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Tight Money-Tight Credit: Coordination Failure in the Conduct of Monetary and Financial Policies

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Abstract

Violations of Tinbergen's Rule and strategic interaction undermine monetary and financial policies significantly in a New Keynesian model with the Bernanke-Gertler accelerator. Welfare costs of risk shocks are large because of efficiency losses and income effects of costly monitoring, but they are larger under a simple Taylor rule (STR) and a Taylor rule augmented with credit spreads (ATR) than under a dual rules regime (DRR) with a Taylor rule and a financial rule targeting spreads, by 264 and 138 basis points respectively. ATR and STR are tight money-tight credit regimes that respond too much to inflation and not enough to spreads, and yield larger fluctuations in response to risk shocks. Reaction curves display shifts from strategic substitutes to complements in the choice of policy-rule elasticities. The Nash equilibrium is also a tight money-tight credit regime, with welfare 30 basis points lower than in Cooperative equilibria and the DRR, but still sharply higher than in the ATR and STR regimes.

Keywords: Monetary policy; Financial frictions; Macroprudential policy; Leaning against the wind; Policy coordination
JEL classification: E3, E44, E52, G18

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1 Introduction

A broad consensus formed after the 2008 Global Financial Crisis around the ideas of implementing macroprudential financial regulation and incorporating financial stability considerations into monetary policy analysis. Putting these ideas into practice has proven difficult, however, partly because of heated debates surrounding two key questions: First, should financial stability considerations be added into monetary policy rules or be dealt with using separate financial policy rules? Second, if separate rules are used, should financial and monetary authorities coordinate their actions? For instance, Cúrdia and Woodford (2010), Eichengreen, Prasad and Rajan (2011), and Smets (2014), among others, have argued that central banks should react to financial stability conditions, even if there is a separate financial authority. This view is in line with the notion of using countercyclical monetary policy to *lean against the wind* of excessive credit or asset market bubbles. In contrast, Svensson (2014, 2015) and Yellen (2014) argue in favor of having a different authority addressing financial imbalances, while keeping the central bank focused on price stability. Other authors, such as De Paoli and Paustian (2017) or Angelini, Neri and Panetta (2014), study whether monetary and financial authorities should cooperate or not, what goals financial policy should pursue, and what policy settings are better for an optimal-policy arrangement.

This paper provides quantitative answers to the above two questions using a New Keynesian model with financial frictions and risk shocks. The model features inefficiencies that justify the use of monetary and financial policies. Monetary policy addresses the inefficiencies due to Calvo-style staggered pricing by monopolistic producers of differentiated intermediate goods. Financial policy addresses the inefficiencies introduced by the Bernanke-Gertler financial accelerator mechanism, which are due to costly state verification of entrepreneurs by financial intermediaries.

The effectiveness of alternative policy regimes is assessed in terms of their implications for social welfare, macroeconomic fluctuations, policy targets, and the elasticities of policy rules. Monetary policy is modeled as either a simple Taylor rule (STR) governing the nominal interest rate, or an augmented Taylor rule (ATR) targeting both inflation and credit spreads. To study the relevance of Tinbergen's rule, we compare the effectiveness of the STR and the ATR v. a dual rules regime (DRR) with a Taylor rule and a separate financial policy rule. The latter targets the external finance premium using as policy instrument a subsidy on the lenders' expected earnings from loans to entrepreneurs net of monitoring costs, so that a higher subsidy incentivizes lending when credit spreads rise. To make these policy regimes comparable, we implement each with welfare-maximizing values of the corresponding policy rule elasticities, defined as those that minimize welfare costs of risk shocks. Welfare costs are measured as compensating lifetime-utility-equivalent consumption variations relative to a deterministic steady state with zero inflation, zero external financial premium, and a subsidy neutralizing the distortion of monopolistic competition.[1]

[1] Since welfare assessments are critical for this analysis, we use a second-order approximation method and apply the pruning approach to simulate the model and evaluate expected lifetime utility.

To examine the importance of strategic interaction, we construct reaction curves in a strategy space defined over the elasticities of the Taylor rule and the financial policy rule. We construct sets of feasible values of these elasticities and compute the value of the elasticitity that maximizes the payoff of the monetary (financial) authority for each feasible value of the financial (monetary) rule elasticity. The payoff functions are in the class of quadratic loss functions widely used in monetary policy studies, defined in terms of the sum of variances of the instrument and target of each authority (as in Taylor and Williams, 2010; Williams, 2010). We then compute Nash and Cooperative equilibria for one-shot games between the two policy authorities, and contrast their implications for welfare and for the values of policy rule elasticities.[2] Since the case in which a single planner sets the elasticities of both policy rules to maximize social welfare (i.e. the DRR with welfare-maximizing elasticities) is equivalent to the outcome of a game in which both authorities share welfare as a common payoff, we label this the "Best Policy" scenario.

The analysis is conducted using the risk-shocks framework proposed by Christiano, Motto and Rostagno (2014) because these shocks strengthen the quantitative importance of the Bernanke-Gertler accelerator, so that the financial sector plays a relevant role in economic fluctuations and financial policy can be more useful.[3] Risk shocks are shocks to the standard deviation of the returns on entrepreneurs' investment projects, which in turn affect the entrepreneurs' probability of default and thus alter the supply of credit and the allocation of capital in the economy: As financial intermediaries cut lending, capital expenditures fall causing a decline in the price of capital and in net worth, which triggers the financial accelerator mechanism. Since the agency costs in the credit market result from a real rigidity, namely costly state verification, risk shocks are akin to financial shocks that create inefficient fluctuations in the external finance premium (i.e. credit spreads). Christiano *et al.* argue that these shocks can explain about 60 percent of U.S. GDP fluctuations.

We study monetary and financial policies in terms of policy rules, rather than optimal Ramsey policies, because of the widespread dominance of the Taylor rule for evaluating monetary policy with New Keynesian DSGE models, and because Ramsey-optimal financial policies often require global, non-linear solution methods and have been solved mainly in parsimonius RBC-like models with financial frictions (see Bianchi and Mendoza, 2018). For monetary policy, it is well-known that log-linear rules like the Taylor rule can be derived as optimal policies when the policymakers' payoffs are specified as quadratic functions of target variables (or linear in their variances), but it has also been established that in most widely-used DSGE models these rules differ from the

[2]This methodology is analogous to the one used by Mendoza and Tesar (2005) to study international tax competition, and is also related to Dixit and Lambertini (2003)'s analysis of monetary-fiscal interactions.

[3]In the online Appendix B.6 we study how our results vary with shocks to TFP, government expenditures, and the price markup of intermediate goods (i.e. nominal cost-push shocks). Financial policy is less relevant with the first two shocks, because of the standard result that in New Keynesian models solved with local methods the amplification produced by the Bernanke-Gertler accelerator in response to those shocks is small. In contrast, financial policy is relevant with markup shocks because they move inflation and output in opposite directions, and hence financial policy can complement monetary policy by reducing the output loss of lowering inflation.

solution of Ramsey optimal policy problems under commitment.[4] Still, monetary and financial authorities act optimally in our setup, in the sense that they set the elasticities of their rules so as to maximize explicit payoff functions.

In the model we propose, Tinbergen's rule applies because two instruments are needed to tackle the two inefficiencies affecting the economy (sticky prices and costly state verification). Hence, the question is not whether Tinbergen's Rule is valid as a theoretical premise in the model, but whether it is quantitatively relevant. In particular, the paper's contribution is in determining whether there are important differences in policy rule elasticities, welfare, and the macro effects of risk shocks across the STR, ATR, and DRR regimes. Similarly, the result that incentives for strategic interaction are present in the model is straightforward, so the contribution of the paper in this regard is also quantitative, and focuses on whether strategic interaction is quantitatively significant for the effectiveness of financial and monetary policies.[5] Incentives for strategic interaction exist because the target variable of each authority is influenced by the instruments of both authorities. Inflation is partly determined by the effect of the financial authority's subsidy on investment and hence aggregate demand, and the credit spread is partly determined by the effect of the nominal interest rate on the lenders' participation constraint.

The risk that costly strategic interaction among financial and monetary policies can undermine their effectiveness is relevant for the various institutional arrangements through which these policies are carried out today. This is clearly the case in countries where the two policies are set by separate authorities, or where financial policy is only partially the purview of the central bank. But strategic interaction can still be an issue even in countries like the United Kingdom, where the two policies are within the domain of the central bank but designed by separate committees that could face incentives for acting strategically.

The quantitative analysis yields four key results:

(1) Welfare costs of risk shocks are generally large. Welfare in the three policy regimes is significantly lower than in the deterministic stationary state. The costs range from 3.9 to 6.5 percent, compared with typical measures of the cost of U.S. business cycles of around $1/10$ of a percent, or estimates of the cost of U.S. tax distortions of around 2 percent. These large welfare costs are the result of income effects and efficiency losses due to changes in the long-run averages of the external finance premium and the resources allocated to monitoring costs, which in turn result from the effects of risk shocks and costly state verification on the model's stochastic stationary state.

[4] Woodford (2010) reviews optimal monetary policy in New Keyenesian models, including the conditions under which monetary policy rules match Ramsey optimal policies. Bodenstein, Guerrieri and LaBriola (2014) analyze strategic interaction in monetary policy between countries and in monetary v. financial policy in a Ramsey setup.

[5] Analytically, the argument is similar to those exposed in other contexts, such as in the large literature dealing with international coordination of tax, monetary, or exchange-rate policies, in which actions of one policy authority affect the variables driving the payoff of another.

(2) The implications of violating Tinbergen's Rule are large. Welfare is 264 and 138 basis points lower under the STR and the ATR, respectively, than under the DRR, and the macro fluctuations in response to risk shocks are markedly smoother with the DRR. Hence, while "leaning against the wind" of financial conditions is welfare-improving relative to not responding to financial conditions at all, as in Cúrdia and Woodford (2010), the DRR regime is significantly better. Moreover, the STR regime yields a higher elasticity in the response to inflation than the ATR and DRR regimes, and by construction it does not respond to spreads. The ATR has a marginally higher inflation response but again a much weaker response to spreads than the DRR. Hence, the ATR and STR are "tight money-tight credit" regimes, because the interest rate responds too much to inflation and not enough to adverse credit conditions. These results reflect the general principle of Tinbergen's Rule, requiring two instruments for two targets: The ATR using one instrument cannot do as well at tackling the two sources of inefficient fluctuations present in the model as the DRR does using two separate instruments. The DRR regime weakens significantly the adverse long-run effects of risk shocks on the external finance premium and monitoring costs, and provides an insurance-like mechanism that weakens the effects of risk shocks on consumption dynamics.

(3) The reaction curves of monetary and financial authorities display shifts from strategic substitutes to complements in the best choice of policy rule elasticities. For the monetary authority, the best elasticity response for the Taylor rule is a strategic substitute of the elasticity of the financial rule if the latter is sufficiently high but a strategic complement otherwise (i.e. the monetary authority's reaction function shifts from downward to upward sloping as the financial rule elasticity rises sufficiently).[6] The reaction function of the financial authority is convex, with the elasticity of the financial rule changing from strategic complement to strategic substitute as the elasticity of the monetary rule increases.

(4) Strategic interaction is quantitatively significant. The Nash equilibrium yields a welfare loss of about 30 basis points relative to either the Best Policy scenario or Cooperative equilibria with either equal welfare weights or weights "optimized" to yield the smallest welfare cost. These cooperative equilibria yield welfare outcomes that are very similar to the Best Policy. The Nash outcome yields again a tight money-tight credit regime relative to the Best Policy case. A Stackelberg game with the financial authority as leader yields a similar outcome as the Nash equilibrium, but if the monetary authority leads the Stackelberg game yields an even tighter money regime with a larger welfare cost. In addition, the Nash equilibrium dominates the STR and ATR regimes by large margins, with welfare outcomes that are 234 and 108 basis points higher than each of these regimes, respectively. Hence, even a regime in which separate authorities engage in non-cooperative Nash competition is better than regimes with just a monetary rule (either STR or ATR) in place.

[6] Usually, the elasticity of a policy rule is strategic complement (substitute) to the elasticity of another policy rule when the best response in the choice of the former increases (decreases) as the latter increases, i.e. when the reaction function is upward (downward) sloping. In our setup, however, lowering the elasticity of the financial rule when the elasticity of the Taylor rule rises means tightening financial policy when monetary policy tightens. Thus, the policy rule elasticities are strategic complements (substitutes) when reaction functions are downward (upward) sloping.

The gains from coordination arise because, around the Nash equilibrium, the reaction function of the monetary authority is almost at the point where the Taylor rule elasticity switches from strategic substitute to strategic complement of the financial rule elasticity, while the financial authority's best response is nearly independent of the elasticity choice of the monetary authority (albeit at a higher level than in the Cooperative outcome). This indicates that there are large adverse spillovers of financial subsidy changes on the volatility of inflation and/or interest rates through the model's general equilibrium dynamics. A small increase or fall in the financial rule elasticity around the Nash equilibrium increases the volatility of inflation and the nominal interest rate sufficiently to justify an increase in the elasticity of the monetary rule as the best response.

Cooperation tackles these adverse spillovers by correcting the tight money-tight credit nature of the Nash policy rules, which implies lowering (increasing) the inflation (spread) elasticity relative to the Nash equilibrium. Without coordination, this is not sustainable because both authorities have incentives to deviate, since the cooperative equilibrium is not a point in either authority's reaction function. At the symmetric Cooperative equilibrium, the financial authority acting unilaterally would aim to reduce its elasticity sharply in order to move back to its reaction curve, and the monetary authority would increase its Taylor rule elasticity sharply for the same reason.

This paper is related to the recent quantitative literature using New Keynesian DSGE models with financial frictions to examine monetary and financial policy interactions, particularly the studies comparing cooperative and noncooperative outcomes by Angelini *et al.* (2014), Bodenstein *et al.* (2014), De Paoli and Paustian (2017) and Van der Ghote (2016). These papers adopt different formulations of financial frictions, financial policy instruments, and exogenous shocks. Our work differs in that we construct reaction curves that characterize strategic behavior and illustrate the changing incentives to adjust policy rule elasticities as strategic substitutes v. strategic complements, and in that we find gains from policy coordination under commitment.

De Paoli and Paustian find that the gains from policy coordination are non-negligible in games without commitment and for mark-up shocks, while for shocks to net worth or productivity the gains are negligible. Bodenstein *et al.* solve for Nash equilibria with commitment using only TFP shocks and payoff functions with a varying degree of bias in favor of inflation (for the central bank) and the credit spread (for the financial authority), and find that gains from cooperation can be significant. Angelini *et al.* find that the benefits of introducing financial policy, in the form of a time-varying capital requirement, are substantial when financial shocks are the driver of business cycle, but policy coordination results in small differences in output, inflation, and credit. Van der Ghote proposes a continuous time-model with TFP shocks and an occasionally-binding leverage constraint but without capital accumulation. He studies welfare-based payoff functions allowing financial policy to produce long-run efficiency gains but using a tax to neutralize those resulting from price stability, and finds a modest gain from coordinating policies of 0.21 percent. In contrast, we study both welfare-based and quadratic-loss payoff functions removing long-run efficiency effects of both monetary and financial policies, and found larger gains from policy coordination.

Our findings on Tinbergen's rule are consistent with results from studies comparing standard with augmented monetary policy rules by Angeloni and Faia (2013), Angelini *et al.* (2014), Kannan, Rabanal and Alasdair (2012) and Quint and Rabanal (2014). Angeloni and Faia study a model with bank runs and nominal rigidities driven by TFP shocks, quantifying the implications of monetary and bank capital rules with given coefficients. They find that responding to financial conditions is always better than not in terms of social welfare and output variability. Moreover, monetary rules with more aggressive inflation responses perform better, in line with our tight money result. Angelini *et al.* also find that a monetary rule that responds to the loan-output ratio yields lower output variability than a standard monetary policy rule, but did not examine the welfare implications. Kannan *et al.* examine a model with housing assuming that the credit spread is given by an exogenous function, increasing in the borrowers' leverage and in a financial policy instrument. In line with our findings, they find that (using a variance loss function as metric) an ATR dominates a STR, and a regime with separate monetary and financial rules is best. Our work differs in that the credit spread follows from an optimal contract and also in that they did not study strategic interaction. Quint and Rabanal study a two-country (core v. periphery) model with risk shocks in housing investment, and find that an ATR yields higher welfare if it responds to nominal credit growth but not if it responds to the credit-to-GDP ratio. Welfare assessments are complex, however, because the model includes two countries and separates savers and borrowers, and financial policy can be costly for the latter. The augmented monetary rule can improve welfare in the periphery because it can reduce macro volatility in that region.

Finally, our work is also related to Aoki, Benigno and Kiyotaki (2015), who analyze the quantitative interaction between monetary and financial policy in a small open economy subject to world interest rate shocks with financial frictions à la Gertler-Karadi-Kiyotaki. They compare welfare effects for a small set of elasticity pairs of the Taylor rule and a financial policy rule (in the form of a tax on bank external debt) for different variances of interest-rate shocks and with fixed v. flexible prices. They do not study strategic interaction or Tinbergen's rule, but their findings are in line with ours in that they find that welfare displays significant interaction effects as the two elasticities change, which are consistent with our finding of shifts between strategic complements and substitutes in reaction functions: In their baseline case, welfare is higher monotonically at higher financial rule elasticities for a given Taylor rule elasticity, and at higher Taylor-rule elasticities for a given financial rule elasticity, but for a larger variance of world interest-rate shocks, welfare is monotonically decreasing (increasing) as the Taylor-rule elasticity rises for a lower (higher) elasticity of the financial rule.

The rest of the paper is organized as follows: Section 2 describes the model. Section 3 provides a diagrammatic analysis of the effects of risk shocks and the interaction of financial and monetary policies. Section 4 describes the calibration of the model and discusses the quantitative findings. Section 5 presents conclusions.

2 Model Structure

The model is based on the one proposed by Christiano *et al.* (2014) to introduce risk shocks into the New Keynesian model with the Bernanke-Gertler financial accelerator developed by Bernanke, Gertler and Gilchrist (1999), CMR and BGG, respectively hereafter. The model includes six types of agents: a final-goods producer, a set of intermediate-goods producers, a physical capital producer, a financial intermediary, entrepreneurs, and households. As mentioned earlier, the model features two sources of inefficiency: Calvo staggered price-setting by non-competitive intermediate goods producers, and costly state verification in financial intermediation. In general, these frictions affect both the steady state allocations and business cycle dynamics, but since our analysis focuses on stabilization policies, we introduce adjustments that neutralize the effects of the frictions on the deterministic steady state. In particular, we postulate Taylor and financial rules that target zero inflation and a zero external finance premium in the steady state, respectively, and introduce a time-invariant subsidy on intermediate goods producers that removes the steady-state effect of monopolistic competition.[7] Because asset markets are incomplete, however, alternative policy regimes yield stochastic steady states that differ from the deterministic steady state due to differences in long-run averages of monitoring costs and the external finance premium (as shown in Section 3). Since several features of the model are similar to those in BGG and CMR, the presentation is kept short, except for parts that are new or key for the questions this paper addresses. Full details of the model structure are provided in Sections A.1-A.9 of the Appendix.

