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

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Abstract

Quantitative analysis of a New Keynesian model with the Bernanke-Gertler accelerator and risk shocks shows that violations of Tinbergen's Rule and strategic interaction between policy-making authorities undermine significantly the effectiveness of monetary and financial policies. Separate monetary and financial policy rules, with the latter subsidizing lenders to encourage lending when credit spreads rise, produce higher welfare and smoother business cycles than a monetary rule augmented with credit spreads. The latter yields a tight money-tight credit regime in which the interest rate responds too much to inflation and not enough to adverse credit conditions. Reaction curves for the choice of policy-rule elasticity that minimizes each authority's loss function given the other authority's elasticity are nonlinear, reflecting shifts from strategic substitutes to complements in setting policy-rule parameters. The Nash equilibrium is significantly inferior to the Cooperative equilibrium, both are inferior to a first-best outcome that maximizes welfare, and both produce tight money-tight credit regimes.

Keywords: Financial Frictions, Monetary Policy, Financial Policy.

JEL classification: E44; E52; E58.

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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 two ideas into practice, however, has proven difficult, largely 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 (2011b), 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. Opposing these arguments, 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 (2013) or Angelini, Neri and Panetta (2014), are concerned with 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 for 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 the result of costly state verification of entrepreneurs by financial intermediaries. Monetary policy is modeled as a standard Taylor rule governing the nominal interest rate. Financial policy is specified as a rule setting a subsidy on the revenue that financial intermediaries earn from loans, so that a higher subsidy incentivizes lending when credit conditions tighten. The effectiveness of alternative policy regimes is assessed in terms of what they imply for social welfare, macroeconomic dynamics, policy targets, and the elasticities of policy rules that maximize the payoffs of policymakers. We compare the performance of dual monetary and financial policy rules

v. a single monetary policy rule augmented to respond to the credit spread, and compute reaction curves of policy rule elasticities and policy game equilibria under various formulations of payoff functions.¹

We follow Christiano, Motto and Rostagno (2014) in emphasizing the role of risk shocks because they enhance the quantitative relevance of the Bernanke-Gertler financial transmission mechanism, so that the financial sector plays a more significant role in economic fluctuations and thus financial policy can be more relevant.² Risk shocks are shocks to the variance of the returns of 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.³ Since the agency costs in the credit market result from a real rigidity (i.e. costly state verification), risk shocks are akin to financial shocks that create inefficient fluctuations in the interest rate lenders charge to entrepreneurs.

We focus on policy rules defined as log-linear functions with elasticities linking policy instruments to their targets. For monetary policy, it is well-known that rules of this type (such as 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 these rules do not always match the solution of Ramsey (i.e. utility maximizing) optimal policy problems under commitment.⁴ We follow this "rules approach" because it is the dominant approach to evaluate monetary policy scenarios in practice, and because Ramsey-optimal *financial* policies often require global, non-linear solution methods and have been solved for only in stylized models (see Bianchi and Mendoza, 2015). Still, monetary and financial authorities act optimally in the sense that they set the elasticities of their rules so as to maximize their particular payoff functions, considering payoffs that minimize the sum of the variances of their instruments and targets (as in Taylor and Williams, 2010; Williams, 2010) or scenarios with a common payoff defined in terms of social welfare or the combined sum of variances of instruments and targets of both poli-

¹Since welfare assessments are critical for this analysis, and the Bernanke-Gertler external financing premium is a convex function of net worth, the quantitative analysis is undertaken using a second-order approximation method.

²We examine in the online Appendix the effects of introducing technology and government expenditure shocks. Financial policy tends to be less relevant with these shocks, because of the standard result that in New Keynesian models the amplification produced by the Bernanke-Gertler accelerator in response to typical shocks is small.

³Christiano *et al.* argue that these shocks can explain a large fraction of U.S. business cycles, equivalent to 60 percent of the fluctuations in GDP growth.

⁴Woodford (2010) reviews optimal monetary policy in New Keynesian models and provides a detailed analysis of 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.

cies. We also compute reaction functions that show the best response of each authority's elasticity to a given choice of the other authority's elasticity, and use them to solve for Nash and Cooperative equilibria of one-shot games between the two authorities. This methodology is analogous to that 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.

The question of whether the monetary policy rule should be augmented with financial stability considerations, or whether there should be instead a separate financial policy rule, is equivalent to asking whether Tinbergen's Rule applies in the design of monetary and financial policies. That is, are two policy instruments needed for two policy targets (price and financial stability)? In the model we propose, two instruments are clearly needed, because of the two inefficiencies that are present (sticky prices and costly state verification). Hence, the question is not whether Tinbergen's Rule is valid in theory, but whether it is quantitatively relevant. To answer this question, we compare a dual regime, in which the monetary policy rule sets the interest rate as a function of the deviation of inflation from its target and the financial policy rule sets the lender's subsidy as a function of the deviation of the expected credit spread from its target, with a single-rule regime in which the monetary policy rule depends on both inflation and the expected spread. The paper's contribution is in determining whether the welfare and business cycle differences across these two regimes are quantitatively significant, and if so in deriving the policy implications that follow.

The question of whether costly strategic interaction among financial and monetary policies makes cooperation between them necessary 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 or departments that could face incentives for acting strategically.

In the model we propose, the 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 terms of the

optimal contract that lenders offer to entrepreneurs. Hence, again the contribution of the paper is not about making a theoretical case for strategic interaction, but about studying if strategic interaction is quantitatively significant and if so analyzing its macroeconomic implications.⁵

In order to assess the quantitative relevance of strategic interaction, we proceed in three steps. First, we solve for a “first-best” scenario, in which a single planner sets the elasticities of the monetary and financial policy rules to maximize social welfare. Second, we consider two separate authorities, each setting the elasticity of its individual rule to maximize social welfare or another common loss function. Since strategic interaction in the model emerges only via conflict in the payoffs of the players, coordination is irrelevant with any common payoff. Using welfare as a common payoff, the Nash and Cooperative equilibria are the same *and* also match the first-best outcome, whereas with other common payoff functions Cooperative and Nash equilibria are still the same but are inferior to the first-best outcome. Third, we study a scenario in which the payoff functions of the two authorities differ, and hence coordination becomes relevant and Cooperative equilibria dominate non-Cooperative ones. In particular, we study the case in which the loss functions take a standard form that depends on the variances of each authority’s instrument and target.

