_{zt} \tag{91}$$

$$\hat{\nu}_{zt} = \rho_{\nu_z}\hat{\nu}_{zt-1} + \hat{\varepsilon}_{\nu_z t} \tag{92}$$

$$\hat{\lambda}_{qt} = \rho_q\hat{\lambda}_{qt-1} + \hat{\varepsilon}_{qt} \tag{93}$$

$$\hat{\nu}_{qt} = \rho_{\nu_q}\hat{\nu}_{qt-1} + \hat{\varepsilon}_{\nu_q t} \tag{94}$$

$$\hat{\lambda}_{at} = \rho_a\hat{\lambda}_{at-1} + \hat{\varepsilon}_{at} \tag{95}$$

$$\hat{\varphi}_t = \rho_\varphi\hat{\varphi}_{t-1} + \hat{\varepsilon}_{\varphi t} \tag{96}$$

$$\hat{\psi}_t = \rho_\psi\hat{\psi}_{t-1} + \hat{\varepsilon}_{\psi t} \tag{97}$$

$$\hat{\theta}_t = \rho_\theta\hat{\theta}_{t-1} + \hat{\varepsilon}_{\theta t} \tag{98}$$

Following Sims (2001), the above linear system can be written in the following state-space form:

$$\Gamma_0 X_t = \Gamma_1 X_{t-1} + \Gamma_2 \varepsilon_t + \Gamma_3 \eta_t \tag{99}$$

where X_t is a 39 dimensional vector containing all the endogenous variables and the forward looking variables, ε_t is a 8 dimensional vector containing the 8 exogenous shocks, and η_t is a 11 dimensional vector containing 11 endogenous expectation errors. In specific, we have

$$X_t = (X_{1t}', \mathbb{E}_t[X_{2t+1}]', X_{3t}')' \tag{100}$$

where

$$X_{1t} = (\hat{\mu}_{ht}, \hat{w}_t, \hat{q}_{lt}, \hat{R}_t, \hat{\mu}_{et}, \hat{\mu}_{bt}, \hat{N}_t, \hat{I}_t, \hat{Y}_t, \hat{C}_{ht}, \hat{C}_{et}, \hat{q}_{kt}, \hat{L}_{ht}, \hat{L}_{et}, \hat{K}_t, \hat{B}_t, \hat{g}_{\gamma t}, \hat{g}_{zt}, \hat{g}_{qt}, \hat{C}_t)'_{20\times 1} \tag{101}$$

$$X_{2t+1} = (\hat{\mu}_{ht+1}, \hat{q}_{lt+1}, \hat{\mu}_{et+1}, \hat{I}_{t+1}, \hat{Y}_{t+1}, \hat{C}_{ht+1}, \hat{C}_{et+1}, \hat{q}_{kt+1}, \hat{g}_{\gamma t+1}, \hat{g}_{qt+1}, \hat{\lambda}_{at+1})'_{11\times 1} \tag{102}$$

$$X_{3t} = (\hat{\theta}_t, \hat{\psi}_t, \hat{\varphi}_t, \hat{\nu}_{qt}, \hat{\nu}_{zt}, \hat{\lambda}_{zt}, \hat{\lambda}_{at}, \hat{\lambda}_{qt})'_{8\times 1} \tag{103}$$

$$\varepsilon_t = (\hat{\varepsilon}_{zt}, \hat{\varepsilon}_{\nu_z t}, \hat{\varepsilon}_{qt}, \hat{\varepsilon}_{\nu_q t}, \hat{\varepsilon}_{at}, \hat{\varepsilon}_{\varphi t}, \hat{\varepsilon}_{\psi t}, \hat{\varepsilon}_{\theta t})'_{8\times 1} \tag{104}$$

$$\eta_t = X_{2t} - \mathbb{E}_{t-1}[X_{2t}] \tag{105}$$

6.2.2 Model with State-Contingent Interest Rate

This is the model described in Section 4.2. Equations are identical to those in Appendix 6.2.1 except for the following changes:

(75)→

$$\hat{\mu}_{ht} - \mathbb{E}_t[\hat{R}_{t+1}] = \mathbb{E}_t\left[\hat{\mu}_{ht+1} + \frac{\lambda_a}{1+\lambda_a}\hat{\lambda}_{at+1} - \hat{g}_{\gamma t+1}\right] \tag{106}$$