2.1 Households

The economy is inhabited by a representative agent who chooses sequences of consumption, c_t, labor supply, ℓ_t^h, and real deposits, d_t, to maximize expected lifetime utility. The agent's optimization problem is:

$$\max_{c_t,\ell_t^h,d_t} \mathrm{E}_T \left\{ \sum_{t=T}^{\infty} \beta^{t-T} \frac{\left[\left(c_t - hC_{t-1}\right)^{\upsilon} \left(1-\ell_t^h\right)^{1-\upsilon} \right]^{1-\sigma} - 1}{1-\sigma} \right\}, \tag{2.1}$$

subject to the budget constraint

$$c_t + d_t \leq w_t \ell_t^h + \frac{R_{t-1}}{1+\pi_t} d_{t-1} + \mathrm{div}_t + \mathcal{A}_t - \Upsilon_t \text{ for all } t. \tag{2.2}$$

In the utility function (2.1), $\beta \in (0,1)$ is the subjective discount factor, $h \in [0,1]$ determines the degree of dependence on external habits, which is driven by aggregate consumption from the previous period (C_{t-1}), $\sigma > 0$ is the coefficient of relative risk aversion, $\upsilon \in (0,1)$ is the labor share parameter, and E_t is the expectations operator conditional on the information available at date t. In the budget constraint (2.2), the uses of income in the left-hand-side are assigned to purchases of consumption goods and bank deposits. The sources of income in the right-hand-side derive from wages, where w_t is the real wage rate, from the real return on deposits carried over from the

[7] Subsidies to producers and financial intermediaries are financed with lump-sum taxes on households, set at rates such that output in the deterministic steady state is the same as under flexible prices and costless monitoring.

previous period, where $1 + \pi_t = P_t/P_{t-1}$ is the gross inflation rate from period $t-1$ to t (P_t is the price of final goods at date t) and R_{t-1} is the gross nominal interest rate paid on one-period nominal deposits, which is also the central bank's policy instrument, and from real profits paid by monopolistic firms (div_t) plus transfers from entrepreneurs ($\mathcal{A}_t$) net of lump-sum taxes levied by government (Υ_t). The first-order conditions of this problem are standard, and hence are included in Appendix A.1.

2.2 Entrepreneurs

There is a continuum of risk-neutral entrepreneurs, indexed by $e \in [0,1]$. At time t, a type-e entrepreneur purchases physical capital, $k_{e,t}$, at a relative price, q_t, using her own net worth, $n_{e,t}$, and one-period debt, $b_{e,t}$. Hence, the entrepreneur's budget constraint is: $q_t k_{e,t} = b_{e,t} + n_{e,t}$. At date $t+1$, entrepreneurs rent out capital services to intermediate goods producers at a real rental rate z_{t+1} and sell the capital stock that remains after production to a capital producer. As in BGG and CMR, entrepreneurs are heterogeneous because the return gained by an individual entrepreneur is affected by an idiosyncratic shock $\omega_{e,t+1}$. Hence, an entrepreneur's real return at time $t+1$ is $\omega_{e,t+1} r^k_{t+1} k_{e,t}$, where r^k_{t+1} is the aggregate real rate of return per unit of capital, given by

$$r^k_{t+1} \equiv \frac{z_{t+1} + (1-\delta) q_{t+1}}{q_t}, \tag{2.3}$$

where δ is the rate of capital depreciation.

The random variable $\omega_{e,t+1}$ is i.i.d. across time and entrepreneurs, with $\mathrm{E}(\omega_{e,t+1}) = 1$, $\mathrm{SD}(\omega_{e,t+1}) = \sigma_{\omega,t+1}$, and a continuous and once-differentiable c.d.f., $F(\omega_{e,t+1})$, over a non-negative support. Following CMR, the stochastic process of $\omega_{e,t+1}$ features risk shocks, which are represented by the time-varying standard deviation $\sigma_{\omega,t+1}$, with a long-run average $\bar{\sigma}_\omega$. An increase in $\sigma_{\omega,t+1}$ implies that $F(\omega_{e,t+1})$ widens. As shown below, this prompts a larger share of entrepreneurs to go bankrupt.

Entrepreneurs participate in the labor market by offering one unit of labor each period at the real wage rate w^e_t.[8] Also, entrepreneurs have finite life horizons, with each entrepreneur facing a probability of exit given by $1-\gamma$. This assumption prevents entrepreneurs from accumulating enough wealth to be fully self-financed. Aggregate net worth in period t is thus given by

$$n_t = \gamma v_t + w^e_t. \tag{2.4}$$

where v_t is the aggregate equity from capital holdings of entrepreneurs who survive at date t, which is defined in the next subsection. Entrepreneurs who exit at t transfer their wages to new entrepreneurs entering the economy and consume part of their equity, such that $c^e_t = (1-\gamma)\varrho v_t$ for $\varrho \in [0,1]$, and the remainder of their equity, $\mathcal{A}_t = (1-\gamma)(1-\varrho) v_t$, is transferred to households as a lump-sum payment.

[8]As noted by BGG, this is necessary so that entrepreneurs have some net worth to begin operations.

2.3 The lender and the financial contract

The financial intermediary takes deposits from households at the risk-free nominal interest rate R_t. Deposits are used to fund loans to entrepreneurs, which are risky and subject to the costly-monitoring financial friction: Nominal loan contracts are made before the entrepreneurs' returns are realized and these returns are not observable by the intermediary, but can be verified at a cost.[9] The optimal credit contract is modeled following the setup developed by Bernanke and Gertler (1989) to introduce the costly-state-verification contracting problem proposed by Townsend (1979) into a New Keynesian business cycles framework. We add to this framework a financial subsidy on the lender's participation constraint that is used as the instrument of financial policy.

At time t, when the financial contract is signed, the idiosyncratic shock $\omega_{e,t+1}$ is unknown to both the entrepreneur and the lender. At $t+1$, if $\omega_{e,t+1}$ is higher than a threshold value $\bar{\omega}_{e,t+1}$, the entrepreneur repays her debt plus interest, $r^L_{e,t+1}b_{e,t}$, where r^L_t is the gross real interest rate on loans. In contrast, if $\omega_{e,t+1}$ is lower than $\bar{\omega}_{e,t+1}$, the entrepreneur declares bankruptcy and gets nothing, while the lender audits the entrepreneur, pays the monitoring cost, and gets to keep any income generated by the entrepreneur's investment. The monitoring cost is a proportion $\mu \in [0,1]$ of the entrepreneur's returns, i.e. $\mu\omega_{e,t+1}r^k_{t+1}q_t k_{e,t}$. The threshold value $\bar{\omega}_{e,t+1}$ satisfies:

$$\bar{\omega}_{e,t+1}r^k_{t+1}q_t k_{e,t} = r^L_{e,t+1}b_{e,t}. \tag{2.5}$$

The optimal contract sets an amount of capital expenditures and a threshold $\bar{\omega}_{e,t+1}$ such that the expected return of entrepreneurs is maximized subject to the lender's participation constraint holding for each value that r^k_{t+1} can take.[10] Since the entrepreneurs' risk is idiosyncratic, and thus can be perfectly diversified, participation by the lenders requires that the return on making loans be equal to the risk-free interest rate paid on deposits.

The type sub-index can be dropped without loss of generality to characterize the optimal contract. The expected return of entrepreneurs is:

$$\mathrm{E}_t\left\{\left[1-\Gamma(\bar{\omega}_{t+1})\right]r^k_{t+1}q_t k_t\right\}, \tag{2.6}$$

where $\Gamma(\bar{\omega}) = \bar{\omega}\int_{\bar{\omega}}^{\infty} f(\omega)d\omega + \int_0^{\bar{\omega}} \omega f(\omega)d\omega$.[11] The participation constraints of the lenders satisfy this condition for each value of r^k_{t+1}:

$$(1+\tau_{f,t})\left[\Gamma\left(\bar{\omega}_{t+1}\right) - \mu G\left(\bar{\omega}_{t+1}\right)\right]r^k_{t+1}q_t k_t \geq r_t b_t, \tag{2.7}$$

where $r_t = \frac{R_t}{1+\pi_{t+1}}$ is the ex-post real interest rate, which reflects the fact that the debt contracts are denominated in nominal terms, $\mu G(\bar{\omega}) = \mu\int_0^{\bar{\omega}} \omega f(\omega)d\omega$ represents the expected monitoring costs per unit of aggregate capital returns, and $\tau_{f,t}$ is a subsidy (a tax if negative) that the financial authority provides to the financial intermediary on its net loan revenues, with the associated cost

[9] For convenience, we express the returns of entrepreneurs and the lender in real terms, but we emphasize in the lender's participation constraint that the relevant opportunity cost of funds is the nominal interest rate R_t.

[10] The contract has an equivalent representation in terms of a loan amount and an interest rate. The loan size follows from the fact that net worth is pre-determined when the contract is entered and $q_t k_{e,t} = b_{e,t} + n_{e,t}$, and the interest rate is given by condition (2.5).

[11] For a given r^k, notice that if $\omega \geq \bar{\omega}$ the returns of the entrepreneur are given by $\omega r^k qk - r^L b$. Using equation (2.5), we can rewrite the last expression as $(\omega - \bar{\omega})\,r^k qk$. Taking expectations with respect to ω yields $\int_{\bar{\omega}}^{\infty}(\omega-\bar{\omega})\,r^k qk\mathrm{d}\omega$, which after some algebraic manipulations leads to (2.6).

(revenue) financed (rebated) as a lump-sum tax (transfer) to households. The left-hand-side of equation (2.7) is the after-subsidy lender's income from lending to entrepreneurs, both those who default and those who repay, net of monitoring costs, and the right-hand-side is the cost of funding all the loans.

The optimal financial contract consists of the pair $(qk, \bar{\omega})$ that maximizes (2.6) subject to the set of constraints (2.7). Except for the addition of the financial subsidy, the first-order conditions of this problem are standard and thus are provided in Appendix A.3. Since the subsidy is non-state-contingent, it is straightforward to see that the results in BGG apply directly (simply redefine the interest rate determining funding costs as $R_t/(1+\tau_{f,t})$). Thus, the equilibrium in the credit market can be summarized by the following external finance premium (efp) condition:

$$\mathrm{E}_t \left\{ \frac{r_{t+1}^k}{r_t} \right\} = \frac{s(x_t)}{1+\tau_{f,t}}. \tag{2.8}$$

The ratio $\mathrm{E}_t \left\{ r_{t+1}^k / r_t \right\}$ is the efp or credit spread, $x_t \equiv q_t k_t / n_t$ is aggregate leverage, and $s(\cdot)$ is a function such that $s(\cdot) \geq 1$ and $\partial s(\cdot)/\partial x_t > 0$ for $n_t < q_t k_t$. This expression is similar to the one assumed by Kannan et al. (2012), but here it is derived from the optimal Bernanke-Gertler contract.

The above expression reflects the equilibrium requirement that, for entrepreneurs that need external financing, the return to capital must equal the marginal external financing cost. The efp depends positively on the leverage ratio, because higher leverage reflects higher reliance on debt to finance capital expenditures. The financial subsidy is akin to a subsidy on monitoring costs that lowers the efp charged for a given value of $s(\cdot)$. Risk shocks increase the efp, because an increase in σ_ω implies more risk, in the sense of a higher probability of a low ω for entrepreneurs. This increases the interest rate that financial intermediaries charge for loans, and thus $s(\cdot)$ rises.

The credit spread also represents the model's financial wedge as the engine of the Bernanke-Gertler financial accelerator of business cycles. Costly verification creates an efficiency wedge in the allocation of capital.[12] If entrepreneurs' average net worth falls and is sufficiently low relative to their assets to generate a positive credit spread, they are more likely to default, which leads the financial intermediary to cut lending, which in turn reduces capital expenditures and increases the returns on capital r^k. This causes a decline in the price of capital, which reduces net worth further and triggers the accelerator mechanism. Risk shocks operate through the same mechanism, because an increase in $\sigma_{\omega,t}$ also makes it more likely that entrepreneurs default, everything else the same. Conversely, the financial subsidy is a tool that aims to offset the higher spreads and larger inefficiencies that would otherwise result from shocks that increase $s(\cdot)$.

The inefficiently low credit and capital allocation under the optimal contract justifies the policy intervention with the financial subsidy. In principle, if the financial regulator had complete information and could impose state-contingent subsidies, the subsidy could be managed optimally to fluctuate over time and across states of nature to remove the credit spread and the inefficiency

[12] The inefficiency follows from the lender's participation constraint (2.7), because moral hazard induces lenders to offer too little credit in order to avoid large monitoring costs. Hence, credit and capital are smaller than in the efficient allocation (i.e. one with no information asymmetries, or $\mu = 0$, and no credit spread).

completely. In this model, however, this is not possible because credit contracts are signed at date t with the value of the subsidy known, but before the realizations of aggregate and idiosyncratic shocks for $t+1$ are known.

The optimal credit contract implies that the aggregate capital gains of entrepreneurs (i.e. the entrepreneurs' equity for the beginning of the next period) are given by:

$$\begin{aligned} v_t &= [1-\Gamma(\bar{\omega}_t)]\, r_t^k q_{t-1} k_{t-1}, \qquad \text{or} \\ &= r_t^k q_{t-1} k_{t-1} [1-\mu G(\bar{\omega}_t)] - \frac{r_{t-1} b_{t-1}}{1+\tau_{f,t}}. \end{aligned} \tag{2.9}$$

2.4 Capital Producer

The representative capital producer operates in a perfectly competitive market. At the end of period $t-1$, entrepreneurs buy from it the capital stock to be used in period t, i.e. k_{t-1}. Once intermediate goods are sold and capital services paid, entrepreneurs sell back to the capital producer the remaining stock of capital, net of depreciation. The capital producer then builds new capital, k_t, by adding investment, i_t, net of adjustment costs, $\Phi\left(\frac{i_t}{i_{t-1}}\right)$, to the existing capital, $(1-\delta)\,k_{t-1}$. The capital producer's problem is:

$$\max_{i_t} \mathrm{E}_T \sum_{t=T}^{\infty} \beta^{t-T} \frac{\lambda_t}{\lambda_T} \left\{ q_t \left[k_t - (1-\delta) k_{t-1}\right] - i_t \right\}, \ \text{ subject to} \tag{2.10}$$

$$k_t = (1-\delta)\, k_{t-1} + \left[1 - \Phi\left(\frac{i_t}{i_{t-1}}\right)\right] i_t, \text{ for all } t.$$

Since households own the firm that produces capital, its profits are discounted at the rate $\beta^{t-T}\frac{\lambda_t}{\lambda_T}$ for $t \geq T$, where λ_t is the Lagrange multiplier of the household's budget constraint. We use the formulation of *investment* adjustment costs from Christiano, Eichenbaum and Evans (2005), according to which old and new investment goods are combined to produce new capital units, with a quadratic form $\Phi\left(\frac{i_t}{i_{t-1}}\right) = (\eta/2)\left[i_t/i_{t-1} - 1\right]^2$.

2.5 Final Goods Producer

Final goods, y_t, are used for consumption and investment, and produced in a competitive market by a representative producer who combines a continuum of intermediate goods indexed by $j \in [0,1]$, via the CES production function $y_t = \left(\int_0^1 y_{j,t}^{\frac{\theta-1}{\theta}} \mathrm{d}j\right)^{\frac{\theta}{\theta-1}}$, where $y_{j,t}$ denotes demand for intermediate good j at date t, and θ is the elasticity of substitution among intermediate goods. Profit maximization yields standard demand functions $y_{j,t} = \left(\frac{P_{j,t}}{P_t}\right)^{-\theta} y_t$. The general price index is given by

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta} \mathrm{d}j\right)^{\frac{1}{1-\theta}}, \tag{2.11}$$

where $P_{j,t}$ denotes the price of the intermediate good produced by firm j.

2.6 Intermediate Goods Producers

Intermediate goods producers engage in monopolistic competition and produce differentiated goods using labor and capital services, namely $\ell_{j,t}$ and $k_{j,t-1}$, for the production of good j at date t. Total labor input in each firm results from combining household labor, $\ell_{j,t}^h$, and entrepreneurial labor, $\ell_{j,t}^e \equiv 1$, with a Cobb-Douglas function $\ell_{j,t} = \left(\ell_{j,t}^h\right)^{\Omega}\left(\ell_{j,t}^e\right)^{1-\Omega}$. Each intermediate good is also produced with a Cobb-Douglas technology

$$y_{j,t} = \ell_{j,t}^{1-\alpha} k_{j,t-1}^{\alpha}. \tag{2.12}$$

The cost function $\mathbb{S}(y_{j,t})$ associated with production of $y_{j,t}$ follows from a standard cost-minimization problem:

$$\mathbb{S}(y_{j,t}) = \min_{\ell_{j,t}^h,\, z_t} \left\{ w_t \ell_{j,t}^h + z_t k_{j,t-1} + w_t^e,\ \text{subject to } (2.12)\right\}. \tag{2.13}$$

The marginal cost is therefore $mc_{j,t} \equiv \partial\mathbb{S}(\cdot)/\partial y_{j,t}$.

Intermediate goods producers face a nominal rigidity in their pricing decision in the form of Calvo (1983)'s staggered pricing mechanism. At every date t, each producer gets to adjust its price optimally with a constant probability $1-\vartheta$, and with probability ϑ it can only adjust its price following a passive indexation rule $P_{j,T} = \iota_{t,T} P_{j,t}$, where $t < T$ is the period of last re-optimization and $\iota_{t,T}$ is a price-indexing rule, defined as $\iota_{t,T} = (1+\pi_{T-1})^{\vartheta_p}(1+\pi)^{1-\vartheta_p}\iota_{t,T-1}$ for $T > t$ and $\iota_{t,t} = 1$. The coefficient $\vartheta_p \in [0,1]$ measures the degree of past-inflation indexation of intermediate goods prices and π is the inflation rate at the deterministic steady state. In order to remove the distortion of monopolistic competition on this steady state, we assume that the government provides a time-invariant subsidy τ_p so that aggregate output in the deterministic steady state reaches the same level as in the flexible-price economy.