The quantitative analysis yields three key results. First, deviations from Tinbergen’s Rule are quantitatively significant. Welfare is higher with separate monetary and financial policy rules than with the monetary policy rule augmented to include the credit spreads. The latter is welfare-improving relative to not responding to financial conditions at all (welfare increases if the central bank responds to credit-spread deviations with the financial authority keeping its instrument constant), in line with previous findings (see Cúrdia and Woodford, 2010). But the dual regime with separate financial and monetary rules yields welfare gains that are 15 percent higher than the one-rule case. In addition, the regime with one rule yields an elasticity in the response to inflation (credit spreads) that is higher (smaller) than the regime with two rules. We refer to this situation as a “tight money-tight credit” regime because the interest rate responds too much to inflation and not enough to adverse credit conditions. The rationale behind these results reflects the general principle of Tinbergen’s Rule, requiring two instruments for two targets. Since there are two inefficiencies in the model, price stickiness and costly state verification, the single monetary policy instrument (i.e. the short-run nominal interest rate) following a rule augmented to respond to credit spreads cannot do as well at tackling both inefficiencies as using separate monetary and financial

⁵Analytically, 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.

policy rules with separate instruments (the interest rate and the credit subsidy). The stronger response to inflation than to credit spreads with one rule is natural, because monetary policy is more effective than financial policy at addressing nominal rigidities, and since we compute rule elasticities that maximize welfare, the elasticities under the one-rule regime reflect this relative advantage.

Second, the reaction curves of monetary and financial authorities are non-linear, and optimal elasticity responses can change from strategic substitutes to complements depending on payoff functions and parameters. Under our baseline calibration to U.S. data and using welfare as the payoff of both authorities, the reaction function of the financial authority shows that the best elasticity response of the financial rule is a strategic substitute if the elasticity of the monetary rule is sufficiently low, and otherwise is a strategic complement. That is, the financial authority's reaction function shifts from downward to upward sloping as the monetary rule elasticity rises. The reaction function of the monetary authority is convex but always consistent with strategic substitutes. When the payoffs are loss functions of the sum of the variances of targets and instruments, similar results are obtained, except that the reaction function of the monetary rule is the one that changes from strategic substitutes to strategic complements as the elasticity of the financial rule rises, and the reaction function of the financial authority is convex but always consistent with strategic substitutes.

Third, with payoff functions given by the sum of variances of each authority's individual instrument and target, strategic interaction is quantitatively significant. The Nash equilibrium results in a welfare loss of 6 percent relative to the Cooperative equilibrium, and both of these equilibria are inferior to the first-best outcome. The Nash and Cooperative outcomes yield again tight money-tight credit regimes relative to the first-best regime, with a much larger inflation bias in the Nash equilibrium than in both the Cooperative and first-best outcomes.

The gains from coordination when the payoff functions differ arise because of the strategic incentives faced by each authority acting unilaterally, taking the other authority's choice as given. Intuitively, each authority focuses on one of the two sources of inefficiency in the economy, with inflation proxying for the inefficiencies due to the nominal rigidities and credit spreads for those due to the financial friction. However, at the equilibrium, changes in the instrument that each authority controls affect the targets of both authorities. In the neighborhood of the Nash equilibrium, 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), but the best response

of the monetary authority is a strong strategic complement of the financial authority's elasticity. This indicates that there are quantitatively large adverse spillovers of financial subsidy hikes on the volatility of inflation and/or interest rates through the model's general equilibrium dynamics. A small increase in the financial rule elasticity increases the volatility of inflation and the nominal interest rate sufficiently to justify sizable increases in the elasticity of the monetary rule as the best response.

Cooperation tackles these adverse spillovers by lowering both the inflation and spread elasticities relative to the Nash equilibrium. The interest rate responds less to inflation, making the policy less tight, but also the financial subsidy responds less to higher spreads, making financial policy tighter. 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. The financial authority increases the elasticity of its rule slightly (i.e. makes financial policy less tight) and keeps it nearly constant regardless of what the monetary authority does, while the monetary authority increases significantly its elasticity (i.e. makes monetary policy tighter) until it attains the best response for that elasticity of the financial rule. On the other hand, both Nash and Cooperative equilibria yield policies that are too tight relative to the welfare-maximizing first-best outcome.

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 (2013) 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, which is behind our finding of tight-money, tight-credit regimes, and in that we find significant gains from policy coordination under commitment.

De Paoli and Paustian found that the gains from policy coordination are non-negligible only in games without commitment and for mark-up shocks, while for games with commitment or 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 in-

roducing 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. They focus on quadratic loss functions as policy objectives, while we consider both social welfare and quadratic loss functions as payoff functions. Van der Ghote (2016) proposes a continuous time-model with TPF 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 only 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 we found that policy coordination yields gains of about 6 percent.

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) and Quint and Rabanal (2014). Angeloni and Faia studied 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 found 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 found that a monetary rule that responds to the loans-output ratio yields lower output variability than a standard monetary policy rule, but did not examine the welfare implications. Quint and Rabanal studied a two-country (core v. periphery) model with risk shocks in housing investment, and found that an augmented Taylor rule 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 separate 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 macroprudential policy. They examine a small open economy subject to world interest rate shocks with financial frictions à la Gertler-Karadi-Kiyotaki (GKK). 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 economy. Section 3 provides a diagrammatic characterization of the spillovers between 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 similar to the setup proposed by Christiano *et al.* (2014) to introduce risk shocks into the New Keynesian model with the Bernanke-Gertler financial accelerator proposed by Bernanke, Gertler and Gilchrist (1999), BGG 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 has two sources of inefficiency: Calvo staggered price-setting by the producers of intermediate goods, and costly state verification in financial intermediation. In general, these two frictions affect both the steady state and cyclical dynamics. Since our analysis focuses on monetary and financial policy interactions for management of business cycles, however, we specify policy rules with long-run properties such that the steady-state inefficiencies due to sticky prices and costly monitoring are neutralized. Several model features are similar to those in BGG and Christiano *et al.*, so the presentation is kept short except for parts that are either non-standard or key for the questions this paper addresses. Full details of the model specification are provided in the online Appendix.