(81)→

$$\hat{\mu}_{et} - \mathbb{E}_t[\hat{R}_{t+1}] = \frac{1}{1+\lambda_a}(\mathbb{E}_t[\hat{\mu}_{et+1} - \hat{g}_{\gamma t+1}] + \lambda_a \hat{\mu}_{bt}) \tag{107}$$

(86)→

$$\alpha \hat{Y}_t = \frac{\tilde{C}_e}{\tilde{Y}}\hat{C}_{et} + \frac{\tilde{I}}{\tilde{Y}}\hat{I}_t + \frac{\tilde{q}_l L_e}{\tilde{Y}}(\hat{L}_{et} - \hat{L}_{et-1}) + \frac{1}{g_\gamma}\frac{\tilde{B}}{\tilde{Y}}(\hat{R}_t + \hat{B}^l_{t-1} - \hat{g}_{\gamma t}) - \frac{1}{R}\frac{\tilde{B}}{\tilde{Y}}\hat{B}^l_t \tag{108}$$

(87)→

$$\hat{R}_{t+1} + \hat{B}^l_t = \hat{\theta}_t + g_\gamma \theta \frac{\tilde{q}_l L_e}{\tilde{B}}\mathbb{E}_t[\hat{q}_{lt+1} + \hat{L}_{et} + \hat{g}_{\gamma t+1}] + \left(1 - g_\gamma \theta \frac{\tilde{q}_l L_e}{\tilde{B}}\right)\mathbb{E}_t[\hat{q}_{kt+1} + \hat{K}_t + \hat{g}_{qt+1}] \tag{109}$$

In state-space form the linearized system is now:

$$\Gamma_0 X_t = \Gamma_1 X_{t-1} + \Gamma_2 \varepsilon_t + \Gamma_3 \eta_t \tag{110}$$

where X_t is a 39 dimensional vector containing all the endogenous variables and the forward looking variables, ε_t is a 9 dimensional vector containing the 9 innovations (including the self-fulfilling one), and η_t is a 12 dimensional vector containing 12 endogenous expectation errors. In specific, we have

$$X_t = (X_{1t}', \mathbb{E}_t[X_{2t+1}]', X_{3t}')' \tag{111}$$

where

$$X_{1t} = (\hat{\mu}_{ht}, \hat{w}_t, \hat{q}_{lt}, \hat{\mu}_{et}, \hat{\mu}_{bt}, \hat{N}_t, \hat{I}_t, \hat{Y}_t, \hat{C}_{ht}, \hat{C}_{et}, \hat{q}_{kt}, \hat{L}_{ht}, \hat{L}_{et}, \hat{K}_t, \hat{B}_t, \hat{g}_{\gamma t}, \hat{g}_{zt}, \hat{g}_{qt}, \hat{C}_t)'_{19\times 1} \tag{112}$$

$$X_{2t+1} = (\hat{\mu}_{ht+1}, \hat{q}_{lt+1}, \hat{R}_{t+1}, \hat{\mu}_{et+1}, \hat{I}_{t+1}, \hat{Y}_{t+1}, \hat{C}_{ht+1}, \hat{C}_{et+1}, \hat{q}_{kt+1}, \hat{g}_{\gamma t+1}, \hat{g}_{qt+1}, \hat{\lambda}_{at+1})'_{12\times 1} \tag{113}$$

$$X_{3t} = (\hat{\theta}_t, \hat{\psi}_t, \hat{\varphi}_t, \hat{\nu}_{qt}, \hat{\nu}_{zt}, \hat{\lambda}_{zt}, \hat{\lambda}_{at}, \hat{\lambda}_{qt})'_{8\times 1} \tag{114}$$

$$\varepsilon_t = (\hat{\varepsilon}_{zt}, \hat{\varepsilon}_{\nu_z t}, \hat{\varepsilon}_{qt}, \hat{\varepsilon}_{\nu_q t}, \hat{\varepsilon}_{at}, \hat{\varepsilon}_{\varphi t}, \hat{\varepsilon}_{\psi t}, \hat{\varepsilon}_{\theta t}, \hat{\varepsilon}_{st})'_{9\times 1} \tag{115}$$

$$\eta_t = X_{2t} - \mathbb{E}_{t-1}[X_{2t}] \tag{116}$$

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