Let $P_{j,t}^\star$ denote the nominal price optimally chosen in time t and $y_{j,t,T}$ denote the demand for good j in period $T \geq t$ for a firm that last re-optimized its price in period t. Producer j selects $P_{j,t}^\star$ to maximize the expected present discounted value of profits (again discounting using the household's stochastic discount factors), taking as given the demand curve for its product:

$$P_{j,t}^\star = \max_{P_{j,t}} \left\{ \begin{array}{c} \mathrm{E}_t \left\{ \sum_{T=t}^{\infty} (\beta\vartheta)^{T-t} \frac{\lambda_T}{\lambda_t} \left[\frac{\iota_{t,T} P_{j,t}}{P_T} y_{j,t,T} - (1-\tau_p)\, mc_T y_{j,t,T} \right] \right\} \\ \text{subject to } y_{j,t,T} = \left(\frac{\iota_{t,T} P_{j,t}}{P_T}\right)^{-\theta} y_T \end{array} \right\}. \tag{2.14}$$

To support the flexible price production levels at the deterministic steady state, the production subsidy must be equal to the inverse of the price markup, so $1-\tau_p = (\theta-1)/\theta < 1$. Despite this adjustment, sticky prices still create a distortion that affects macroeconomic fluctuations in the form of price dispersion. Following Yun (1996), we show in Appendix A.6, that aggregate production can be expressed as:

$$y_t = \frac{1}{\Delta_t} (k_{t-1})^{\alpha} (\ell_t)^{1-\alpha}, \tag{2.15}$$

where $\Delta_t = \int_0^1 (P_{j,t}/P_t)^{-\theta} \mathrm{d}j \geq 1$ represents the efficiency cost of price dispersion.

2.7 Policy rules

Policy rules are specified as standard log-linear rules that adjust policy instruments to deviations of policy objectives from their targets. In the STR regime, there is no financial policy rule and the monetary policy rule sets the nominal interest rate following this simple Taylor rule:

$$R_t = R \times \left(\frac{1+\pi_t}{1+\pi} \right)^{a_\pi}, \tag{2.16}$$

where a_π is the elasticity of R_t with respect to inflation deviations from target, R is the steady-state gross nominal interest rate, and π is the central bank's inflation target.[13] In the ATR regime, there is again no financial policy rule but the Taylor rule is augmented with the deviation of the efp from its target, so that the monetary policy rule becomes:

$$R_t = R \times \left(\frac{1+\pi_t}{1+\pi} \right)^{a_\pi} \left(\frac{\mathrm{E}_t \left\{ r^k_{t+1}/r_t \right\}}{r^k/r} \right)^{-\breve{a}_{rr}}, \tag{2.17}$$

with $\breve{a}_{rr} \geq 0$. The elasticity with respect to the credit spread enters with a negative sign because increases in the credit spread cause a decline in investment and hence aggregate demand, to which the monetary authority responds by lowering its policy interest rate.

In the DRR regime, monetary policy follows the same Taylor rule as in the STR regime, but in addition the financial authority follows this rule to set the financial subsidy:

$$1+\tau_{f,t} = (1+\tau_f) \times \left(\frac{\mathrm{E}_t \left\{ r^k_{t+1}/r_t \right\}}{r^k/r} \right)^{a_{rr}}, \tag{2.18}$$

where r^k/r is the target value of the gross external finance premium (credit spread) at steady state, which as we explained earlier is set to a net value of zero (i.e. $r^k/r = 1$) so as to remove the steady-state effect of the efp. Hence, τ_f is the value of the financial subsidy that ensures that $r^k = r$ in the deterministic steady-state. Notice that τ_f is present even in the STR and ATR regimes that do not have a financial policy rule for targeting efp, so that all policy regimes yield the same steady-state capital-output ratio.

2.8 Resource and government budget constraints

The government's budget constraint is:

$$\Upsilon_t = g + \tau_p s_t \int_0^1 y_{j,t} \mathrm{d}j + \tau_{f,t} \left[\Gamma(\bar{\omega}_t) - \mu G(\bar{\omega}_t) \right] r^k_t q_{t-1} k_{t-1}. \tag{2.19}$$

Government expenditures, g, are kept constant. The government runs a balanced budget, so that the sum of government expenditures, plus subsidies to monopolist producers, plus financial subsidies is paid for by levying lump-sum taxes in the amount Υ_t on households.

[13] We do not include the output gap for simplicity and because quantitatively this model yields higher welfare if the Taylor rule does not respond to the output gap than if it does (see Subsection 4.4.2 for details).

Combining the resource flow conditions of the various agents in the model (budget constraints, net worth, equity of entrepreneurs, firm dividends, etc.) together with the above government budget constraint yields the following aggregate resource constraint:

$$y_t = c_t + i_t + c_t^e + g + \mu G(\bar{\omega}_{e,t}) r_t^k q_{t-1} k_{t-1}. \tag{2.20}$$

Total production is allocated to consumption, investment, government expenditures, and monitoring costs. At equilibrium, all markets must clear, and the intertemporal sequences of prices and allocations must satisfy the optimality conditions of each set of agents.

2.9 Social welfare

In order to compare welfare across equilibria with different policy rules, we use standard compensating lifetime consumption variations that make agents indifferent between the levels of expected lifetime utility attainable under a given policy regime and a reference equilibrium of the model, as proposed by Lucas (1987). We use the deterministic stationary equilibrium as the reference level, because it is constructed with the adjustments mentioned earlier that neutralize long-run effects of price stickiness, by having zero inflation, the external finance premium, with the financial subsidy τ_f, and monopolistic competition, with the production subsidy τ_p. If welfare is lower under the stochastic version of the model with any of the three policy regimes, our welfare measures show the welfare *cost* of that particular regime with its particular policy rule elasticities.

The welfare measures are constructed as follows: Define $\mathbb{W}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$ as the unconditional expected lifetime utility attained by the representative household in the competitive equilibrium of the model for a given parameterization defined in the vector $\boldsymbol{\varrho}$ and a pair of policy rule elasticities a_π and a_{rr}, (or $\breve{a}_{rr}$ in the case of the ATR regime). Hence, $\mathbb{W}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$ satisfies:

$$\mathbb{W}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right) \equiv \mathrm{E}\left\{\sum_{t=0}^{\infty} \beta^t \mathcal{U}\left(c_t\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right), \ell_t^h\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right), C_{t-1}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)\right)\right\}, \tag{2.21}$$

where $c_t\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$, $\ell_t^h\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$, and $C_{t-1}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$ are equilibrium allocations of individual consumption, labor supply, and aggregate consumption for specific parameter values and policy rule elasticities, and $\mathcal{U}\left(c_t, \ell_t^h, C_{t-1}\right)$ is the period utility function used in equation (2.1). Since we are assuming a representative agent, $C_{t-1}(.) = c_{t-1}(.)$.

Define next $\mathbb{W}_d$, c_d, ℓ_d^h, and C_d as the welfare and allocations in the deterministic steady state, so that:

$$\mathbb{W}_d \equiv \frac{\mathcal{U}\left(c_d, \ell_d^h, C_d\right)}{1-\beta} = \frac{\left\{\left[c_d(1-h)\right]^\upsilon \left(1-\ell_d^h\right)^{1-\upsilon}\right\}^{1-\sigma} - 1}{(1-\beta)(1-\sigma)},$$

where again the representative agent assumption implies $c_d = C_d$.

The welfare effect of a particular pair of policy elasticities is then defined as the percent change in consumption, ce, relative to the reference consumption levels (i.e. those in the deterministic steady state), such that the following condition holds:

$$\mathbb{W}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right) = \frac{\mathcal{U}\left(\left(1-ce\right)c_d, \ell_d^h, \left(1-ce\right)C_d\right)}{1-\beta}.$$

Hence, a positive (negative) ce measures how much the steady state consumption levels would need to fall (increase) so that welfare in the deterministic steady state is the same as in a stochastic equilibrium under given parameters and policy rule elasticities. Thus, $ce > 0$ ($ce < 0$) is a welfare cost (gain) relative to the deterministic steady state. With CRRA utility, we can solve for ce as:

$$ce\left(a_{\pi}, a_{rr}; \boldsymbol{\varrho}\right) = 1 - \exp\left\{(1-\beta)\frac{\left[\mathbb{W}\left(a_{\pi}, a_{rr}; \boldsymbol{\varrho}\right) - \mathbb{W}_d\right]}{\upsilon(1-\sigma)}\right\}. \tag{2.22}$$

Since $ce\left(a_{\pi}, a_{rr}; \boldsymbol{\varrho}\right)$ is always measured relative to the same deterministic steady state, the welfare cost or gain of changing from a policy regime with elasticities $(a_{\pi}^{x}, a_{rr}^{x})$ to one with elasticities $(a_{\pi}^{y}, a_{rr}^{y})$ is given by the difference between $ce\left(a_{\pi}^{x}, a_{rr}^{x}; \boldsymbol{\varrho}\right)$ and $ce\left(a_{\pi}^{y}, a_{rr}^{y}; \boldsymbol{\varrho}\right)$.

3 Risk Shocks & Policy Responses: Diagrammatic Analysis

This Section provides a diagrammatic analysis of the effects of risk shocks and of how financial and monetary policy responses alter those effects. This analysis serves two purposes. First, it shows how each policy instrument affects the determination of its policy goal, which is behind the validity of Tinbergen's rule in the model. Second, it illustrates the spillovers from the monetary (financial) policy into the credit spread (inflation), which drive the incentives for strategic interaction between the two authorities.

The three panels of Figure 1 show plots with the equilibrium of the markets for credit (external financing), capital goods and final goods. These charts are only a one-period snapshot of the full model's equilibrium. The model does not yield closed-form solutions for the demand and supply functions plotted, and allocations and prices in the model incorporate dynamic, stochastic general equilibrium effects absent from these plots.

The equilibrium of the market for external financing is determined where the demand for capital by entrepreneurs (which is also the demand for credit) intersects the supply of funds. This diagram is analogous to Figure 1 in Bernanke and Gertler (1989). The demand for capital follows from condition (2.3), taking into account that the rental rate of capital at equilibrium matches the decreasing marginal product of capital. The supply of credit, labeled $\frac{s(x)}{1+\tau_f}$, follows from the equilibrium condition (2.8) which determines the efp. Equilibrium in this market determines the allocation of capital expenditures purchases k and the rate of return on capital r^k (as noted in Section 2, there is an equivalent representation in terms of a loan amount and an interest rate). Notice that $r^k \geq r$, otherwise the financial intermediary would not participate in the contract.

In the capital goods market, the supply schedule, labeled k^s, is given by the standard Tobin's Q investment optimality condition. This schedule is upward sloping because of the investment adjustment costs. The demand is given again by the marginal product of capital that pins down the gross real returns of capital goods. Equilibrium in this market determines the relative price of capital goods, q, and the optimal investment amount k.

In the final goods market, aggregate supply is given by the standard Phillips curve, labeled PC, which is upward sloping due to nominal rigidities affecting price-setting and production plans of producers of intermediate and final goods. Aggregate demand, labeled y^d, is given by the resource constraint, and it is downward sloping because of standard assumptions regarding income and substitution effects so that consumption declines with the interest rate, and because investment also falls as the interest rate rises. For ease of exposition, we abstract from monitoring costs in this graphic analysis, which reduces the resource constraint to $y_t = c_t + c_t^e + i_t + g_t$. We briefly explain later in this Section how monitoring costs affect the trade-off between financial and price stability.

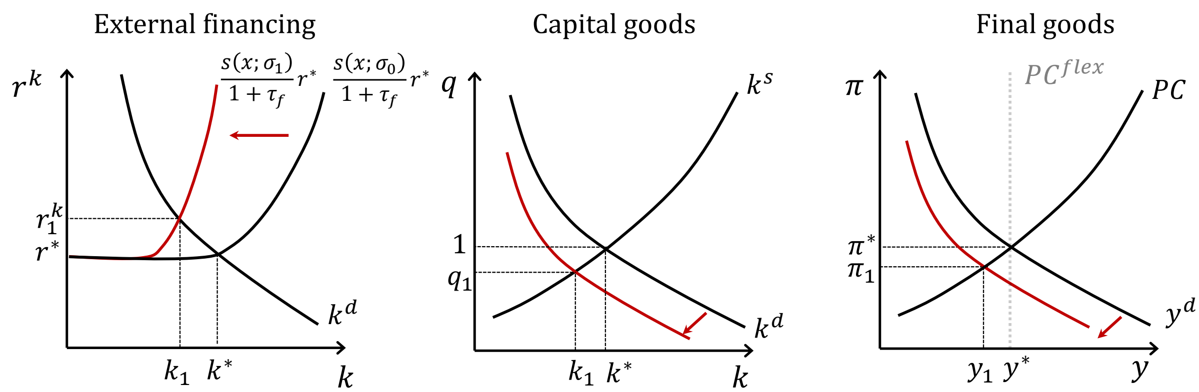
Panel (a) of Figure 1 shows the effects of an increase in σ_ω. For simplicity, we assume that before the shock the economy was at its steady-state equilibrium, in which the financial wedge is zero (i.e. $r^k = r$), the relative price of capital equals 1, and the capital stock, production, inflation, and the real interest rate equal their corresponding deterministic steady-state levels (identified by asterisks). The risk shock causes the entrepreneurs' probability of default to increase, which shifts the supply of external financing to the left. The vertical intercept is unchanged, because the nominal interest rate is set by the central bank and we are abstracting in these plots from changes in expected inflation for $t+1$, and the horizontal segment shrinks, because the risk shock reduces the maximum level of capital covered by internal financing. The shift in the supply of loans reduces capital purchases and increases the efp to $k_1 < k^*$ and $r_1^k > r^*$ respectively. Investment falls along with the demand for capital goods, which reduces the relative price of capital ($q_1 < 1$) as well as the net worth of entrepreneurs (not shown in the plots). The latter feeds into the Bernanke-Gertler accelerator and creates a wedge between the returns of capital and deposits, so after the shock efp is positive (i.e. $r^k > r$), which lowers output and inflation to $\pi_1 < \pi^*$ and $y_1 < y^*$ respectively.

Panel (b) shows the effects of a financial policy response to the risk shock, by increasing τ_f. This increases the expected return on loans, which helps counter the drop in the supply of external financing. Notice that again the vertical intercept of the supply of loans does not change, and now the horizontal segment extends. The extent to which the supply of loans recovers depends on the parameters of the financial policy rule, and on general equilibrium feedback effects not captured in the plots, including those that depend on the parameters of the monetary policy rule. In the scenario as plotted, the financial policy is effective but falls short of returning the economy to the initial equilibrium. Hence, financial policy yields the equilibrium identified with "f" subscripts. Capital, inflation, output, and Tobin's Q are higher than in the absence of the financial policy response, but lower than in the initial equilibrium, and the external financing premium is lower than without the policy response but higher than in the initial equilibrium.

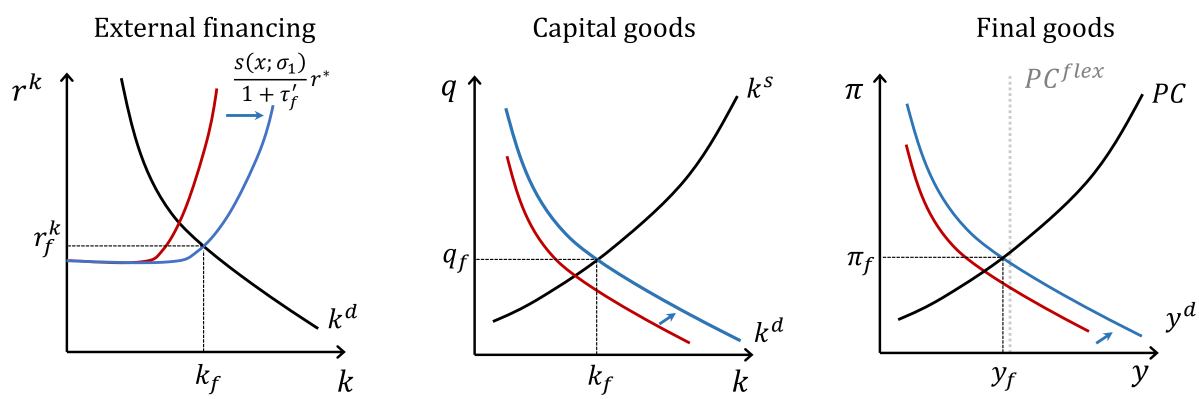
Panel (c) shows the effects of a monetary policy response to the risk shock, by cutting R. Since we are abstracting from changes in expected inflation, this lowers the real interest rate r. The lower r shifts the entire supply of funds curve down and to the right, because it lowers the intermediaries' cost of raising deposits. The price and quantity effects on the three markets are qualitatively similar to those obtained with the financial policy, but monetary policy exerts a stronger effect on aggregate demand, because in addition to the effect on credit markets, it also affects saving-spending

Figure 1: Risk Shocks and Policy Responses

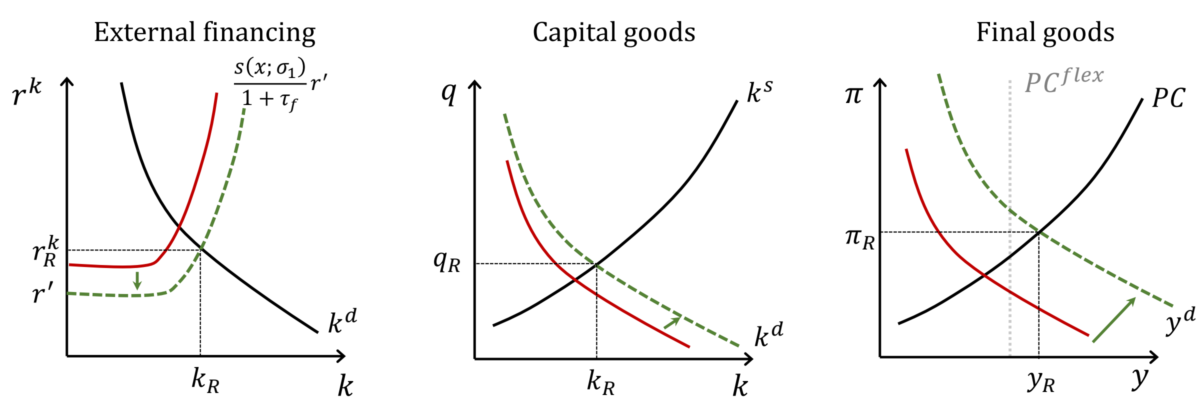
Panel (a): Effects of a positive risk shock



Panel (b): Countercyclical financial policy



Panel (c): Countercyclical monetary policy



decisions of households via the standard effects present in New Keynesian DSGE models. Hence, while prices and allocations move in the same direction under both policies, their quantitative effects are different in general because of the stronger transmission channel of monetary policy.

In the scenario drawn in Panel (c), the cut in R helps increase capital purchases and reduce the efp towards their initial values, but at the cost of pushing inflation above its initial level ($\pi_R > \pi^*$). Moreover, if we were to add monitoring costs to aggregate demand, the trade-off between a lower external financing premium and higher inflation worsens, because aggregate demand rises more as monitoring costs increases with the risk shock (as more entrepreneurs default and the intermediary spends resources to audit them). Hence, this example suggests that the interest-rate path needed to achieve financial stability may be very different than the path needed to achieve price stability. In turn, this argument is indicative of the relevance of Tinbergen's rule: Dual policy rules, a financial rule aimed at the financing premium and a monetary rule aimed at inflation, are more likely to succeed because they allow adjusting two policy instruments to target two macro variables.