2.1 Households

The economy is inhabited by a representative agent. The agent chooses sequences of consumption, c_t , labor supply, ℓ_t , and real deposit holdings, d_t , to maximize expected utility. The optimization problem of this agent is:

$$\max_{c_t, \ell_t, d_t} \mathbb{E}_t \left\{ \sum_{t=0}^{\infty} \beta^t \mathcal{U}(c_t, \ell_t^h) \right\}, \text{ with } \mathcal{U}(c_t, \ell_t^h) = \frac{\left[(c_t - hC_{t-1})^v (1 - \ell_t^h)^{1-v} \right]^{1-\sigma} - 1}{1 - \sigma} \quad (2.1)$$

subject to the budget constraint

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

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, $v \in (0, 1)$ is the labor share parameter, and \mathbb{E}_t is the expectations operator conditional on the information available at date t . In the budget constraint (2.2), the household's uses of income in the left-hand-side are assigned to buy consumption goods and make bank deposits. The sources of income in the right-hand-side derive from wage income, where w_t is the real wage rate, from the real return on deposits carried over from the 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 transfers from government (Υ_t). The first-order conditions of this problem are standard, and hence we describe them in the online Appendix.

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 the stock of capital $k_{e,t}$ at a relative price q_t , using her own net worth $n_{e,t}$ and one-period-maturity debt $b_{e,t}$. Hence, the budget constraint for these capital purchases 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, the return gained by an individual entrepreneur is affected by an idiosyncratic shock ω_{t+1} , with $\mathbb{E}(\omega_{t+1}) = 1$ and $\text{Var}(\omega_{t+1}) = \sigma_{\omega, t+1}$. Hence, the real returns of an individual entrepreneur e at time $t + 1$ are $\omega_{e, t+1} r_{t+1}^k k_{e,t}$, where r_{t+1}^k is the aggregate gross real rate

of return per unit of capital, which is given by

$$r_{t+1}^k \equiv \frac{z_{t+1} + (1 - \delta)q_{t+1}}{q_t}, \quad (2.3)$$

where δ is the rate of capital depreciation.

Heterogeneity among entrepreneurs emerges because $\omega_{e,t+1}$ is an i.i.d. random variable across time and types, with a continuous and once-differentiable c.d.f., $F(\omega_{t+1})$, over a non-negative support. Following Christiano *et al.* (2014), the stochastic process of $\omega_{e,t+1}$ features risk shocks, which are represented by the time-varying variance $\sigma_{\omega,t+1}$. An increase of $\sigma_{\omega,t+1}$ implies that $F(\omega_{t+1})$ widens, which, as will become clear below, makes it possible for a larger share of entrepreneurs to be in default. Hence, at the equilibrium of the credit market, a higher $\sigma_{\omega,t+1}$ worsens financial conditions and affects negatively economic activity through a drop in investment demand.

Entrepreneurs participate in the labor market by offering one unit of labor each period at the real wage rate w_t^e .⁶ Also, entrepreneurs have finite life horizons, with each entrepreneur facing a probability of exit given by $1 - \gamma$. This assumption prevents entrepreneurs to accumulate enough wealth to be fully self-financed. Aggregate net worth in period t is thus given by

$$n_t = \gamma v_t + w_t^e. \quad (2.4)$$

The value of v_t in the first term in the right-hand-side of (2.4) is the aggregate equity from capital holdings of entrepreneurs who survive at date t , which is defined in the next subsection. Those who exit at t transfer their wages to new entrepreneurs entering the economy, consume part of their equity, such that $c_t^e = (1 - \gamma)\varrho v_t$ for $\varrho \in [0, 1]$, while the rest, $\mathcal{A}_t = (1 - \gamma)(1 - \varrho)v_t$, is transferred to households as a lump-sum payment.

2.3 The lender and the financial contract

The financial intermediary takes deposits from households (on which it pays the risk-free nominal interest rate R_t) and uses them to fund loans to entrepreneurs, which are risky and subject to the same financial friction as in BGG: 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. The optimal credit contract is modeled following the setup developed by Bernanke and Gertler (1989)

⁶This is useful because, as noted by BGG, it is necessary for entrepreneurs to start off with some net worth in order to allow them to begin operations.

to introduce the costly-state-verification contracting problem proposed by Townsend (1979) into a general equilibrium 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 interests, $r_{e,t+1}^L b_{e,t}$, where r_t^L is the gross real interest rate they pay under repayment. 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., $\mu\omega_{e,t+1}r_{t+1}^k q_t k_{e,t}$. The threshold value $\bar{\omega}_{e,t+1}$ satisfies:

$$\bar{\omega}_{e,t+1} r_{t+1}^k q_t k_{e,t} = r_{e,t+1}^L b_{e,t}. \quad (2.5)$$

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 lenders' participation constraint holding for each value that r_{t+1}^k can take.⁷ 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:

$$E_t \{ [1 - \Gamma(\bar{\omega}_{t+1})] r_{t+1}^k q_t k_t \}, \quad (2.6)$$

where $\Gamma(\bar{\omega}) = \bar{\omega} \int_{\bar{\omega}}^{\infty} f(\omega) d\omega + \int_0^{\bar{\omega}} \omega f(\omega) d\omega$.⁸ The participation constraints of the lenders satisfy this condition for each value of r_{t+1}^k :

$$(1 + \tau_{f,t}) [\Gamma(\bar{\omega}_{t+1}) - \mu G(\bar{\omega}_{t+1})] r_{t+1}^k q_t k_t \geq r_t b_t, \quad (2.7)$$

where $r_t = \frac{R_t}{E_t \{1 + \pi_{t+1}\}}$ is the expected real interest rate, $\mu G(\bar{\omega}) = \mu \int_0^{\bar{\omega}} \omega f(\omega) d\omega$ 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 (revenue) financed (rebated) as part of the lump-sum transfers to households. The

⁷The 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).

⁸For a given r^k , notice that if $\omega \geq \bar{\omega}$ the returns of the entrepreneur are given by $\omega r^k q k - r^L b$. Using equation (2.5), we can rewrite the last expression as $(\omega - \bar{\omega}) r^k q k$. Taking expectations with respect to ω yields $\int_{\bar{\omega}}^{\infty} (\omega - \bar{\omega}) r^k q k d\omega$, which after some algebraic manipulations leads to (2.6).