The need for two instruments to target π and efp can be illustrated as a feature of the full DSGE model by noting that condition (2.8) implies that, if the central bank is expected to target inflation successfully using rule (2.16), then in the neighborhood of the stochastic steady state $r_t = R/(1+\pi)$. Hence, monetary policy cannot be used to target the credit spread, because once it is targeting inflation, the spread still fluctuates as implied by condition (2.8), with r_t approximately constant at the value implied by inflation targeting. Then, the financial subsidy is needed in order to target the spread with an instrument independent of the monetary policy instrument.

Notice that under flexible prices (the scenario represented by the PC^{flex} curve in Figure 1), the monetary and financial instruments could be used indistinctly, because the inefficiencies due to nominal rigidities vanish. Tinbergen's Rule is irrelevant because inflation becomes an irrelevant target. In this case, there are two possible instruments to target one variable, the credit spread.

The unintended implication of Tinbergen's rule is that, by justifying the use of separate monetary and financial policy rules, it also raises the potential for strategic interaction. As Panels (b) and (c) show, the monetary (financial) policy response causes spillover effects on the variables that are likely to determine the payoff of the financial (monetary) authority: Inflation and output are affected by $\tau_{f,t}$, while efp, credit and leverage are affected by R_t. Hence, if the payoff functions of the two authorities differ (e.g. if one depends on price, interest rate and output stability and the other on the stability of spreads, credit and leverage), strategic interaction would yield inferior equilibrium outcomes when the authorities act unilaterally than when they coordinate their actions. Moreover, we can infer from Panels (b) and (c) that the relative size of the policy rule elasticities matters for whether each authority sees the elasticity of its own rule as an strategic substitute or complement of the other authority's elasticity. For example, if a_{rr} is sufficiently high, the monetary authority may find optimal to increase a_π when the financial authority increases a_{rr} (i.e. the two are strategic complements), so as to tighten monetary policy more to keep inflation from increasing when the financial authority is increasing the subsidy to lenders by more.[14] In this case, the curves

[14]In this model, a_{rr} and a_π are strategic substitutes when the best response in the choice of one increases as the other increases, because higher a_{rr} *relaxes* financial policy while higher a_π *tightens* monetary policy.

in Panel (b) would shift out significantly more, and hence the central bank may find optimal to adjust its elasticity so that the curves in Panel (c) shift out less. Conversely, if a_{rr} is sufficiently low, the central bank may prefer to lower the elasticity of the monetary rule. The quantitative analysis of the next Section shows that indeed the monetary rule elasticity switches from strategic substitute to strategic complement of the financial rule elasticity as a_{rr} rises above a threshold value.

4 Quantitative Analysis

4.1 Calibration & Deterministic Steady State

In the remainder of the paper we conduct a quantitative analysis to study the model's implications for the relevance of Tinbergen's rule and strategic interaction in the management of monetary and financial policies. The model is calibrated to a quarterly frequency, with most parameters taken from the studies by CMR and BGG. Table 1 lists the values of the model's parameters in the Baseline calibration. As explained earlier, we set inflation in the deterministic steady state to zero ($\pi = 0$) in order to remove the steady-state effects of price stickiness. We also set υ, the parameter governing the disutility of labor, such that the household's steady-state labor allocation is 1/3rd (i.e. $\ell^h = 1/3$), and set the habit persistence parameter to $h = 0.85$ so as to match the estimate obtained by Schmitt-Grohé and Uribe (2008).

The values of the discount factor, the coefficient of relative risk aversion, the capital share in the intermediate sector, the elasticity of demand for intermediate goods, the depreciation rate, the investment adjustment costs, the government expenditures-GDP ratio, the price indexing weight, and the degree of price stickiness are taken from CMR. They set some of these parameters by calibrating to data targets or estimates from the literature, and obtain others as estimation results using U.S. quarterly data for the period 1985:I-2010:II. The calibrated parameter values are: $\beta = 0.99$, $\sigma = 1$, $\alpha = 0.4$, $\theta = 11$, $\delta = 0.025$, and $g = 0.2$.[15] The estimated parameters, which correspond to modes of the posterior distribution of the estimation, are: $\eta = 10.78$, $\vartheta_p = 0.1$ and $\vartheta = 0.74$. Given these parameter values, the value of the subsidy to intermediate goods producers that neutralizes the steady-state effects of monopolistic competition is $\tau_p = 9.1\%$.

The financial sector parameters are taken mostly from BGG. As is standard in models with the Bernanke-Gertler accelerator, the transfers from failed entrepreneurs to households are set to a very small value ($1 - \varrho = 0.01\%$), so that the entrepreneurs' consumption process, which is quite volatile, does not affect aggregate consumption significantly. We take from BGG their calibrated values for the survival rate of entrepreneurs ($\gamma = 0.98$), the monitoring cost coefficient ($\mu = 0.118$), the unconditional standard deviation of the entrepreneurs idiosyncratic shocks ($\bar{\sigma}_\omega = 0.27$), and the fraction of households' labor on production ($\Omega = 0.98$).[16] BGG obtained

[15] $\beta = 0.99$ implies a 4 percent annual real interest rate in the deterministic steady state, which is standard in RBC model calibrations. This is also a reasonable value here because of the adjustments neutralizing the inefficiencies of monopolistic competition, the external finance premium and inflation in the deterministic steady state.

[16] The value of $\bar{\sigma}_\omega = 0.27$ is very similar to the value of 0.2713 estimated by Lambertini, Nuguer and Uysal (2017) and the 0.26 estimate used by CMR. Lambertini *et al.* (2017) estimated a model with nominal and real rigidities, a housing sector with risk shocks, mortgages, and endogenous default using quarterly U.S. data.

Table 1: Baseline Calibration

Parameter		Value	Source or Target
Preferences, technology & policy parameters			
β	Subjective discount factor	0.99	CMR
σ	Coefficient of relative risk aversion	1.00	CMR
υ	Disutility weight on labor	0.06	$\ell^h = 1/3$
h	Habit parameter	0.85	Schmitt-Grohé and Uribe (2008)
α	Capital share in production function	0.40	CMR
δ	Depreciation rate of capital	0.02	CMR
η	Investment adjustment cost	10.78	CMR
$\bar{g}$	Steady state government spending-GDP ratio	0.20	CMR
ϑ_p	Price indexing weight	0.10	CMR
ϑ	Calvo price stickiness	0.74	CMR
θ	Elasticity of demand for intermediate goods	11.00	CMR
π	Inflation in the deterministic steady state	0	target value[1]
τ_p	Subsidy to intermediate goods producers	9.1%	target value[2]
Financial sector			
$1 - \varrho$	Transfers from failed entrepreneurs to households	0.01%	BGG
γ	Survival rate of entrepreneurs	0.98	BGG
μ	Monitoring cost	0.118	BGG
Ω	Share of households' labor on total labor	0.98	BGG
$\bar{\sigma}_\omega$	Mean of stnd. dev. of entrepreneurs shocks	0.27	BGG
ρ_{σ_ω}	Persistence of risk-shock process	0.97	CMR
σ_ϵ	Standard deviation of risk-shock innovations	0.1	CMR
τ_f	Financial subsidy in the deterministic steady state	0.96%	target value[3]

[1]Targeted to remove steady-state effects of nominal rigidities.

[2]Targeted to remove steady-state effects of monopolistic competition.

[3]Targeted to obtain $\mathrm{efp} = 0$ in the steady state.

these calibrated parameters so that the deterministic steady state of their model matches an entrepreneurial labor income share of 0.01, a default rate of entrepreneurs of 3 percent per year, a capital-net worth ratio of 2, and a 2 percent long-run external finance premium, which are figures based on historical U.S. averages. Here, we take the financial sector parameters they obtained as given, and solve for the value of the steady-state financial subsidy τ_f that reduces the steady state efp to zero. This yields $\tau_f = 0.96\%$.[17]

[17]This approach implies that with $\mathrm{efp} = 0$ our model yields higher steady-state values for the default rate of entrepreneurs and the capital-net worth ratio than in BGG. As shown in Appendix B.3 however, our results on Tinbergen's rule and strategic interaction for the three policy rules we examined do not vary much if we set $\tau_f = 0$, so that the steady state of the model matches the same data targets as the BGG calibration.

The entrepreneurs' idiosyncratic productivity shocks, ω_t, follow an i.i.d. log-normal process with an unconditional expectation of 1 and a time-varying standard deviation characterized by the following AR(1) process:

$$\log(\sigma_{\omega,t}) = (1 - \rho_{\sigma_\omega}) \log(\bar{\sigma}_\omega) + \rho_{\sigma_\omega} \log(\sigma_{\omega,t-1}) + \sigma_\epsilon \epsilon_t \quad (4.1)$$

where $\sigma_{\omega,t}$ is the standard deviation of ω_t, and σ_ϵ is the standard deviation of the innovations to the risk shock process. We set $\rho_{\sigma_\omega} = 0.97$ and $\sigma_\epsilon = 0.1$ using the estimates from CMR, including in σ_ϵ both surprise and anticipated components.

The key ratios of the model's deterministic steady state under the Baseline calibration are listed in Table 2, together with the ratios for two alternative stationary equilibria, one corresponding to the standard BGG model and another for a variant of the model without financial frictions. The Baseline case differs from the BGG setup in that it includes the financial subsidy that removes the external finance premium in the steady state, and it differs from the case without financial frictions in that it still uses up resources in monitoring costs. In the Baseline case, monitoring costs amount to $\mu G(\bar{\omega}) rk$, where $\bar{\omega}$ is the threshold value of ω below which an entrepreneur defaults with zero efp (i.e. $r^k = r$) and k is the associated steady-state capital stock. All three scenarios include the subsidy to intermediate producers and assume zero inflation to neutralize the steady-state effects of monopolistic competition and nominal rigidities, respectively.

In the BGG case, the steady state is affected by both the distortionary effect of the external finance premium on credit and capital and by the income effect of the resources spent in monitoring costs. Because $\mathrm{efp} > 0$, the investment rate and the capital-output ratio are lower than in the other two scenarios which have zero efp. For the same reason, the steady-state investment rates and capital-output ratios are the same without financial frictions and in the Baseline case, and in both scenarios steady-state output equals its efficient level. In contrast, in the BGG setup the capital-output ratio is about 150 percentage points lower and output is nearly 10 percent lower.

The Table also shows that while τ_f removes the investment inefficiency in the Baseline case by removing the external finance premium, the consumption-output ratio is lower than in either the BGG case or without financial frictions. The consumption-output ratio is higher in the BGG case because, although resources are going into paying monitoring costs, the positive efp reduces the investment rate below that in the Baseline case. Without financial frictions, the consumption-output ratio is higher than in the Baseline case because now the investment rate and the output level are the same but in the Baseline case some resources are used up to pay monitoring costs. These differences are worth noting because, as we show later, in the stochastic stationary state with risk shocks, alternative policy regimes yield different long-run averages for efp and monitoring costs, and these effects have important welfare implications. Qualitatively, these stochastic steady states are more similar to the deterministic BGG case than to the Baseline case, because they feature both adverse income effects from monitoring costs and efficiency losses in the allocation of capital due to positive external finance premia.

Table 2: Steady State Results

	BGG	No Finan Fric	Baseline
External Finance Premium efp, annual rate	2%	0%	0%
Monitoring Cost μ	12%	0%	12%
Financial Policy τ_f	-	-	1%
Consumption over output $\frac{c}{y}$	0.55	0.52	0.50
Investment over output $\frac{i}{y}$	0.25	0.28	0.28
Capital over output $\frac{k}{y}$	9.97	11.40	11.40
Output over efficient output $\frac{y}{y_{nf}}$	0.91	1.00	1.00

Note: The model without financial frictions corresponds to the case in which the cost of monitoring is zero, and hence at equilibrium $\mathrm{efp} = 0$. The efficient output, y_{nf}, is defined as the one attained without financial frictions, which corresponds also to the one attainable in a standard Neoclassical model (since it is a steady state with zero inflation and with a subsidy removing the distortion of monopolistic competition on production).

We used a second-order perturbation method to solve for the model's stochastic steady state, as proposed by Schmitt-Grohé and Uribe (2004), which is important for improving the accuracy of the welfare calculations critical for our anaylsis. To compute expected lifetime utility values avoiding explosive sample paths, we simulated the second-order solutions using the pruning method developed by Andreasen, Fernández-Villaverde and Rubio-Ramírez (2013). The model is solved using Dynare, version 4.

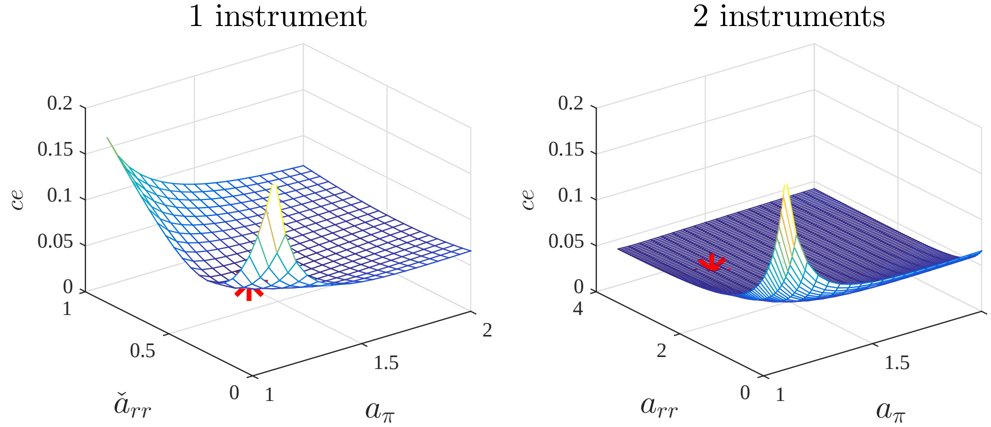
4.2 Tinbergen's rule

We evaluate the relevance of Tinbergen's rule by comparing the performance of the DRR, STR and ATR regimes in terms of social welfare for a set of values of the policy rule elasticities, the welfare-maximizing elasticities (i.e. the ones that yield the lowest welfare cost relative to the deterministic steady state), and the macroeconomic dynamics in response to risk shocks. The welfare-maximizing elasticities are denoted "optimized elasticities" for simplicity.

Figure 2 shows surface plots of welfare costs for a set of elasticity pairs under the ATR (labeled "1 instrument" in the left plot) and the DRR (labeled "2 instruments" in the right plot). The results for the STR regime are also included. They correspond to the cases with $\breve{a}_{rr} = 0$ in the ATR case or with $a_{rr} = 0$ in the DRR case. Both of these are identical because in these cases the ATR and DRR are equivalent STR regimes at the given inflation elasticity (recall that both the ATR and DRR have the same constant financial subsidy τ_f).

These surface plots show two key results. First, welfare costs are large in all three policy regimes and for all the elasticity pairs considered, with ce ranging from about 6 to 17 percent. This is due to long-run effects of changes in efp and monitoring costs, as we explain in more detail below. Second, the curvature of the surface plots is indicative of the relevance of Tinbergen's rule and strategic interaction. In particular, at low levels of a_π, welfare costs in the ATR show a marked

Figure 2: Welfare Costs under Alternative Policy Regimes



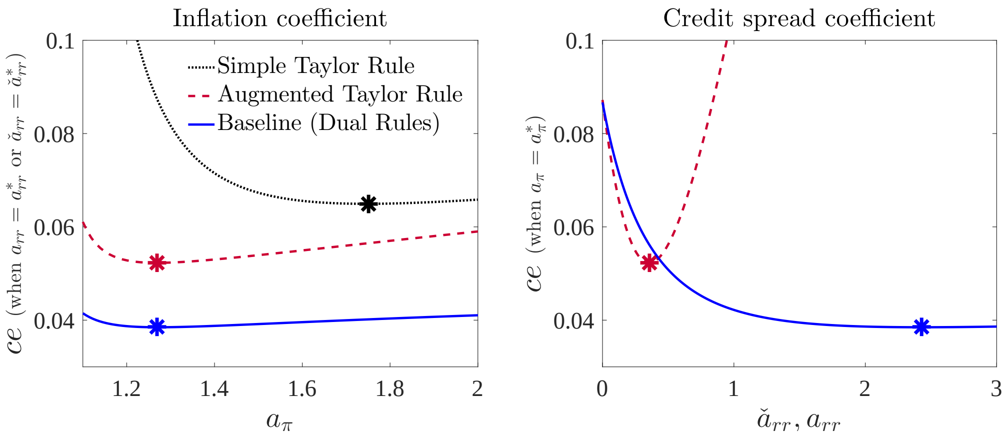
Note: ce is the welfare cost for each pair of elasticities shown in the plots, computed as averages over the ergodic distribution of the welfare measure defined in eq. (2.22). Asterisks denote the minimum of ce (i.e. the best outcome in terms of welfare), which defines the optimized elasticities for the ATR and DRR cases.

U shape as $\breve{a}_{rr}$ varies, whereas in the DRR regime they first fall sharply as a_{rr} rises from 0 but then change only slightly. For arbitrarily chosen elasticities either regime can be the most desirable. Welfare costs are slightly higher with the DRR than with the ATR for a_{rr} and $\breve{a}_{rr}$ near 0 for all values of a_π, but lower if those efp elasticities are sufficiently high. Moreover, for $a_{rr} \geq 1.2$, welfare costs for $a_\pi = 1$ are nearly unchanged as a_{rr} rises in the DRR, whereas under the ATR they are sharply increasing in $\breve{a}_{rr}$ when a_π is low but moderately decreasing in $\breve{a}_{rr}$ when a_π is high. These differences in the curvature of the two surface plots indicate that Tinbergen's rule is relevant because they show that the DRR can avoid sharply increasing welfare costs as a_{rr} rises for a given a_π, which is possible because it has separate instruments to tackle price and financial stability. The curvature also indicates that there are significant policy spillovers, which provide the incentives for strategic interaction we study later.

The differences in the welfare costs across policy regimes are illustrated further in Figure 3. This Figure provides plots that show how ce varies as one of the elasticities changes, keeping the other fixed at its optimized value. The plot on the left is for a_π and the one on the right is for $\breve{a}_{rr}$ and a_{rr}. The dashed-red curves are for the ATR and the solid-blue curves are for the DRR, and in the left plot the dotted-black line is for the STR. In each curve, asterisks identify the value of the elasticity in the horizontal axis that yields the lowest welfare cost.