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 the online Appendix. 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 with the following external finance premium condition:

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

The ratio $\mathbb{E}_t \{r_{t+1}^k/r_t\}$ denotes the external finance premium (or the 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 $n_t < q_t k_t$.

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 credit spread 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 external finance premium charged for a given value of $s(\cdot)$. Risk shocks increase the external finance premium, 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.⁹ 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,

⁹The 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).

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 completely. In this model, however, 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. Under these conditions, one could still study the constrained-efficient optimal subsidy that could maximize social welfare, but as we explained in the Introduction, we focus instead on log-linear policy rules.

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:

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

2.4 Capital Producer

Capital producers operate in a perfectly competitive market. At the end of period $t - 1$, entrepreneurs buy the capital stock to be used in period t , i.e. k_{t-1} , from the capital producers. Once intermediate goods are sold and capital services paid, entrepreneurs sell back to the capital producers the remaining un-depreciated stock of capital. The representative capital producer then builds new capital stock, k_t , by combining investment goods, i_t , and un-depreciated capital, $(1 - \delta) k_{t-1}$. The capital producer's problem is:

$$\begin{aligned} \max_{i_t} E_t \sum_{t=0}^{\infty} \beta^t \frac{\lambda_{t+1}}{\lambda_0} \{q_t [k_t - (1 - \delta)k_{t-1}] - i_t\}, \quad \text{subject to} \quad (2.10) \\ k_t = (1 - \delta) k_{t-1} + \left[1 - \Phi\left(\frac{i_t}{i_{t-1}}\right)\right] i_t, \end{aligned}$$

Since households own the firms that produce capital, profits are discounted at the rate $\beta^t \frac{\lambda_{t+1}}{\lambda_t}$ for $t \geq 0$, where λ_t is the Lagrange multiplier of the household's budget constraint. The function $\Phi\left(\frac{i_t}{i_{t-1}}\right)$ denotes adjustment costs in capital formation. We consider an *investment* adjustment cost, according to which the capital producer uses a combination of old investment goods and new investment goods to produce new capital units (see Christiano, Eichenbaum and Evans, 2005), where $\Phi\left(\frac{i_t}{i_{t-1}}\right) = (\eta/2) [i_t/i_{t-1} - 1]^2$. The first-order conditions of this problem imply that at equilibrium the relative price of capital, q_t , satisfies this condition:

$$q_t = 1 + \Phi\left(\frac{i_t}{i_{t-1}}\right) + \frac{i_t}{i_{t-1}} \Phi'\left(\frac{i_t}{i_{t-1}}\right) - \beta E_t \left\{ \frac{\lambda_{t+1} q_{t+1}}{\lambda_t q_t} \left[\frac{i_{t+1}}{i_t}\right]^2 \Phi'\left(\frac{i_{t+1}}{i_t}\right) \right\}. \quad (2.11)$$

2.5 Final Goods

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 $y_t = \left(\int_0^1 y_{j,t}^{\frac{\theta-1}{\theta}} dj\right)^{\frac{\theta}{\theta-1}}$, 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

$$P_t = \left(\int_0^1 P_{j,t}^{1-\theta} dj\right)^{\frac{1}{1-\theta}}, \quad (2.12)$$

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

2.6 Intermediate Goods

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 producer of good j at date t respectively. Total labor input in each firm, $\ell_{j,t}$, results from combining household labor, $\ell_{j,t}^h$, and entrepreneurial labor, $\ell_{j,t}^e \equiv 1$, with a Cobb-Douglas function $\ell_{j,t} = [\ell_{j,t}^h]^\Omega [\ell_{j,t}^e]^{1-\Omega}$. Each intermediate good is also produced with a Cobb-Douglas technology

$$y_{j,t} = \ell_{j,t}^{1-\alpha} k_{j,t-1}^\alpha. \quad (2.13)$$

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

$$\mathbb{S}(y_{j,t}) = \min_{\ell_{j,t}^h, z_t} \{w_t \ell_{j,t}^h + z_t k_{j,t-1} + w_t^e, \text{ subject to (2.13)}\}. \quad (2.14)$$

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 each 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 steady state. In order to remove the steady-state distortion caused by intermediate-good producers' monopolistic power, we assume that the government provides a subsidy τ_p so that aggregate output reaches the level of the flexible-price economy at the steady state.

Let $P_{j,t}^*$ 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 $P_{j,t}^*$ 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:

$$P_{j,t}^* = \max_{P_{j,t}} \left\{ \begin{array}{l} \mathbb{E}_t \left\{ \sum_{T=t}^{\infty} (\beta \vartheta)^{T-t} \frac{\lambda_T}{\lambda_t} \left[\frac{\iota_{t,T} P_{j,t}}{P_T} y_{j,t,T} - (1 - \tau_p) s_T y_{j,t,T} \right] \right\} \\ \text{subject to } y_{j,t,T} = \left(\frac{\iota_{t,T} P_{j,t}}{P_T} \right)^{-\theta} y_T \end{array} \right\}. \quad (2.15)$$

To support the efficient (flexible price) production levels at the 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, the sticky prices still creates a dynamic distortion in the form of price dispersion. Following Yun (1996), we show in the online Appendix that aggregate production can be expressed as:

$$y_t = \frac{1}{\Delta_t} (k_{t-1})^\alpha (\ell_t)^{1-\alpha}. \quad (2.16)$$

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

2.7 Policy rules

In the general setup of the model, we assume that the central bank and the financial authority follow log-linear rules to set their instruments. In the next Section's analysis of Tinbergen's Rule, we will consider alternative formulations of both rules.

The monetary policy rule sets the nominal interest rate following this simple formulation of the Taylor rule:

$$R_t = R \times \left(\frac{1 + \pi_t}{1 + \pi} \right)^{a_\pi}, \quad (2.17)$$

where a_π is the elasticity of R_t with respect to inflation deviations, R is the steady-state gross nominal interest rate, and π is the central bank's inflation target.¹⁰

The financial authority sets the financial subsidy according to this rule:

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

where $r^k / r = 1$ is the value of the external finance premium (credit spread) at steady state, which has a zero spread because we are removing the long-run effect of the credit friction, and τ_f is the steady-state value of the financial subsidy that ensures that $r^k = r$.