The left panel shows that, for all values of a_π considered, ce is uniformly lower under the DRR than under the ATR, and much lower than under the STR. The right panel shows that for spread elasticities below 0.5 ce does not differ much between the DRR and ATR, but for higher spread elasticities ce is much lower under the DRR. Welfare costs under the ATR rise much faster with the spread elasticity, producing a markedly U-shaped curve, while under the DRR welfare costs are nearly unchanged as the spread elasticity rises. This is again evidence of Tinbergen's rule relevance: a_{rr} in the DRR can increase with much less adverse welfare consequences than $\breve{a}_{rr}$ in the ATR because the separate financial rule of the DRR targets efp with its own instrument, and

Figure 3: Welfare Costs as Policy Elasticities Vary



Note: Asterisks show the lowest welfare cost on each curve.

hence without affecting the instrument of monetary policy. Notice also that in all the curves in the two plots, there is always an internal solution for the value of the policy rule elasticity with the smallest welfare cost. These findings are important because they show that the different policy regimes, by having different effects on the mechanisms that drive the financial accelerator and the nominal rigidities, produce significant differences in equilibrium allocations and welfare as policy rule elasticities vary, and that as a result there is a non-trivial interaction between monetary and financial policies that yields well-defined optimized rule elasticities.

Table 3: Comparison of Policy Regimes

Regime	Optimized Elasticities			ce v. DRR	Decomp. of ce into mean and SD eff.			
	a_π	a_{rr}	$\check{a}_{rr}$		Full ce	Mean eff. Total	Mean eff. Net	SD eff.
Dual rules (Best Policy)	1.27	2.43	0	-	3.85%	3.75%	2.51%	0.10%
Augmented Taylor rule	1.27	0	0.36	138bp	5.23%	4.97%	4.07%	0.26%
Simple Taylor rule	1.75	0	0	264bp	6.49%	6.08%	5.41%	0.41%

Note: "Optimized Elasticities" are the elasticities from the sets used in constructing Figure 2 that produce the lowest welfare cost under each policy regime. ce v. DRR is the difference in ce under the ATR or STR relative to the DRR in basis points. "Full ce" is the welfare measure defined in equation (2.22). Full ce is decomposed into an effect due to changes in long-run averages ("Mean eff. Total") and an effect due to fluctuations ("SD eff."). Mean eff. Total is computed as in equation (2.22) but replacing $\mathbb{W}(a_\pi, a_{rr}; \boldsymbol{\varrho})$ with $\mathcal{U}\left(E[c], E[\ell^h], E[C]\right)/(1-\beta)$, where $E[c], E[\ell^h], E[C]$ are long-run averages in the stochastic steady state of the model solved under each policy regime. "Mean eff. Net" removes the long-run average of monitoring costs from the Mean eff. calculation, by treating monitoring costs as private consumption in the resource constraint.

Table 3 demonstrates the quantitative relevance of Tinbergen's rule by comparing the main characteristics of the DRR, ATR, and STR when each is operating with its optimized elasticities. The Table includes the values of the optimized elasticities, the difference in the value of ce in the ATR and STR relative to the DRR, and a decomposition of ce in terms of Mean and Standard Deviation (SD) components for each regime. We denote the DRR as the "Best Policy" scenario because it yields the best welfare outcome of the three regimes, and also because it matches the outcome of a Cooperative policy game in which social welfare is the common payoff of the two policy authorities. In the welfare effect decompositions, the Total Mean Effect is computed using equation (2.22) but replacing the value of welfare under a given regime with the welfare value of a hypothetical stationary state in which equilibrium allocations are constant at the average values of the same regime's stochastic stationary state (i.e. we replace $\mathbb{W}\left(a_{\pi}, a_{rr}; \boldsymbol{\varrho}\right)$ with $\mathcal{U}\left(E[c], E[\ell^{h}], E[C]\right)/(1-\beta)$, where $E[c], E[\ell^{h}], E[C]$ are long-run averages of the stochastic model solved under each policy regime). The SD effect is just ce minus the Mean effect. We also show the Mean effect net of monitoring costs, which is calculated by treating the long-run mean of monitoring costs as private consumption in the resource constraint. The aim is to illustrate the relevance of long-run changes in resources used up in costly monitoring for the welfare costs.

The optimized elasticities in the DRR are $a_{\pi} = 1.27$ and $a_{rr} = 2.43$, compared with $a_{\pi} = 1.27$ and $\breve{a}_{rr} = 0.36$ in the ATR. Interestingly, the inflation elasticities are similar in these two regimes (with the one in the ATR just marginally higher), and both are about 50 basis points smaller than the inflation elasticity of the STR regime. The efp elasticities, however, differ markedly, the one under DRR is much higher than in the other two regimes, 2.43 in the DRR v. 0.36 in the ATR and 0 in the STR. The STR and ATR regimes are tight money-tight credit regimes because financial policy does not respond enough to worsening spreads and monetary policy responds too much to higher inflation, albeit by a negligible amount in the case of the ATR. In line with the intuition of Tinbergen's rule, policy responds less to worsening financial conditions under the ATR because it cannot respond with an instrument independent from the monetary policy instrument. Moreover, the only instrument it can respond with under the ATR, the interest rate, happens to be the one with the stronger transmission mechanism, because as we explained earlier, it has first-order effects on the inefficiencies caused by both Calvo pricing and the Bernanke-Gertler accelerator.

The welfare estimates show that the violations of Tinbergen's Rule entail large welfare costs. Comparing across regimes, ce in the ATR and STR is 138 and 264 basis points larger than in the DRR, respectively, and 126 basis points lower in the ATR than in the STR. Hence, if the choice is only between allowing the Taylor rule to respond to the credit spread or not (ATR v. STR), the first alternative wins, but using separate financial and monetary rules is significantly better.

The overall welfare costs of the three regimes are large relative to other standard measures. As Table 3 shows, under the optimized elasticities, the STR regime yields a cost of 6.5 percent v. 5.2 and 3.9 percent under the ATR and DRR, respectively. These are all large numbers compared with typical estimates of the welfare cost of business cycles of about 0.1 percent (see Lucas, 1987), and larger even than estimates of the welfare costs of distortionary taxation in the $1-3$ percent range. In order to understand the factors behind this result, we conducted a series of counterfactual experiments isolating the welfare implications of key model parameters (monitoring costs coefficient, habit persistence, price stickiness, properties of risk shocks, labor elasticity, etc.) and we found that by far changing the coefficient of monitoring costs contributes the most to the large welfare costs, followed by habit persistence.[18]

Table 3 provides two sets of results to illustrate this point. First, the decomposition of ce into Mean and SD effects shows that the Mean effects are the main source of the large welfare costs. These in turn are due to differences in the long-run averages of consumption and leisure across policy regimes, of which further analysis showed consumption differences are more important. The SD effects isolate the contribution of business cycle variability per-se to the welfare costs, and the results are in line with typical measures of the welfare cost of business cycles. In fact, the SD effect under the DRR is just about the same as the Lucas estimate. Second, the Table shows that net mean effects are markedly smaller than total mean effects (by 124, 90, and 67 basis points in the DRR, ATR, and STR respectively). This is because although the zero-inflation target and the time-invariant subsidies to entrepreneurs and financial intermediaries neutralize the *deterministic* steady-state effects of nominal rigidities, monopolistic competition, and the efp, each policy regime yields different results for the long-run averages of efp and resources assigned to monitoring costs in the corresponding *stochastic* steady state, and also because in the DRR the average financial subsidy changes as the average efp changes. It is important to note, however, that these changes are long-run implications of the business cycle volatility induced by risk shocks: The means of monitoring costs and the efp are higher in the stochastic than in the deterministic steady states because of the dynamic equilibrium effects of risk shocks under incomplete markets, which differ markedly across policy regimes.[19] We document these differences and their effects on the welfare calculations by studying differences in long-run moments and impulse response functions for risk shocks under each policy regime.

Table 4 shows the main moments of the model's key variables in the stochastic steady state of each policy regime under the corresponding optimized elasticities, and their corresponding deterministic steady state values. The Table shows means, standard deviations, standard deviations relative to the standard deviation of output, and correlations with output.

A comparison of the model averages v. the deterministic steady state provides further evidence of the role that changes in efp and monitoring costs play in explaining the large welfare costs of risk shocks. In the determnistic steady state, $\mathrm{efp} = 0$ and monitoring costs are about 1.1 percent of output. In contrast, the long-run averages of monitoring costs rise to 1.6, 1.7, and 2 percent of output in the DRR, ATR, and STR, respectively, and the long-run averages of efp increase to 0.18, 0.65, and 0.99 percent in each regime, respectively. The resulting effects on average household leisure are small, but the changes in average consumption, investment, and capital are large. Relative to their deterministic steady-state values, mean consumption falls -1, -2.6 and -3.2 percent in the DRR, ATR, and STR, respectively. These changes in average consumption are the main determinant of the large welfare costs, and they are due to both the increases in monitoring

[18]Schmitt-Grohé and Uribe (2005) also found that increasing habit persistence increases welfare costs. Appendix B.5 provides a detailed analysis of the role of the model's key parameters in determining welfare costs.

[19]The second-order solution method, which does not impose certainty equivalence that makes long-run averages match deterministic stationary states, and the welfare calculations based on pruned (stable) time-series simulations of the model's second-order dynamics are critical for these results.

Table 4: Aggregate Statistics of the Deterministic and Stochastic Steady States under Each Policy Regime

Variable	DSS		DRR					ATR					STR				
	Mean	Share of y	Mean	Share of y	Change rel. to DSS	Std.dev. rel. to y	Corr. with y	Mean	Share of y	Change rel. to DSS	Std.dev. rel. to y	Corr. with y	Mean	Share of y	Change rel. to DSS	Std.dev. rel. to y	Corr. with y
y	1.717	1.000	1.709	1.000	-0.47%	1.000	1.000	1.680	1.000	-2.12%	1.000	1.000	1.672	1.000	-2.61%	1.000	1.000
c	0.865	0.504	0.856	0.501	-1.02%	0.924	0.297	0.843	0.502	-2.55%	1.135	0.202	0.837	0.501	-3.18%	1.079	0.290
i	0.489	0.285	0.481	0.281	-1.70%	3.797	0.104	0.462	0.275	-5.58%	4.911	0.516	0.453	0.271	-7.45%	4.819	0.567
g	0.343	0.200	0.343	0.201	-	-	-	0.343	0.204	-	-	-	0.343	0.205	-	-	-
mont. costs	0.020	0.011	0.028	0.016	43.46%	2.403	-	0.029	0.017	47.73%	1.501	-	0.033	0.020	70.55%	1.516	-
$c+i+g$	1.697	0.989	1.681	0.984	-0.98%	1.271	0.203	1.651	0.983	-2.71%	1.277	0.686	1.638	0.980	-3.48%	1.339	0.709
k	19.564	2.849*	19.248	2.816*	-1.62%	1.682	0.545	18.574	2.763*	-5.06%	2.107	0.777	18.259	2.730*	-6.67%	2.107	0.815
b	10.677	1.555*	10.087	1.476*	-5.53%	3.208	0.444	9.537	1.419*	-10.68%	7.537	0.708	9.274	1.387*	-13.14%	5.745	0.753
ℓ^h	0.333	-	0.335	-	0.36%	1.406	0.554	0.334	-	0.32%	1.104	0.416	0.335	-	0.39%	1.000	0.387
$U(c,\ell^h,C)$	-0.504	-	-0.506	-	-	0.700	-0.510	-0.507	-	-	0.549	-0.330	-0.508	-	-	0.513	-0.294
R, annual %	4.102	-	4.100	-	-	0.339	0.760	4.901	-	-	0.318	0.607	4.096	-	-	0.289	0.744
τ_f	0.960	-	1.073	-	-	0.587	0.408	0.960	-	-	0.000	0.084	0.960	-	-	0.000	0.111
efp, annual %	0.000	-	0.184	-	-	0.242	0.364	0.654	-	-	0.502	-0.004	0.992	-	-	0.484	-0.064
π, annual %	0.000	-	-0.001	-	-	0.267	0.760	0.790	-	-	0.319	0.471	-0.003	-	-	0.165	0.744
q	1.000	-	1.000	-	-	1.361	-0.705	0.996	-	-	1.948	-0.261	0.994	-	-	2.190	-0.236

Note: DSS is the deterministic steady state. "mon. costs" is the total amount of resources allocated to monitoring costs. Output is $y = c + i + g$+mon. costs. $U(c,\ell^h,C)$ is period utility.
"Std.dev. rel. to y" is the ratio of the standard deviation of the corresponding variable divided by the standard deviation of output. The standard deviation of output equals 0.014, 0.028, and 0.037 in the DRR, ATR, and STR, respectively.
* Annualized ratio.

costs and the efficiency losses in investment and the capital stock caused by the increases in efp. Investment in the DRR (ATR and STR) falls by -1.7 (-5.6 and -7.5) relative to the deterministic steady state, while capital falls by -1.6 (-5.1 and -6.7) percent.

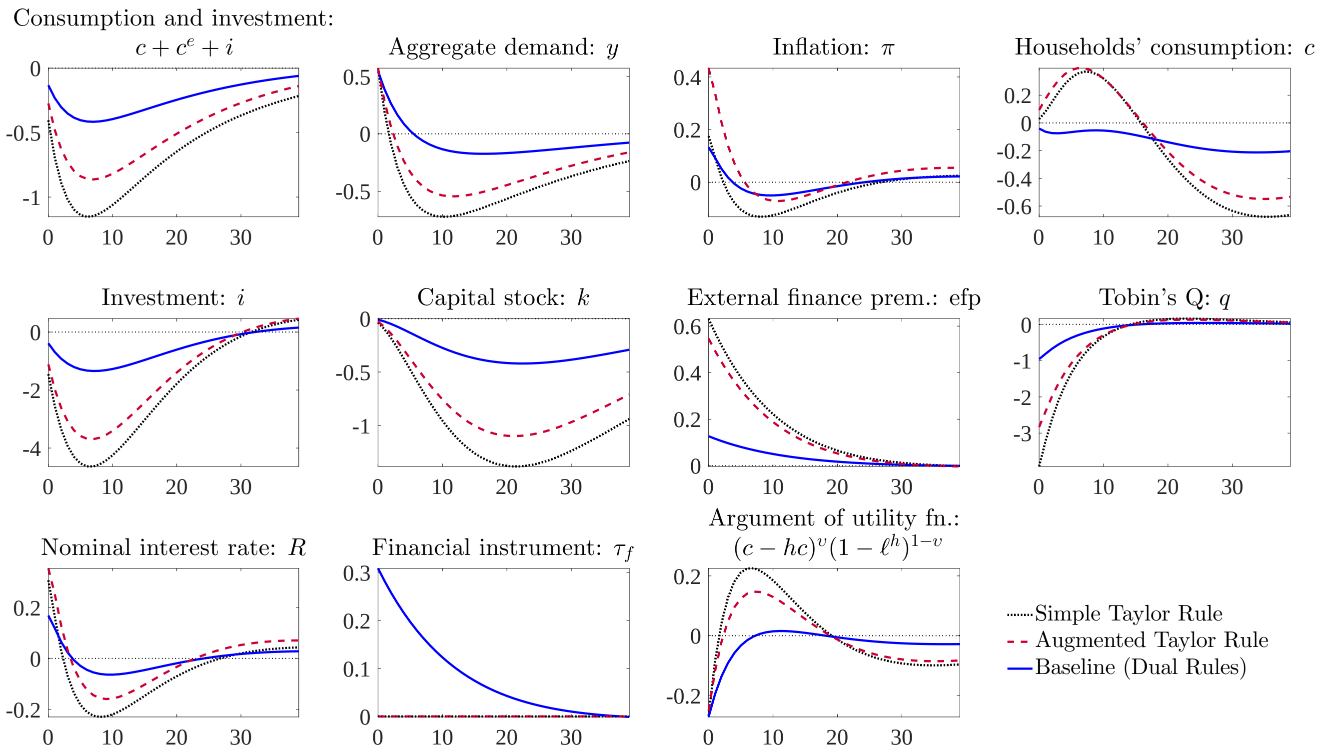
The DRR is significantly inferior to the deterministic steady state in terms of welfare, but also significantly better than the ATR and STR regimes, and this is the case because the increases in monitoring costs and efp, and their associated declines in consumption, investment and the capital stock are smaller in the DRR regime than in the other two regimes. In turn, these differences are due to the fact that the DRR can respond to the movements in efp by adjusting the financial subsidy. The financial subsidy rises from 0.96 percent in the deterministic steady state to 1.07 percent in the average of the stochastic steady state of the DRR, while in the ATR and DRR regimes the financial subsidy cannot deviate from its deterministic steady state. This higher subsidy results in higher lump-sum taxes in the DRR, but welfare is higher because the higher lump-sum taxes are not distortionary and help offset the higher efficiency losses under the ATR and SDR. These movements also allow the DRR to sustain more credit than in the ATR and STR regimes. Credit in the DRR is 5.5 percent lower than in the deterministic steady state, but this is a smaller decline than 10.7 and 13.1 percent in the ATR and STR, respectively.

The DRR's ability to respond to financial headwinds by adjusting $\tau_{f,t}$ also reduces business cycle variability. Relative to the standard deviation of output, the standard deviations of consumption, investment, and the capital stock are 0.9, 3.8, and 1.7 in the DRR, while in both the ATR and STR these relative standard deviations are about 1.1, 4.9, and 2.1. The correlations of investment and the capital stock with output are also significantly smaller, at 0.1 and 0.55 in the DRR v. 0.52 (0.57) and 0.78 (0.82) in the ATR (STR).

Next we compare the responses of key macroeconomic aggregates to risk shocks in the three optimized policy regimes. Figure 4 shows impulse response functions for a one-standard-deviation shock to σ_ϵ at $t = 0$ (equivalent to a 10-percent increase in $\sigma_{\omega,t}$), plotted as percent deviations from the long-run averages of each variable under each policy regime. The continuous-blue curves are for the DRR, the dashed-red curves are for the ATR, and the dotted-black curves are for the STR.

The responses of all variables are qualitatively similar across the three regimes but significantly smoother under the DRR, with the exception of the consumption response, which differs both quantitatively and qualitatively in the DRR. In all three regimes, the risk shock increases the probability of default on impact, and thus increases efp, and as the risk shock fades monotonically the increase in the efp also reverses monotonically. The efp rises to about 0.6 percent on impact under the STR and the ATR, while in the DRR it only rises to 0.13 percent, illustrating again the ability of the DRR to respond to risk shocks with the financial subsidy, and the relevance of Tinbergen's Rule: Separate financial and monetary rules are much more effective at stabilizing prices and the credit spread than the ATR and STR regimes. Inflation rises on impact in all three regimes, because although aggregate demand excluding monitoring costs falls, total demand inclusive of monitoring costs rises and exerts upward pressure on prices.

Figure 4: Impulse Response Functions to Risk Shocks



Note: Responses to a one-standard deviation shock to $\sigma_{\omega,t}$. The y axis is measured as percent deviations from the long-run averages of each policy regime, the x axis are quarters.

The higher π and efp trigger different policy responses determined by the rules corresponding to each regime. Inflation rises significantly more in the ATR regime than in the other two, yet the impact increases in R are similar. The STR and the ATR yield nearly the same initial interest rate, because the former has a higher inflation elasticity but experiences a smaller increase in inflation. The interest rate rises more in these regimes than in the DRR, reflecting their tight money-tight credit nature. Under the STR, the inflation elasticity is higher than in the DRR, and hence with a similar impact increase in π it yields a higher R. Under the ATR, the inflation elasticity is similar than in the DRR but the impact increase in π is larger, and even tough the increase in the efp contributes to lower R, the spread elasticity is not big enough to prevent the interest rate from rising more than with the DRR.