2.8 Resource and government budget constraints

The government's budget constraint is:

$$\Upsilon_t = g + \tau_p s_t \int_0^1 y_{j,t} dj + \tau_{f,t} [\Gamma(\bar{\omega}_t) - \mu G(\bar{\omega}_t)] r_t^k q_{t-1} k_{t-1}. \quad (2.19)$$

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.

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:

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

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

¹⁰We abstract for a term related to the output gap because our quantitative findings show that in the model we proposed, driven only by risk shocks, it is optimal for the monetary rule not to respond to the output gap (see subsection 4.2).

2.9 Social welfare

In order to compare welfare across equilibria with different policy rules, we use standard compensating consumption variations that make agents indifferent between the levels of expected lifetime utility attainable under alternative equilibria, as originally proposed by Lucas (1987). Since we are focusing on the cost of inefficient economic fluctuations caused by price stickiness and costly state verification, we use the deterministic stationary equilibrium as the reference level against which the compensating consumption variations are measured. Since the deterministic steady state also coincides with the deterministic Pareto efficient first-best, because of the time-invariant subsidies that neutralize the price-setting and financial inefficiencies, welfare must be weakly lower under any stochastic version of the model with any pair of policy rule elasticities than in the reference welfare level, and thus our welfare measures are negative numbers (i.e. they show the welfare cost of a particular pair of policy rule elasticities). One pair of elasticities is preferable to another in terms of welfare if it yields a smaller, or less negative, welfare cost.

The welfare measures are constructed as follows: Define $\mathbb{W}(a_\pi, a_{rr}; \boldsymbol{\varrho})$ as the unconditional expected lifetime utility of agents in the economy under a pair of policy rule elasticities a_π and a_{rr} , for a given parameterization of the model given by vector $\boldsymbol{\varrho}$. Hence, $\mathbb{W}(a_\pi, a_{rr}; \boldsymbol{\varrho})$ satisfies:

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

where $c_t(a_\pi, a_{rr}; \boldsymbol{\varrho})$ and $\ell_t^h(a_\pi, a_{rr}; \boldsymbol{\varrho})$ are the household's equilibrium decision rules for consumption and labor, which are also functions of the policy rule elasticities and the model's parameters. Define next \mathbb{W}_d , c_d , and ℓ_d^h as the levels of welfare, consumption, and labor, respectively, that prevail in the deterministic steady state, so that \mathbb{W}_d , satisfies:

$$\mathbb{W}_d = \frac{1}{1-\beta} \mathcal{U}(c_d, \ell_d^h).$$

The welfare cost of a particular pair of policy elasticities is then defined as the compensating percent change in consumption, ce , relative to the reference consumption level, such that the following condition holds:

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

Given the CRRA utility function, we can solve for ce as:

$$ce(a_\pi, a_{rr}; \boldsymbol{\varrho}) = 1 - \exp \{ (1-\beta) [\mathbb{W}(a_\pi, a_{rr}; \boldsymbol{\varrho}) - \mathbb{W}_d] \}. \quad (2.22)$$

3 Policy Interactions: Diagrammatic Analysis

This Section provides a diagrammatic analysis of the effects of risk shocks on the markets for credit, capital goods and final goods, and of how financial and monetary policies alter those effects. This analysis serves two purposes: First, it shows how each policy instrument affects the determination of its policy goal (i.e. how the interest rate affects inflation and the financial subsidy affects the credit spread), 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) that determines the payoff of the financial (monetary) authority, and hence drive the incentives for strategic interaction.

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 approximations to a one-period snapshot of the model's equilibrium. The model does not yield closed-form solutions for the demand and supply functions plotted, and the equilibrium of the model incorporates dynamic, stochastic general equilibrium effects.

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 external finance premium. Equilibrium in this market determines the allocation of capital expenditures purchases k and the rate of return on capital r^k (recall from Section 2 that there is an equivalent representation of this equilibrium 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 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 the nominal rigidities, and results from the optimal 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 how monitoring costs in affect the trade-off between financial stability and price stability.

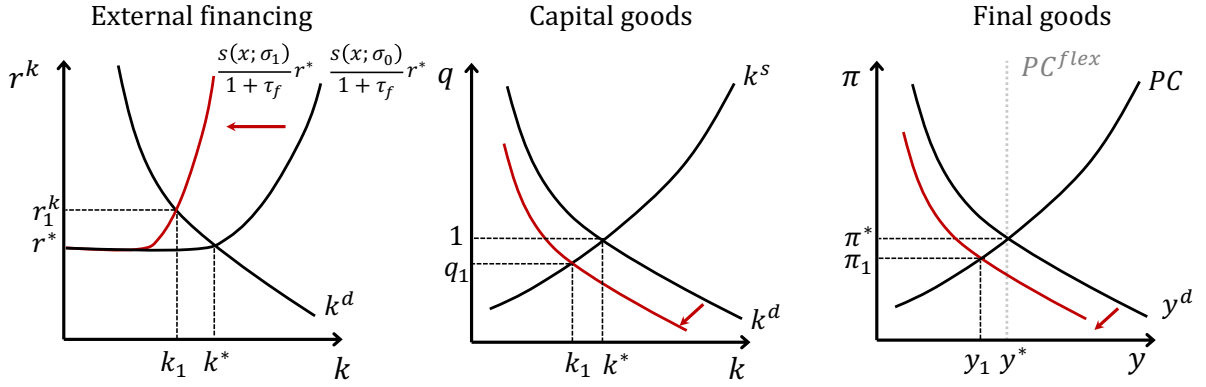
Panel (A) of Figure 1 shows the effects of a positive risk shock (i.e. a sudden increase in the variability of entrepreneurs' returns) in the three markets. We assume that before the shock the economy was at its steady-state equilibrium, in which the financial wedge is zero (i.e. $r^k = r$), the relative price of capital equals 1, and the capital stock, production, inflation, and the real interest rate equal their corresponding 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, reducing the amount of capital purchases and increasing the external financing premium 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 financial accelerator mechanism and creates a wedge between the returns of capital and deposits, so after the shock $r^k > r$, which lowers output and inflation to $\pi_1 < \pi^*$ and $y_1 < y^*$ respectively.

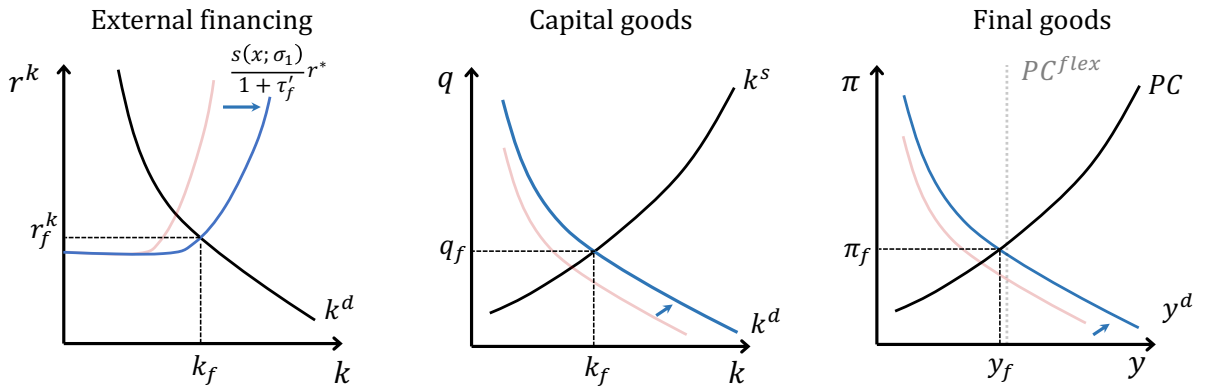
Panel (B) shows the effects of responding to the risk shock with financial policy, by increasing $\tau_f > 0$. This increases the expected return on loans, which helps counter the drop in the supply of external financing caused by the risk shock. Notice that only the increasing segment of the supply of funds shifts, because the horizontal segment corresponds to levels of capital covered by internal financing, for which the subsidy on intermediaries is irrelevant and the associated value of r^k is the unchanged interest rate on deposits (recall these plots are a snapshot for a given date t in the model, thus abstracting from changes in expected inflation for $t + 1$). 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

Figure 1: Risk Shocks, Policy Effects and Interactions

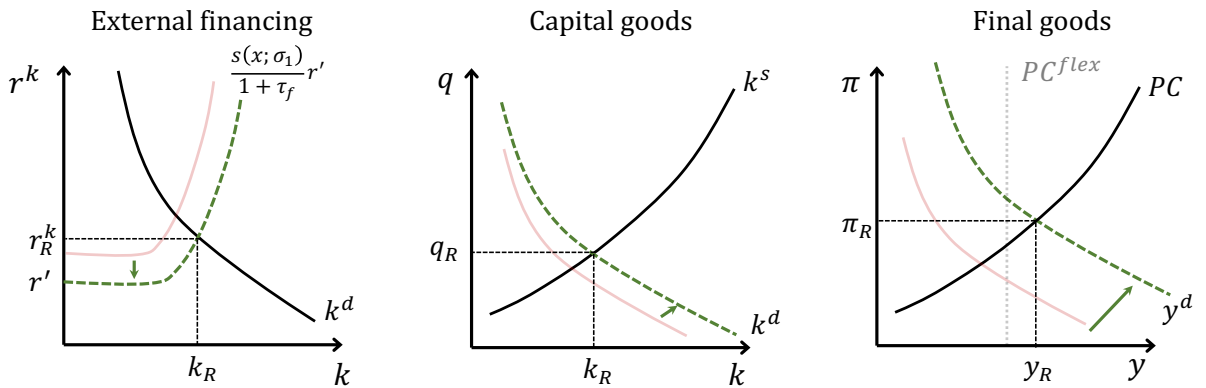
Panel (A): Effect of a sudden increase of entrepreneurs' risk



Panel (B): Countercyclical financial policy



Panel (C): Countercyclical monetary policy



Note: Panel (A) shows the impact effects of a risk shock on the credit market, the capital goods market, and the final goods market. Panels (B) and (C) illustrate static the effects of increasing the financial subsidy and an expansionary monetary policy that lowers the short-run real interest rate.

returning the economy to the initial equilibrium. Hence, financial policy yields the equilibrium identified with “f” subscripts, at which capital, inflation, output and Tobin’s Q are higher than in the absence of a policy response to the risk shock, but lower than in the initial equilibrium, and the external financing premium is lower than without policy response but higher than in the initial equilibrium.

Panel (C) shows the effects of responding to the risk shock with monetary policy, by cutting the policy rate R to achieve a lower real interest rate r . The lower real interest rate shifts the entire supply of funds curve down and to the right, because it lowers the intermediaries’ cost of raising deposits from the households. 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 it affects saving-spending decisions of households via the standard effect from NeoKeynesian models. Hence, while prices and allocations move in the same direction under the two policies, their quantitative effects should be very different in general. The first-order effects of τ_f are restricted to financial-market variables, while R has a broader transmission channel.

In the scenario drawn in Panel (C), the cut in R helps increase capital purchase and reduce the external financing premium 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 rise 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.

Notice that if prices were flexible (the scenario represented by the PC^{flex} curve in Figure 1), the monetary and financial instruments could be used indistinctly to counter the risk shock, because in this case the central bank is neutral on inflation, since there is no price dispersion and no welfare costs caused by it. Effectively, Tinbergen’s Rule is no longer relevant because inflation becomes an irrelevant target. In this case there are two possible instruments to target one variable, the credit

spread. When prices are sticky, however, Tinbergen’s Rule applies. The central bank can set an optimal path for R , conditional on a path for τ_f , such that the costs caused by Calvo pricing are minimized. Similarly, the financial authority can set an optimal path for τ_f , conditional on a path for R , such that the costs caused by costly state verification are minimized. If policymakers share a common payoff function, the outcome under this dual regime cannot be inferior than that under a monetary rule augmented with a financial target, because at worst the dual regime can replicate it exactly. If their payoffs differ, however, there are incentives for strategic interaction that can reduce policy effectiveness and welfare, because as Panels (B) and (C) show clearly, the use of each policy instrument causes spillover effects on the variables that determine the payoffs of both policymakers.