In the DRR, the financial subsidy displays the same monotonic reversion as the efp, so 30 quarters after the risk shock hits both are back at their long-run averages. Interestingly, the nearly identical efp responses under the STR and the ATR indicates that, although the interest rate responds to the credit spread in the latter but not in the former (producing slightly higher interest rates with the ATR than with the STR), the resulting equilibrium credit spreads do not differ much. This is again showing the quantitative relevance of Tinbergen's rule: the ATR does a poor job at altering the efp because it does not use a separate instrument to target it. In contrast, with the DRR, the financial subsidy results in significantly lower spreads.

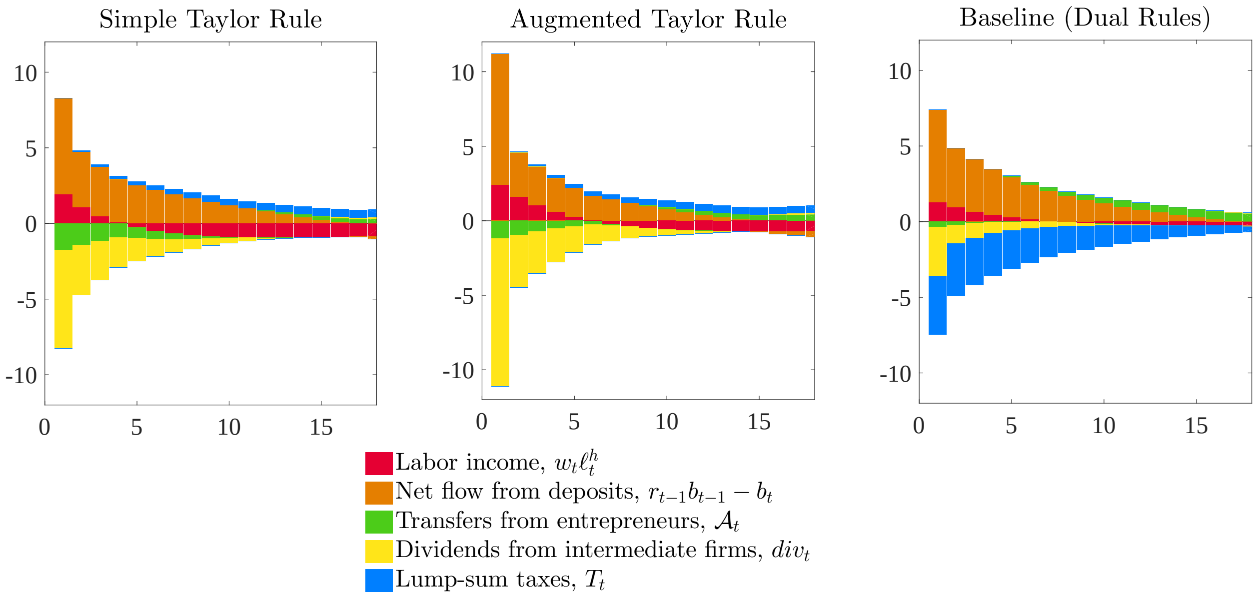
The higher spreads, combined with the investment adjustment costs, produce a gradual but substantial decline in investment as entrepreneurs respond to the higher cost of borrowing. This in turn produces gradual declines in the capital stock, aggregate demand, and inflation. Investment and private absorption reach their troughs around the 7th quarter after the risk shock, and the capital stock around the 20th quarter, followed by gradual recoveries in all three regimes. These recoveries are driven by the reversal of the increase in efp and the temporarily lower interest rates. These fluctuations in investment, capital, and aggregate demand are significantly smoother under the DRR than under the other two regimes, and those under the ATR are in turn smaller than with the STR. This is due to the higher spreads under the ATR and STR, both of which lack a separate instrument to respond to the effect of risk shocks on credit spreads. Note that interest rates between the 4th and 20th quarter are in fact higher under the DRR, but since this regime has the financial subsidy as a separate policy instrument, it yields lower spreads and can thus smooth capital accumulation and aggregate demand more effectively –again indicating the relevance of Tinbergen's rule.

Consumption is not only smoother under the DRR than in the other two regimes, it also displays very different dynamics. Consumption falls slightly on impact in the DRR, and then continues to decline slowly down to a through of about -0.2 percent below its long-run average by the 40th quarter. In contrast, in the other two regimes consumption rises to a peak about 0.4 percent above their long-run averages by the 8th quarter, and then falls sharply and steadily for 26 quarters down to a through about 0.65 below their long run averages. The initial drop in consumption and the gradual decline under the DRR are due to the increase in lump-sum taxes needed to pay for the financial subsidy that smooths the effects of the risk shock on spreads and investment. As we show below, this subsidy allows household income from dividends and transfers from entrepreneurs to fall much less than in the other two regimes, partially offsetting the higher lump-sum taxes. After the 20th quarter, consumption becomes higher in the DRR than in the other two regimes, as the financial subsidy and lump-sum taxes fall. In the long-run, consumption reaches a level slightly higher in the DRR than in the other two regimes, as shown in Table 4.

The different consumption patterns under the three policy regimes reflect differences in the evolution of disposable income and its components. Figure 5 shows the contributions of these components to the consumption impulse response functions. The plots breakdown the contributions of five components: labor income, $w_t\ell_t$, the net resource flow from deposits, $r_{t-1}b_{t-1} - b_t$, transfers from entrepreneurs, $\mathcal{A}_t$, dividend income, div_t, and lump-sum taxes, Υ_t. Dividends fall more on impact under the ATR than in the other two regimes but yet consumption is actually higher in this regime than in the other two. This happens largely because faced with the reduced dividend income, households reduce deposits sharply (i.e. $r_{t-1}b_{t-1} - b_t$ rises). After the impact effect, the components of income display a similar evolution under the ATR and STR regime.

The key feature of Figure 5 is that it illustrates how the DRR smooths disposable income, and hence yields a consumption path with higher welfare than the other two regimes. By producing smaller increases in efp that yield smaller efficiency losses and smaller increases in monitoring costs, the DRR regime provides an implicit vehicle for insuring disposable income against risk shocks that is more effective than under the other two regimes. Instead of experiencing large changes in the components of income on impact, these are spread more evenly over the first 10 quarters. Moreover, while lump-sum taxes reduce disposable income much more than under the

Figure 5: Decomposition of Disposable Income Available for Consumption



Note: The graphs display the different components of the disposable income used for consumption according to the households' budget constraint, equation (2.2). The y axis represents weighted deviations from the long-run averages under each regime, such that the bars add up to the percent deviation of consumption for a given period in the impulse response functions. The x axis are quarters.

ATR and STR, since they are needed to pay the high financial subsidy of the early periods, the financial subsidy and the smaller associated efficiency losses and monitoring costs produce a much smaller fall in dividends under the DRR than in the other two regimes. In fact, on impact the combined loss of disposable income due to dividends and taxes is much smaller than under the ATR and STR. This implies also that resources drawn from deposits need to increase less on impact and are more evenly allocated intertemporally. This is also possible because of the temporarily higher interest rates from the 4th to the 20th quarter under the DRR. Since inflation rates are not that different from those under the ATR, real interest rates are higher in the DRR during those periods, generating higher returns on deposits and incentives to reallocate them intertemporally.

These results are important because they show that, even tough the direct effect of the financial policy instrument is on the lender's participation constraint, it has nontrivial effects on both the demand and supply sides of the economy, and on the dynamics of disposable income. In computing the optimized elasticities of the DRR, the financial authority trades off the effects of $\tau_{f,t}$ as it tilts the consumption profile over time, reducing consumption initially but increasing it steadily in future periods through the effects on disposable income described above. The last plot of Figure 4 shows that period utility has a similar response on impact in all three regimes, then from the 2nd to about the 20th period it is lower with the DRR, but after that it is higher under the DRR (and converges to a higher long-run average as shown in Table 4). This time profile of utility flows yields higher welfare than under the STR and ATR.

In summary, the results reported in this Section show that the implications of violating Tinbergen's rule in the design of monetary and financial policies are quantitatively large. A regime with dual rules for monetary and financial policies yields higher welfare, smaller efficiency losses, and smoother macroeconomic fluctuations in response to risk shocks than regimes in which the monetary policy rule is augmented with the credit spread or follows a STR. The results also show, however, that the spillover effects from changes in the policy instrument that one authority controls on the target variable of the other authority are large, raising the potential for strategic interaction to undermine the effectiveness of both policies and reduce welfare. The DRR examined here sidesteps this issue, because it implicitly assumes cooperation by the two authorities in setting the elasticity of their policy rules (i.e. it is equivalent to a regime in which they choose them so as to maximize the household's expected utility function). In the next Section we study the implications of relaxing this assumption by quantifying the effects of strategic interaction.

4.3 Strategic Interaction

In this Section, we analyze the effects of strategic interaction between the monetary and financial authorities. Each policymaker has a payoff function denoted by L_m for $m \in \{CB, F\}$, where CB is the central bank and F is the financial authority. The payoff functions are in the class of quadratic loss functions, and in particular we use functional forms defined by the sum of the variances of each authority's policy instrument and target: $L_{CB} = -\left[\mathrm{Var}\left(\pi_t\right) + \mathrm{Var}\left(R_t\right)\right]$ and $L_F = -\left[\mathrm{Var}\left(r_t^k/r_t\right) + \mathrm{Var}\left(\tau_{f,t}\right)\right]$, where $\mathrm{Var}\left(x_t\right)$ denotes the unconditional variance of x_t in the economy's stochastic steady state. These payoff functions are in line with those used in the quantitative studies of monetary policy by Taylor and Williams (2010) and Williams (2010), which included the variability of instruments and targets. We also compare results vis-à-vis a case in which both authorities share a common payoff function given by the household's expected lifetime utility function (i.e. social welfare): $L_m = \mathbb{W}\left(a_\pi, a_{rr}; \boldsymbol{\varrho}\right)$ for $m \in \{CB, F\}$. Since sharing a common payoff removes the incentives for strategic interaction, this scenario does not yield coordination failure (i.e. cooperative and noncooperative equilibria coincide), but we use it to provide intuition about some of the results.

Including $\mathrm{Var}\left(\pi_t\right)$ in L_{CB} is consistent with the widely accepted policy of inflation targeting, which is desirable in the model because of the inefficient fluctuations caused by price dispersion under sticky prices, as explained in Section 2. For the financial authority, including $\mathrm{Var}\left(r_t^k/r_t\right)$ in L_F is in line with the aim to use financial policy as a tool to counter financial instability (as stated, for example, in IMF, 2013; Galati and Moessner, 2013), and is also consistent with the literature on quantitative financial policy analysis using DSGE models. In this literature, financial policy generally targets the credit-output ratio, credit growth, or the volatility of the credit spread (see Angelini *et al.*, 2014; Bodenstein *et al.*, 2014; De Paoli and Paustian, 2017). As we showed earlier, in our model targeting efp is desirable because of its effects on monitoring costs and efficiency losses over the cycle and in the long-run.[20] Moreover, as we discuss later in this Section, switching to targeting credit is equivalent to targeting efp up to a first-order approximation.

[20] De Paoli and Paustian (2017) show that the credit spread appears in a linear-quadratic approximation of the utility function in a model with credit constraints, and can therefore be viewed as a source of welfare costs. It can also be argued that large changes in asset prices cause welfare costs (see Taylor and Williams, 2010).

To conduct the quantitative analysis of strategic interaction, we construct reaction functions that return the payoff-maximizing choice of one authority's policy rule elasticity for a given value of the other authority's rule elasticity.[21] Denote the reaction function of the monetary authority $a^*_\pi(a_{rr})$, and the reaction function of the financial authority $a^*_{rr}(a_\pi)$, both defined over discrete grids of admissible values of elasticities, such that $A_\pi = \left\{a^1_\pi, a^2_\pi, ..., a^M_\pi\right\}$ and $A_{rr} = \left\{a^1_{rr}, a^2_{rr}, ..., a^N_{rr}\right\}$ with M and N elements, respectively. Hence, the strategy space is defined by the $M \times N$ pairs of rule elasticities. Also, denote as $\boldsymbol{\varrho}(a_{rr}, a_\pi)$ the vector of equilibrium allocations and prices of the model for a given set of parameter values (e.g. the baseline calibration) and a particular pair of policy rule elasticities (a_{rr}, a_π). The reaction functions satisfy the following definitions:

$$
\begin{aligned}
a^*_\pi(a_{rr}) &= \left\{(a^*_\pi, a^s_{rr}) : a^*_\pi = \underset{a_\pi \in A_\pi}{\arg\max}\ \mathrm{E}\left\{L_{CB}\right\},\ \text{s.t. } \boldsymbol{\varrho}(a^*_\pi, a_{rr}) \text{ and } a_{rr} = a^s_{rr}\right\}_{a^s_{rr} \in A_{rr}}, \\
a^*_{rr}(a_\pi) &= \left\{(a^s_\pi, a^*_{rr}) : a^*_{rr} = \underset{a_{rr} \in A_{rr}}{\arg\max}\ \mathrm{E}\left\{L_F\right\},\ \text{s.t. } \boldsymbol{\varrho}(a_\pi, a^*_{rr}) \text{ and } a_\pi = a^s_\pi\right\}_{a^s_\pi \in A_\pi}.
\end{aligned}
$$

In these definitions, the authorities maximize the *unconditional* expectation of their payoff, which corresponds to its mean in the stochastic steady state.

A Nash equilibrium of a non-cooperative game between the policy authorities is defined by the intersection of the two reaction curves: $N = \left\{\left(a^N_\pi, a^N_{rr}\right) : a^N_\pi = a^*_\pi(a^N_{rr}), a^N_{rr} = a^*_{rr}(a^N_\pi)\right\}$. A Cooperative equilibrium is defined by a pair of policy rule elasticities that maximize a linear combination of L_{CB} and L_F, with a weight of φ on the monetary authority's payoff, subject to the constraints that the Cooperative equilibrium must be a Pareto improvement over the Nash equilibrium and the arguments of the loss functions must correspond to the equilibrium allocations and prices for the corresponding policy rule elasticities:

$$
C(\varphi) = \left\{ \begin{array}{c} \left(a^C_\pi, a^C_{rr}\right) \ \in \arg\max_{a^s_\pi, a^{s'}_{rr} \in A_\pi \times A_{rr}} \ L_{coop} = \mathrm{E}\left\{\varphi L_{CB} + (1-\varphi) L_F\right\} \\ \\ \text{s.t.} \quad \boldsymbol{\varrho}(a^s_\pi, a^{s'}_{rr}), \quad \mathrm{E}[L_{CB}] \geq \mathrm{E}^N[L_{CB}], \quad \& \quad \mathrm{E}[L_F] \geq \mathrm{E}^N[L_F] \end{array} \right\},
$$

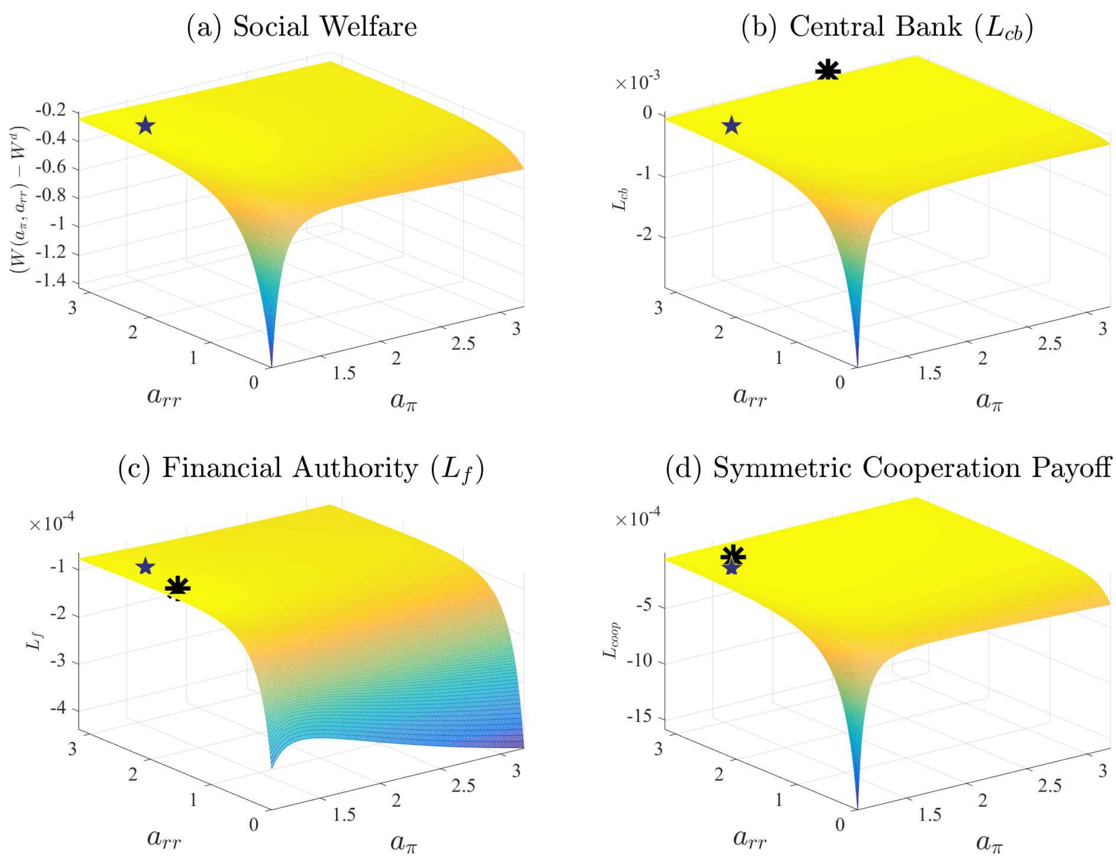
where $\mathrm{E}^N[L_{CB}]$ and $\mathrm{E}^N[L_F]$ are the payoffs of the central bank and the financial authority in the Nash equilibrium. There can be more than one Cooperative equilibrium depending on the value of φ (i.e. the set of Cooperative equilibria corresponds to the core of the contract curve of the two authorities). For simplicity, we focus on two cases, the symmetric Cooperative equilibrium ($\varphi = 1/2$) and one with the value of φ such that the Cooperative equilibrium yields the highest level of social welfare, denoted φ^*. We also compute Stackelberg equilibrium solutions with either the monetary or the financial authority as leaders. When the monetary (financial) authority is the leader, we compute the value of a_π (a_{rr}) that maximizes L_{CB} (L_F) along the financial (monetary) authority's reaction function.