4 Quantitative Analysis

4.1 Calibration and solution strategy

Table 1 lists the values assigned to each of the model’s parameters in the baseline calibration. The calibration is set to a quarterly frequency and based largely on the parameterization in Christiano *et al.* (2014), except for the parameters of the financial accelerator, which are taken from BGG.

For simplicity, we assume that steady-state inflation is zero ($\pi = 0$), and we set v , the parameter governing the disutility of labor, such that the household’s steady-state labor allocation is 1/3rd (i.e. $\ell^h = 1/3$). The subjective discount factor is set to $\beta = 0.99$, which implies an annual real interest rate of 4 percent in the deterministic steady state. This is consistent with the standard RBC target, which is a reasonable target given that in the deterministic steady state the inefficiencies of financial and pricing frictions are neutralized and the inflation rate is zero. The habit persistence parameter is set to $h = 0.85$.

The values of 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, government expenditures, the price indexing weight, and the degree of price stickiness are set using values from Christiano *et al.* (2014), some of which they set by calibration and some they obtained as model estimation results using data for the U.S. economy with quarterly data for

Table 1: Calibration

Parameter		Value
<i>Preferences and technology</i>		
β	Subjective discount factor	0.99
σ	Coefficient of relative risk aversion	1.00
v	Disutility weight on labor	0.06
h	Habit parameter	0.85
α	Capital share in production function	0.40
δ	Depreciation rate of capital	0.02
η	Investment adjustment cost	10.78
\bar{g}	Steady state government spending-GDP ratio	0.20
ϑ_p	Price indexing weight	0.10
ϑ	Calvo price stickiness	0.74
θ	Elasticity of demand for intermediate goods	11.00
<i>Financial sector</i>		
$1 - \varrho$	Transfers from failed entrepreneurs to households	0.01
γ	Survival rate of entrepreneurs	0.98
Ω	Share of households' labor on total labor	0.98
$\bar{\sigma}_\omega$	Standard error of idiosyncratic shock	0.27
ρ_{σ_ω}	Persistence of risk shock	0.89

the period 1985:I-2010:II. The calibrated parameter values are: $\sigma = 1$, $\alpha = 0.4$, $\theta = 11$, $\delta = 0.025$, and $g = 0.2$. The estimated parameters, which correspond to modes of the posterior distribution of the estimation, are: $\eta = 10.78$, $\vartheta_p = 0.1$ and $\vartheta = 0.74$.

The financial sector parameters are taken mostly from BGG. As in BGG, the target default rate of entrepreneurs in the deterministic steady state is 3 percent per year, and the target ratio of capital to net worth equals 2, both taken from historical averages of U.S. data. Matching these BGG targets requires a survival rate of entrepreneurs of $\gamma = 0.9792$ and a monitoring cost coefficient of $\mu = 0.1175$, both nearly identical to the values BGG used. BGG also set the entrepreneurial income share to 0.01, which implies that the fraction of households' labor on production, Ω , equals 0.9846, and they set the transfers from entrepreneurs to households, φ , to 0.01 percent.

The time-series process of the entrepreneurs' idiosyncratic productivity shocks, ω , follows a log-normal distribution with an unconditional expectation of 1 and a standard deviation of $\bar{\sigma}_\omega = 0.2713$. The latter is set to match the estimates obtained by Lambertini, Nuguer and Uysal (2017) using quarterly U.S. data for the period 1981:I-2006:IV, and it is almost identical to the value set

by BGG of 0.28. We also adopt the specification of risk shocks that Lambertini *et al.* estimated, according to which the standard deviation of the distribution of ω follows an AR(1) process. They estimated the autoregressive coefficient of this process at $\rho_{\bar{\sigma}_\omega}=0.87$.¹¹

The key ratios of the model's deterministic steady state produced by 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 in which the financial friction was removed. The Baseline calibration differs from the BGG setup in that it includes the financial subsidy that removes the external finance premium in the steady state. Both the Baseline case and the case without financial frictions include the subsidy to intermediate producers that neutralizes the steady-state effects of nominal rigidities.

Since, as noted earlier, costly state verification in credit markets introduces a distortion that reduces the level of investment, the steady-state investment rate is 300 basis points lower in the BGG setup than when either the financial friction is absent or the steady-state financial distortion is removed with the financial subsidy, as in the Baseline case. Accordingly, the steady-state capital-output ratios without the financial friction and in the Baseline case are identical, 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 below the efficient level.

The Table also shows that reducing to zero the external finance premium in the steady state requires a financial subsidy of about 1 percent. Note that, while this removes the investment inefficiency, the consumption-output ratio is lower in the Baseline than in either the BGG case or the setup without the financial friction. The consumption-output ratio is higher in the BGG case because, although resources are going into paying monitoring costs, output and the investment rate are lower than 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 the setup without financial frictions does not use up resources in monitoring costs.

¹¹Lambertini *et al.* (2017) used Bayesian techniques to estimate a DSGE model with nominal and real rigidities, a housing sector, mortgages, and endogenous default. The housing investment is subject to a risk shock.

Table 2: Steady State Results

	BGG	No Finan Fric	Baseline
External Finance Premium \tilde{r} , 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 $\tilde{r} = 0$ and $\mu = 0$. The efficient output, y_{nf} , is defined as the one attained without financial frictions.

We used a second-order perturbation method to solve for the model’s stochastic steady state, as proposed by Schmitt-Grohé and Uribe (2004). A second-order method is more suitable because several of our key results hinge on welfare calculations, including those related to Tinbergen’s rule and the solution of Nash and Cooperative equilibria between monetary and financial authorities, and first-order methods are less accurate for welfare analysis. The model is solved using Dynare, version 4.

4.2 Tinbergen’s rule

We evaluate the relevance of Tinbergen’s rule for the conduct of monetary and financial policies with quantitative experiments that compare the predictions of the Baseline model, which features the regime with dual policy rules, v. a regime without financial policy rule and a monetary policy rule augmented to include the credit spread. We compare these two regimes in terms of social welfare, the welfare-maximizing elasticities of the policy rules, and the cyclical behavior of the economy. As noted in the Introduction, the issue of whether monetary policy rules need to incorporate financial stability considerations so as to “lean against the wind” of the financial sector is central to ongoing policy debates. For instance, Brookings (2011a), Eichengreen *et al.* (2011b), Smets (2014), and Woodford (2012), among others, favor an augmented monetary policy rule, while Svensson (2012, 2014, 2015) and Yellen (2014) favor a regime with dual rules.