Figure 6 shows four surface plots of different payoff functions for the set of policy rule elasticities in the strategy space. Plot (a) shows social welfare in terms of welfare costs relative to the deterministic steady state, (b) shows L_{CB}, (c) shows L_F, and (d) shows the symmetric cooperative payoff function. The blue star in plot (a) identifies the elasticity pair that maximizes social wel-

[21] In doing this, we are implicitly assuming commitment to the log-linear policy rules and abstract from studying strategic interaction under discretion (see also De Paoli and Paustian, 2017; Bodenstein *et al.*, 2014).

fare, and the blue stars in plots (b)-(d) identify the location of the same elasticity pair in the payoff functions of the central bank, the financial authority, and the symmetric cooperative payoff. The black asterisks identify the elasticity pairs that maximize each payoff function (for (b) and (c) these are also the bliss points that maximize each authority's payoff unconditionally). All of these plots are single peaked, and more importantly, the bliss points of the monetary and financial authorities differ from each other and also differ from the welfare-maximizing and the Cooperative outcomes. These differences reflect the conflict of objectives of the two authorities and their incentives for engaging in strategic behavior.

Figure 6: Payoffs and Policy Rule Elasticities



Note: The blue stars in each figure show the point that maximizes welfare in Plot (a). The black asterisks show the maximum point for each of the corresponding plots.

By construction, the pair of elasticities that maximizes welfare in plot (a) matches the "Best Policy" scenario under the DRR (i.e. the elasticity pairs that yield the best welfare outcome).[22] As noted earlier, the elasticities in the Best Policy case are $(a_\pi^\star, a_{rr}^\star) = (1.27, 2.43)$. It is straightforward to see that this Best Policy outcome also corresponds to a Cooperative equilibrium of a game in which both authorities share welfare as a common payoff, for any value of φ.

[22]This plot is related to the right-side panel in Figure 2, except that in that figure we plotted the value of ce in the vertical axis, and here we show differences in lifetime utility itself.

Figure 7: Reaction Curves and Equilibrium Outcomes

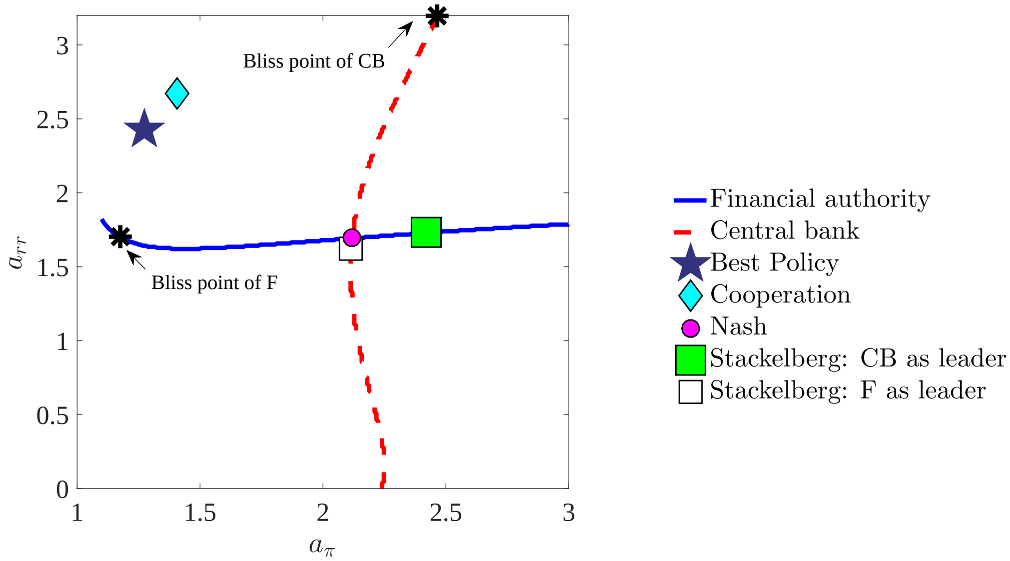


Figure 7 displays the reaction functions of the central bank (red-dashed curve) and the financial authority (blue-solid curve) and the equilibria of the various games: Cooperative with $\varphi = 0.5$ (blue rhombus), Nash (pink dot), and Stackelberg with CB (F) as leader (green and transparent squares, respectively). The plots also identify the locations of each authority's bliss point (black asterisks) and of the Best Policy elasticity pair (blue star).

The two reaction curves are convex and change slope, indicating the relevance of the incentives for strategic interaction. The monetary authority's reaction curve has a more pronounced curvature than the one for the financial authority. In the financial authority's reaction curve, for $a_\pi < 1.5$, $a_{rr}^*(a_\pi)$ falls slightly as a_π rises, while the opposite happens for $a_\pi \geq 1.5$. Hence, the financial authority shifts from treating the two elasticities as strategic complements to treating them as strategic substitutes.[23] The monetary authority's reaction curve has analogous features but with stronger curvature. For $a_{rr} \geq 1.7$, $a_\pi^*(a_{rr})$ increases as a_{rr} rises, so that the elasticities are seen as strategic substitutes, but for most values in the interval $a_{rr} < 1.77$, $a_\pi^*(a_{rr})$ falls as a_{rr} rises, so the elasticities are treated as strategic complements.[24]

The features of the reaction curves described above can be rationalized with the diagrammatic analysis of monetary and financial policy responses to risk shocks described in Section 3, considering that the relative magnitude of the shifts in credit, investment, and aggregate demand induced by one policy v. another depend on the relative values of the policy rule elasticities. The shift from strategic complements to strategic substitutes in the monetary authority's reaction curve occurs

[23]The change would be from substitutes to complements if we just consider the change in the slope of the reaction curve, but recall that a lower a_{rr} means that the financial subsidy increases by less as efp rises, and thus lowering a_{rr} when a_π rises means tightening financial policy when monetary policy tightens. Hence, in terms of strategic interaction, the two policies are strategic complements (substitutes) if a_{rr} falls (rises) when a_π rises, or if a_π falls (rises) when a_{rr} rises.

[24]For a_{rr} very close to 0, $a_\pi^*(a_{rr})$ is negligibly upward sloping but this can due to numerical approximation.

because, at low values of a_{rr}, the financial subsidy does not rise as needed to prop up aggregate demand in response to a risk shock, thus making it optimal for the central bank to lower a_π as a_{rr} increases. For $a_{rr} \geq 1.7$, the situation reverses. Now the monetary authority finds that the financial subsidy props up demand too much and thus finds it optimal to increase a_π as a_{rr} increases. A similar argument explains the shift from strategic complements to strategic substitutes in the financial authority's reaction curve. At low values of a_π, the interest rate does not react as needed to stimulate credit and investment in response to a risk shock, thus the financial authority finds it optimal to pick a high value for a_{rr} the lower a_π is. At high values of a_π, the interest rate reacts too much, thus making it optimal for the financial authority to increase a_{rr} as a_π increases.

Now we compare the equilibria of the different games. Qualitatively, the relative location of the various equilibria in Figure 7 is consistent with standard results when coordination failure is present. The Cooperative outcome is in between the two bliss points (connected by a nonlinear contract curve not shown in the Figure), and the Nash equilibrium differs sharply from the Cooperative equilibrium. Interestingly, the Stackelberg equilibrium when the financial authority leads is very close to the Nash outcome, and not too different from the Stackelberg equilibrium with the monetary authority as leader.

Table 5 compares the outcome of Nash and Cooperative equilibria (symmetric and with the welfare-maximizing value of φ, which is $\varphi^* = 0.23$) against the Best Policy DRR. The Nash equilibrium features a higher a_π than both the two Cooperative equilibria and the DRR outcome (2.12 v. 1.41, 1.33 and 1.27, respectively). Similarly, a_{rr} in the Nash equilibrium is lower than in the Cooperative and DRR equilibria (1.69 v. 2.67, 2.1 and 2.43, respectively). Hence, relative to the DRR and the Cooperative equilibria, the Nash equilibrium is a tight money-tight credit regime: The interest rate rises too much when inflation is above target, and the financial subsidy does not rise enough when the spread is above target. Comparing Cooperative equilibria v. the DRR, the former are still tight-money regimes, but the symmetric Cooperative equilibrium is a loose-credit regime (the financial subsidy rises too much when the spread is above target). The welfare-maximizing Cooperative equilibrium, however, is a tight money-tight credit regime compared with the DRR.

In terms of welfare, the Nash equilibrium is a "third-best" outcome, in the sense that it is inferior to both the Best Policy regime and the Cooperative outcomes. The gains from policy coordination are sizable: Relative to the DRR, the Nash equilibrium implies a reduction in social welfare equivalent to a decline of 30 basis points in the ce measure of welfare. In contrast, the Cooperative equilibrium with $\varphi^* = 0.23$ implies a welfare loss of only 1 basis point. Hence, the welfare cost of coordination failure is roughly 29 basis points (or 26 if we compare v. the symmetric Cooperative equilibrium). It is worth noting that the welfare-maximizing Cooperative outcome increases the weigh of the financial authority from 50 to 77 percent, which reflects how a social planner would aim to compensate for the large costs of risk shocks due to the increased efficiency losses and monitoring costs as efp rises. Note also that the decomposition of welfare costs continues to show large total welfare costs with the bulk coming from differences in averages in the stochastic steady state v. the deterministic steady state.

A comparison of Tables 3 and 5 adds to the result highlighted earlier noting that the ATR dominates the STR but both are inferior to the DRR. The comparison of the two tables shows that the Nash and Cooperative equilibria also dominate both the ATR and STR regimes. Hence, strategic interaction of the monetary and financial authorities is preferable to a STR regime and to a regime in which the Taylor rule is augmented with a response to financial conditions. In other words, while both forms of coordination failure (Tinbergen's rule violations and strategic interaction) have quantitatively significant positive and normative effects in the model we proposed, designing a regime of monetary and financial policies that complies with Tinbergen's rule is relatively more important than dealing with strategic interaction.

Table 5: Strategic Interaction Results

Regime x v. regime y	Param. values of x		ce v.	Decomp. of ce into mean and SD eff.		
	a_π	a_{rr}	DRR	Full ce	Mean eff.	SD eff.
Nash	2.12	1.69	30bp.	4.15%	4.06%	0.09%
Cooperative ($\varphi = 0.5$)	1.41	2.67	4bp.	3.89%	3.80%	0.09%
Cooperative ($\varphi^* = 0.23$)	1.33	2.10	1bp.	3.85%	3.76%	0.09%
DRR (Best Policy)	1.27	2.43		3.85%	3.75%	0.10%

Note: ce corresponds to the consumption equivalent welfare measure defined in equation (2.22).

In Appendix B.1, we study reaction curves for cases in which either welfare or the sum of L_{CB} and L_F are used as the common payoff function for each authority. In both cases, the financial authority displays the same shift from strategic complements to substitutes in the policy elasticities, albeit with significantly more curvature than in Figure 7. In turn, the monetary authority's reaction curve is always downward sloping when welfare is the common payoff, so in that case the monetary authority always treats the elasticities as strategic complements. Interestingly, when the sum of L_{CB} and L_F is the common payoff, the monetary authority's reaction curve shifts from strategic substitutes to complements as a_{rr} increases, with an inflection point near $a_{rr} = 0.25$. Regardless of the shape of the common payoff, the Cooperative, Nash, and Stackelberg equilibria coincide, because there is no coordination failure. This is a straightforward result, since the spillovers of the policy rule elasticities chosen by each authority are relevant only through their effect on the arguments of the payoff function of the other authority. What changes, however, is that when social welfare is the payoff, the cooperative and noncooperative equilibria also match the DRR Best Policy outcome, which is not the case in general for other common payoff functions. It is also worth noting that the fact that cooperative and noncooperative equilibria are the same assuming a common payoff implies that in this model this is equivalent to assuming cooperation. Hence, the notion that coordination failure could be removed with the seemingly simple step of giving the two authorities the same payoff function is in fact as complex as asking them to coordinate fully.

4.4 Extensions & robustness

We examine below the robustness of the findings we have reported to changes in some of the key features of the model (the degree of price stickiness, the severity of financial frictions, and the persistence of habits), and the implications of introducing some important extensions (adding the output gap to monetary rules, introducing shocks to government expenditures, TFP and price markups, and modifying the targets of the financial policy rule). Overall, the qualitative features of our main findings continue to hold, with the exception that without risk or markup shocks financial transmission weakens to the point that financial policy has negligible effects. Full details are provided in Sections B.1-B.7 of the Appendix .

4.4.1 Price stickiness & financial sector parameters

Appendix B.3 reports the results of re-evaluating the quantitative implications of Tinbergen's rule and strategic interaction under four alternative parameterizations: (a) *"stickier" prices* ($\vartheta = 0.85$ instead of 0.74 in the baseline), so that firms reset prices every two years on average rather than once a year, (b) *larger monitoring costs* ($\mu = 0.30$ instead of the baseline value of 0.12), which increases monitoring costs to nearly a third of the entrepreneurs' gross returns, (c) *riskier entrepreneurs* ($\bar{\sigma}_{\omega} = 0.40$ v. the baseline value of 0.27), which nearly doubles the average variability of the entrepreneurs' profits, and (d) *zero steady-state financial subsidy* ($\tau_f = 0$ v. 0.96% in the baseline), which allows costly state verification to distort the deterministic stationary equilibrium and makes the financial rule more likely to fluctuate between subsidies and taxes. For each scenario, we re-compute the optimized policy rule elasticities that minimize welfare costs under the STR, ATR, and DRR regimes, and solve for the cooperative and non-cooperative equilibria with quadratic payoffs.

Tinbergen's rule is quantitatively relevant in all four cases. The DRR delivers welfare gains of roughly 1% and 2% relative to the ATR and STR regimes, respectively. Also in all cases, strategic interaction delivers results that echo the baseline findings, with some variations worth noting. For instance, as in the baseline, the reaction function of the monetary authority displays the same shift from strategic complements to substitutes in the best-response-choice of a_{π} to changes in a_{rr} when $\bar{\sigma}_{\omega} = 0.40$ and $\tau_f = 0$, while this best response displays only strategic complementarity when $\vartheta = 0.85$ and $\mu = 0.30$. In contrast, the reaction curves of the financial authority display in all cases a shift from strategic complements to substitutes similar to what we found in the baseline. In all cases the Nash equilibrium yields a tight-money, tight-credit regime with respect to the best-policy and cooperative outcomes. In turn, the latter is a tight-money regime with respect to the best policy regime when $\vartheta = 0.85$, $\bar{\sigma}_{\omega} = 0.40$, and $\tau_f = 0$, but it is a loose-money regime when $\mu = 0.30$. The credit policy of the cooperative equilibrium does not display a clear pattern with respect to the best policy case. It is a tight-credit regime when $\tau_f = 0$, slightly tighter when $\vartheta = 0.85$, and looser when $\mu = 0.30$ and $\bar{\sigma}_{\omega} = 0.40$.

In case (a), with a higher degree of price stickiness than in the baseline, we find a more aggressive response of the central bank, particularly when the financial authority adopts a relatively passive rule (i.e. for low values of a_{rr}). As documented in Appendix B.3, when $\vartheta = 0.85$, the best response of the monetary rule elasticity features larger complementarities with the financial rule elasticity, so that the monetary authority finds optimal to increase a_π more aggressively than in the baseline as a_{rr} decreases, and more so when a_{rr} is low. Hence, the central bank aims to meet its inflation target by being very active when the financial authority is quite passive.

In cases (b) and (c), making financial frictions more severe by either increasing monitoring costs or the average variance of the entrepreneurs returns, increases the variability of the external finance premium and inflation, which imply that the policy rules under all the policy regimes considered have to respond to potentially larger deviations from their targets. If the change in the variance of efp is relatively larger than that of π, we should expect a more aggressive reaction by the financial authority, reflected in an upward shift of its reaction function relative to the baseline (i.e. a shift towards an easier credit policy that aims to reduce the distortions generated by an inefficiently restrictive credit market). In contrast, if the change in the variance of π is relatively larger than that of efp, then we should observe a rightward shift in the reaction function of the monetary authority with respect to the baseline (i.e. a shift towards tighter monetary policy). In Appendix B.3, we show that when $\mu = 0.30$, efp becomes much more volatile than π, and thus we find a shift towards easier credit policy by the financial authority in comparison to the baseline, while monetary policy increases its strategic complementarity with financial policy. As a result, with larger monitoring costs, the policy regime is loose-money, loose-credit in comparison to the baseline. In the case with $\bar{\sigma}_\omega = 0.40$, the variances of efp and π increase in a similar manner, and so we find just a slight shift towards a regime of tighter-money, tighter-credit with respect to the baseline, with only moderate displacements in the reaction curves of the two policymakers.

In case (d), which removes the steady-state financial subsidy, the Nash equilibrium yields a slightly tighter financial policy rule (lower a_{rr}) and a much tighter monetary policy rule (higher a_π) than in the baseline Nash equilibrium and in the cooperative and best-policy equilibria with $\tau_f = 0$. The curvature of the reaction curves is similar to that in the baseline case, but the monetary (financial) authority's reaction curve shifts rightward (downward). Hence, the policy spillovers reflected in the curvature of reaction curves are similar with and without the steady-state financial subsidy, but the optimal elasticity of one authority's rule changes when the other authority's elasticity is set to its lowest level.[25]

The monetary authority sets a_π higher when $a_{rr} = 0$ in the case with $\tau_f = 0$ than in the baseline, because when both $a_{rr} = 0$ and $\tau_f = 0$ effectively there is no financial policy. Since in the neighborhood of $a_{rr} = 0$ the two policy rule elasticities are strategic complements, when the financial policy is completely removed the central bank cannot benefit from the effect of the financial policy response to risk shocks on inflation, and thus it finds optimal to choose a higher Taylor rule elasticity. The reaction curve of the financial authority shifts because of an analogous effect. The financial authority sets a_{rr} lower (i.e. tightens financial policy) when a_π is close to 1 in the case with $\tau_f = 0$ than in the baseline, because when $a_\pi \to 1$ the monetary policy reacts

[25]Setting $\tau_f = 0$ also reduces the long-run investment- and capital-output ratios because of the efficiency losses due to costly monitoring, as we explained earlier (see Table 2), but with the local solution method these effects do not alter significantly the cylical tradeoffs that determine the curvature of reaction curves.

passively to inflation deviations. Since in the neighborhood of $a_\pi \to 1$ the two policy rule elasticities are strategic complements, when the monetary policy becomes less responsive to inflation, the financial authority cannot benefit from the effect of the monetary policy response to risk shocks on efp, and thus it finds it optimal to respond more aggressively by choosing a lower a_{rr}.

4.4.2 Monetary rules responding to output gap

Appendix B.4 documents results of experiments showing that adding the output gap to the monetary rules does not yield higher welfare than the monetary rules we studied (i.e. monetary rules with a zero elasticity on the output gap yield the lowest welfare costs). Hence, our quantitative findings on Tinbergen's rule are identical to those obtained with the baseline model. This finding holds for two specifications of output: one consistent with the model's resource constraint (2.20), so that output equals aggregate demand plus monitoring costs ($y_t = c_t + c_t^e + i_t + g + \mu G(\bar{\omega}_t) r_t^k q_{t-1} k_{t-1}$), and one that matches the definition of output in the national accounts, so that output equals aggregate demand only ($\tilde{y}_t = y_t - \mu G(\bar{\omega}_t) r_t^k q_{t-1} k_{t-1}$). The output gap is then defined as either $\hat{y}_t = (y_t/y - 1)$ or $\hat{y}_t = (\tilde{y}_t/\tilde{y} - 1)$ for the first and second formulation, respectively. We add $\hat{y}_t$ with an elasticity a_y to both the STR and the ATR and compute the welfare-maximizing values of the policy rule elasticities.

To find the welfare-maximizing elasticities, we performed a two-dimensional search over a_π and a_y for the STR regime, and a three-dimensional search over a_π, $\breve{a}_{rr}$, and a_y for the ATR regime, and over a_π, a_{rr}, and a_y for the DRR regime. The lowest welfare costs are always obtained when $a_y = 0$. This result echoes Schmitt-Grohé and Uribe (2007), who found that interest-rate rules with $a_y > 0$ may lead to significant welfare losses. This is the case because inflation volatility tends to increase with $a_y > 0$ and this makes the inefficiencies caused by price dispersion larger. Notice that the outcome would be different if we assume that the central bank does not aim for the best welfare outcome but instead minimizes a quadratic loss function that includes the variance of the output gap. In this case, the central bank may find optimal to set $a_y > 0$, even if social welfare is lower. See Appendix B.4 for an analysis of the effects of varying a_y on output variability.

4.4.3 Determinants of welfare costs

Appendix B.5 reports the results of a sensitivity analysis showing how changes in key parameter values affect the welfare assessments, and evaluating the robustness of the result obtained under the baseline calibration indicating that changes in the model's long-run averages are the key determinant of the large welfare costs of risk shocks. We consider the effects of changes in habit formation, the coefficient of monitoring costs, and the degree of nominal rigidities in the STR, ATR, and DRR regimes. We vary the habit parameter h in the interval $[0, 0.95]$, the monitoring costs parameter μ in the interval $[0, 0.50]$, and the Calvo pricing parameter ϑ in the interval $[0, 0.90]$. These parameter changes are introduced one at a time, keeping all other parameters at the values set in the baseline calibration.

The total welfare cost of risk shocks, ce, is generally large and varies non-linearly for all three of the parameter variations considered, with regions in which it is nearly invariant to parameter variations and regions in which it rises sharply. For instance, ce rises sharply as μ starts to increase starting from zero, reaching roughly 4%, 5%, and 6% when $\mu = 0.05$ in the DRR, ATR, and STR regimes respectively. As μ rises above 0.05 the value of ce increases at a much slower pace and eventually becomes slightly decreasing in μ. The opposite pattern is observed for the variations in h and ϑ. The value of ce is nearly unchanged as these parameters increase starting from zero, until eventually ce becomes a very steep function of both. For ϑ, there is an intermediate region of values of ϑ in which ce is slightly negatively-sloped, but as ϑ rises above 0.8 the value of ce increases rapidly with ϑ. The highest welfare costs are roughly 5%, 7% and 8% when ϑ is about 0.9 in the DRR, ATR, and STR regimes respectively. For h, ce becomes a steep, increasing function of h for $h > 0.7$, reaching vertical asymptotes as h approaches 1 in all policy regimes. For $h = 0.9$ (higher than the 0.85 baseline value), the welfare costs reach about 5%, 7.5%, and 10% in the DRR, ATR, and STR regimes respectively. This high sensitivity of welfare costs to high degrees of habit formation is in line with Campbell (1999), who argues that consumers with strong habits can be viewed as less able to make short-term adjustments in consumption to adjust to shocks, which implies that fluctuations have stronger negative effects on welfare.

The DRR regime always dominates the ATR and STR regime, and this is because it delivers consumption processes with higher averages and lower variances. For instance, in the baseline DRR regime the mean of consumption is 1.5% and 2.2% higher than in the ATR and STR regimes, respectively. In turn, the standard deviation of consumption in the ATR (STR) regime is 2.5 (3.1) times higher than in the DRR regime.

We also provide in Appendix B.5 a detailed analysis showing that, in line with the baseline results, the main determinant of the large welfare costs of risk shocks in all the experiments reviewed here are changes in the mean levels of lifetime utility relative to the deterministic steady state. In turn, monitoring activity explains a large proportion of welfare costs. And finally, the contribution of business cycle volatility is small and comparable to the negligible costs of business cycles found by Lucas (1987). Across all three policy regimes and all values of h, μ, and ϑ considered, the overall welfare costs of risk shocks range between 1.54% and 7.95%, and the *mean effect* accounts for at least 90% of these costs. Welfare costs of business cycles range between 0.01% and 0.68%.

4.4.4 Results for other aggregate shocks

We study next the implications of considering aggregate shocks other than risk shocks (see Appendix B.6 for details). In particular, we study whether an ATR regime with a non-zero $\check{a}_{rr}$ elasticity, or a DRR regime with a non-zero a_{rr} elasticity in the financial policy rule, still dominates the STR regime if risk shocks are replaced with shocks to government expenditures, TFP, or price markups.

In sharp contrast with the predictions of the baseline model, we find that using the ATR to "lean against the wind" of financial conditions is suboptimal for all of the three alternative shocks, because the corresponding welfare-maximizing values of $\check{a}_{rr}$ equal zero. In the model we proposed, if business cycles are driven by fiscal, TFP or markup shocks, the central bank does best by setting the interest rate focusing only on inflation targeting, ignoring fluctuations on efp. Because of this result, for these alternative aggregate shocks the STR and ATR regimes are equivalent, and hence we refer to them jointly as the STR/ATR regime.

In the case of the DRR regime, we find again that for government-spending and TFP shocks there is no role for financial policy in the model, since the corresponding welfare-maximizing values of a_{rr} equal zero. Thus, for these two shocks, DRR is also equivalent to the STR. A Taylor rule with an inflation elasticity of about 2.3 (2) for government expenditure (TFP) shocks yields the best welfare outcome. For markup shocks, however, the welfare-maximizing value of a_{rr} is positive, and hence the DRR regime differs from the STR/ATR regime. In the STR/ATR regime, the welfare-maximizing inflation elasticity of the Taylor rule is $a_{\pi} = 2.1$ (and $\check{a}_{rr} = 0$), while in the DRR regime the welfare-maximizing elasticities of the separate policy rules are $a_{\pi} = 2.2$ and $a_{rr} = 2.4$. Thus, monetary policy is slightly less tight in the the STR/ATR than in the DRR regime, but financial policy is much tighter. Tinbergen's rule is again quantitatively relevant: welfare increases by about 1% by shifting from the STR/ATR to the DRR regime (i.e. the welfare costs of markup shocks fall by roughly 1%).

The sharp contrast in the relevance of financial policy with risk or markup shocks v. its irrelevance with TFP or government expenditure shocks follows from differences in the way the various shocks interact with the Bernanke-Gertler financial accelerator. For the risk shocks, the previous analysis and quantitative results showed that these shocks have a first-order effect in the optimality conditions that determine efp, and the resulting changes in the variability and long-run average of efp have significant implications for allocations, prices and welfare via the financial accelerator. Hence, in the case of risk shocks, it is natural to expect that financial policy to be relevant. For the other three shocks, however, we need to examine further the mechanism that links them with the financial sector in order to understand why financial policy is relevant with markup shocks but not with TFP and government expenditure shocks.

One reason for financial policy to be less relevant with these alternative shocks is methodological: The perturbation methods used to solve New Keynesian DSGE models to do not allow us to capture fully the non-linear implications of the financial accelerator. The external finance premium is a convex function of net worth, and to the extent that shocks cause large changes in net worth the local methods underestimate the response of efp, and hence its real effects. This is less of a problem for risk shocks because they have first-order effects on efp.

Beyond the above methodological issue, there are also features of the model's financial transmission mechanism that play a role in the weaker interaction of TFP and government expenditure shocks with the financial accelerator relative to the stronger interaction under markup shocks. In Appendix B.6, we show the impulse response functions of the model for positive shocks to government expenditures and markups, and a negative TFP shock, and use the results to explain why financial transmission is less relevant for shocks to government expenditures and TFP. These shocks result in higher inflation and declines in consumption, investment and the price of capital.[26] The shock to government expenditures has a positive effect on output, while the other two have a negative effect. But for financial transmission the key difference across these shocks is in the response of intermediate goods producers and their effect on credit spreads. With shocks to government expenditures or TFP, intermediate goods producers increase their demand for labor and capital, as they aim to meet the excess demand in the final good market. As a result, the rental rate of capital increases, which increases capital returns and the entrepreneurs' net worth, counteracting the downward pressure on these variables that the fall in the price of capital exerted, and thus weakening the effects of the financial accelerator. The efp rises around 2 basis points after the shock to government spending and 5 basis point after the shock to TFP (8 and 20 basis points in annual terms, respectively), while investment falls 0.5% and 0.8% in each case.[27] In contrast, an increase in markups strengthens the monopolistic distortions affecting the inputs market, causing firms producing intermediate goods to reduce their demand for inputs, so that wages and the rental rate of capital fall. The latter intensifies the reduction in entrepreneurs' net worth, strengthening the financial accelerator. In this case, efp rises 10 basis points (40 in annual terms) under the STR/ATR policy, and investment and output decrease 1.5% and 0.4%, respectively.

In the setup with markup shocks, when financial policy is active under the DRR regime, the increase in the efp moderates to just 2 basis points (8 in annual terms) after the shock, and investment and output fall only 0.9% and 0.3%. The DRR regime has a short-term cost in terms of consumption, however, due to the increase in lump-sum taxes that are collected to finance the financial subsidy (see Section 4.2). Still, this short-term cost pays off in the long term since consumption has a higher steady-state mean under the DRR regime than under the STR/ATR regime (about 2.2% higher). In turn, welfare costs are 100 basis points lower in terms of ce in the DRR regime in comparison to the STR/ATR regime, as mentioned above.

Since of the three alternative shocks we examined here, financial transmission is only relevant in the case of markup shocks, we study strategic interaction of monetary and financial policy only for this case. We found that again the reaction curves are nonlinear, and that the Nash equilibrium yields again a tight-money, tight-credit regime, with a welfare cost 1.23 percentage points higher than with the Best Policy (DRR) outcome.

In summary, these results indicate that in the model we proposed, Tinbergen's rule and strategic interaction in the conduct of monetary and financial policies are relevant only to the extent that risk and/or markup shocks are important drivers of economic fluctuations. If fluctuations are driven mainly by shocks to TFP or government expenditures, a STR guiding monetary policy dominates both leaning against the wind of financial conditions or introducing a separate financial policy rule.

[26] Shocks to government expenditures have opposing effects on inflation. On the one hand, higher government expenditures increase aggregate demand and hence push for higher inflation. On the other hand, since agents in the model are Ricardian, government expenditures crowd out private expenditures, weakening aggregate demand. Inflation still rises with government expenditures, but by less than a one-to-one effect.

[27] These numbers are consistent with results showing that the financial accelerator accounts for a small share of business cycles in standard BGG models with shocks to TFP or government expenditures.

4.4.5 Alternative financial policy rules

Appendix B.7 shows that there are alternative financial policy rules targeting other variables that turn out to be equivalent, up to a first-order approximation, to the baseline financial policy rule targeting efp. One rule targets fluctuations in leverage and the variability of the entrepreneurs' profits. The second rule targets the ratio of debt to net worth and again the dispersion of profits. We verified that these two alternative financial rules deliver the same impulse response functions, up to a first-order approximation of the model, as the baseline rule targeting efp.

Using the first-order conditions of the optimal financial contract, we prove that the baseline financial rule, equation (2.18), in which the financial instrument reacts to deviations of efp with respect to its steady-state level, is equivalent, up to a first-order approximation, to a rule that sets the financial subsidy to respond to deviations of leverage and the standard-deviation of entrepreneurs' profits from their steady-state levels, with the elasticities of this rule set to particular values. The alternative financial rule has this form:

$$1+\tau_{f,t}=(1+\tau_f)\times\left(\frac{x_t}{x}\right)^{a_x}\left(\frac{\sigma_{\omega,t}}{\bar{\sigma}_\omega}\right)^{a_\sigma}, \tag{4.2}$$

where $a_x, a_\sigma > 0$ are the elasticities of the subsidy with respect to leverage and the variability of profits. Intuitively, an increase in either leverage or in the dispersion of entrepreneurs' profits raises the probability of default of entrepreneurs, and thus the external finance premium, and hence a financial rule that reacts to these two variables is akin to one that targets efp. First-order equivalence is obtained by setting $a_b = \chi_x a_{rr}/(1+a_{rr})$ and $a_\sigma = \chi_\sigma a_{rr}/(1+a_{rr})$, where $\chi_x, \chi_\sigma > 0$ are reduced-form coefficients that depend on the structural parameters of the model (see Appendix B.7 for details).[28]

Similarly, the balance sheet of entrepreneurs implies that there is a close relationship between an entrepreneur's debt, its leverage, and its net worth, since $x_{e,t} \equiv q_t k_{e,t}/n_{e,t} = 1 + b_{e,t}/n_{e,t}$ (see Section 2.2). Therefore, a financial rule that reacts to efp is also mathematically equivalent, up to a first-order approximation, to the following rule setting the financial subsidy to respond to changes in aggregate private debt, aggregate net worth, and the dispersion of entrepreneurs' profits:

$$1+\tau_{f,t}=(1+\tau_f)\times\left(\frac{b_t/n_t}{b/n}\right)^{a_b}\left(\frac{\sigma_{\omega,t}}{\bar{\sigma}_\omega}\right)^{a_\sigma}, \tag{4.3}$$

where $a_b > 0$ is the elasticity of the subsidy with respect to the ratio b_t/n_t. This rule is equivalent (up to a first-order approximation) to the baseline financial rule if we set $a_b = \chi_b \upsilon_b a_{rr}/(1+a_{rr})$ where $\upsilon_b \equiv (x-1)/x$.[29]

[28]A first-order approximation to the first-order conditions of the optimal financial contract yields: $\widehat{\mathrm{efp}}_t + \hat{\tau}_{f,t} = \chi_x \hat{x}_t + \chi_\sigma \hat{\sigma}_{\omega,t}$. Combining this result with the first-order approximation of the baseline financial rule ($\hat{\tau}_{f,t} = a_{rr}\widehat{\mathrm{efp}}_t$), we obtain $\widehat{\mathrm{efp}}_t = (\chi_x \hat{x}_t + \chi_\sigma \hat{\sigma}_{\omega,t})/(1+a_{rr})$. From here, it is straightforward to see that an alternative financial rule that reacts to x_t and $\sigma_{\omega,t}$, of the form $\hat{\tau}_{f,t} = a_x \hat{x}_t + a_\sigma \hat{\sigma}_{\omega,t}$, can be constructed to be equivalent to the baseline financial rule. Making the two rules equivalent requires $\chi_x - a_x = \chi_x/(1+a_{rr})$ and $\chi_\sigma - a_\sigma = \chi_\sigma/(1+a_{rr})$.

[29]A linear approximation to the aggregate balance sheet of entrepreneurs yields $\hat{x}_t = \upsilon_x(\hat{b}_t - \hat{\eta}_t)$. It follows that an alternative financial rule that responds to b_t, n_t, and $\sigma_{\omega,t}$, so that $\hat{\tau}_{f,t} = a_b(\hat{b}_t - \hat{n}_t) + a_\sigma \hat{\sigma}_{\omega,t}$ is mathematically equivalent to the linearized baseline rule as long as $a_b = \chi_x \upsilon_x a_{rr}/(1+a_{rr})$ and $a_\sigma = \chi_\sigma a_{rr}/(1+a_{rr})$.

5 Conclusions

This paper studies coordination failure in the implementation of monetary and financial policies in a New Keynesian model with risk shocks. Because of Calvo-style staggered pricing and Bernanke-Gertler costly monitoring of borrowers, risk shocks cause inefficient business cycle fluctuations and long-run efficiency losses in capital accumulation and resources allocated to monitoring costs. Monetary and financial policies can tackle these distortions but are subject to two forms of coordination failure. First, violations of Tinbergen's rule, because a lean-against-the-wind policy regime in which monetary policy aims to tackle *both* distortions is inferior to one in which separate monetary and financial policy rules tackle *each* distortion separately. Second, strategic interaction between the authorities formulating the two policies, because the equilibrium determination of each authority's target depends on the policy instruments controlled by both authorities, and these spillovers incentivize strategic behavior.

The theoretical principles behind these two forms of coordination failure are well established. Hence, our contribution is in assessing their quantitative relevance in an explicit dynamic stochastic general equilibrium framework. The quantitative analysis provides four key results: 1) Welfare costs of risk shocks are large, ranging from 3.8 to 6.5 percent across the various policy regimes we examined, because of long-run effects of risk shocks that produce a higher external finance premium on average (and hence larger efficiency losses in investment and larger monitoring cost payments). 2) Violations of Tinbergen's rule are quantitatively significant. A regime in which the Taylor rule is augmented with financial stability considerations produces lower welfare and larger macroeconomic responses to risk shocks than a dual-rules-regime in which monetary policy follows a Taylor rule to set the nominal interest rate and financial policy follows a rule to set a subsidy on financial intermediation. Moreover, the augmented Taylor rule results in a tight money-tight credit regime, in which the interest rate rises too much when inflation increases and does not fall enough when the credit spread widens. 3) Reaction curves that describe the optimal choice of policy rule elasticities of the monetary and financial authorities are convex, and display switches from strategic complements to strategic substitutes in the adjustment of those elasticities. 4) Standard quadratic payoff functions yield a Nash equilibrium in the setting of policy rule elasticities significantly inferior to a Cooperative equilibrium and to a welfare-maximizing dual rules regime, and both the Nash and the Cooperative equilibria are also tight money-tight credit regimes. Still, even the Nash equilibrium dominates the simple Taylor and augmented Taylor Rule regimes.

The findings of our analysis proved to be robust to several parameter variations, including changes in the degree of price stickiness, the severity of financial frictions, and the persistence of habits, and modifications in the baseline model adding the output gap to monetary rules, introducing shocks to price markups, and modifying the targets of the financial policy rule. One important exception is that we found that if government expenditures or TFP shocks are the only drivers of economic fluctuations, financial transmission weakens to the point that financial policy is nearly neutral and a policy regime with a standard Taylor rule dominates.

This analysis raises two important issues for further research. First, for tractability, we used perturbation methods to quantify the amplification effects of risk shocks in the Bernanke-Gertler financial accelerator. As explained by Mendoza (2016), the perturbation methods underestimate the magnitude of the financial amplification, and thus are likely to underestimate the magnitude of the distortions that the financial subsidy should address. Second, our analysis included only the features of financial intermediation and the financial transmission mechanism embodied in the Bernanke-Gertler setup. Hence, this setup does not include important features of actual financial systems that are worth considering in further research, such as securitization, systemic risk, and balance sheet leveraging.

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