For the regime with the augmented monetary policy rule, the policy rule becomes:

$$R_t = R \left(\frac{1 + \pi_t}{1 + \pi} \right)^{a_\pi} \left(\frac{E_t \{ r_{t+1}^k / r_t \}}{r^k / r} \right)^{-\check{a}_{rr}}, \quad (4.1)$$

with $\check{a}_{rr} \geq 0$. The elasticity with respect to the credit spread enters with a negative sign because, in line with the arguments of the previous Section, an adverse risk shock pushes up the credit spread and causes a decline in investment, to which the monetary authority responds by lowering its policy interest rate to offset the investment drop. In the Baseline regime with the separate policy rules, the authorities follow the rules defined earlier in equations (2.17) and (2.18).

Figure 2 shows welfare levels, as measured by compensating consumption variations attained by the augmented monetary policy rule (labeled “1 instrument” in the left panel) and the baseline regime with the dual rules (labeled “2 instruments” in the right panel) for different values of the elasticities to inflation and the credit spread. The x and y axes show the values of the rule elasticities, and the vertical axes show the associated welfare cost for each elasticity pair in each regime. Note that both of these plots include cases in which deviations of the credit spread from its target are disregarded. In the augmented monetary policy rule, the case with $\check{a}_{rr} = 0$ represents the standard Taylor rule scenario, in which monetary policy does not respond to financial factors. In the dual rules regime, the case with $a_{rr} = 0$ represents a scenario in which the financial subsidy remains constant at $\tau_{f,t} = \tau_f$.

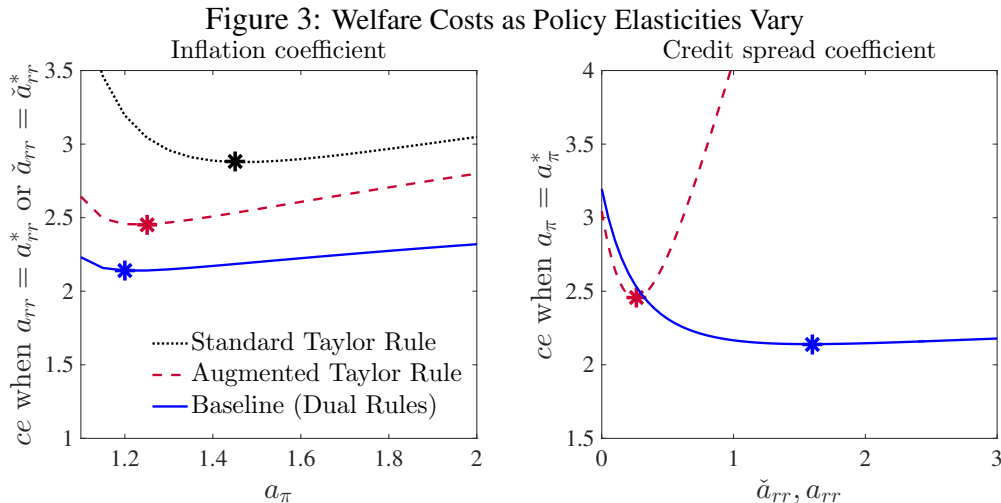
Consider first the 1-instrument case. In the standard Taylor rule scenario (i.e. when $\check{a}_{rr}, a_{rr} = 0$), it is optimal to react to inflation with an elasticity of about 1.45. On the other hand, if the inflation elasticity is fixed at its lowest value, it is optimal to set an elasticity to the credit spread of about 0.2. Hence, at both ends there are clear internal solutions to the choice of elasticities that minimize the welfare costs of the two inefficiencies in the model, which reflects the fact that the financial accelerator and the nominal rigidities both respond to the nominal interest rate and both have real effects that alter inflation and the credit spread, as explained in the previous Section. When the augmented rule is fully at play, so that both elasticities can be freely chosen, the optimal choice of elasticities is $a_\pi = 1.25$ and $\check{a}_{rr} = 0.26$.

regime, and the solid-blue line is for the dual rules regime. The left plot also shows the case for the standard Taylor rule that does not respond to the credit spread (in the dotted-black line). The left panel shows that, for all values of a_π considered, welfare is higher under the dual rules regime than under the augmented Taylor rule, and much higher than under the standard Taylor rule (i.e. the welfare costs relative to the first-best deterministic steady state are smaller with the dual rules). The right panel shows that for spread elasticities below 0.25 welfare is about the same under the dual rules or augmented Taylor regimes, but for elasticities above 0.25 welfare is much higher under the dual rules regime.¹² It is also important to note that welfare costs are very sensitive to changes in the spread elasticity with the augmented Taylor rule, producing a markedly U-shaped curve, and in particular as the elasticity rises above 0.25 the welfare cost rises rapidly, while under the dual regimes the welfare cost remains nearly unchanged.

Comparing the optimal elasticity pairs in the 1-instrument v. 2-instrument cases, the former has a slightly higher inflation elasticity (1.25 v. 1.22) and a much weaker response to the credit spread (0.26 v. 1.56). Hence, the augmented Taylor rule yields a regime that tightens monetary policy too much in response to an increase in inflation and does not relax it enough in response to a higher credit spread (i.e. a tight-money, tight-credit regime). The standard Taylor rule displays a tighter monetary policy, as inflation elasticity amounts to 1.45, which is the local minimum under that regime.

Comparing welfare effects with the optimal elasticities of each regime, welfare under the augmented Taylor rule is 17.3 percent higher than under the standard Taylor rule without the credit spread. Hence, if the choice were between allowing the Taylor rule to respond to the credit spread or not, the first alternative clearly dominates. But still, because Tinbergen's rule applies and is quantitatively significant, welfare under the dual rules regime is 14.7 percent higher than under the augmented Taylor rule, and 34.5 percent higher than under the standard Taylor rule. In short, responding to financial stability conditions is better than not, but responding with separate instruments is much better.

¹²For robustness, we also examined a case with dual rules in which the monetary policy rule responds to deviations in inflation, the credit spread, and the output gap, i.e. $R_t/R = (\pi_t - \pi)^{a_\pi} (E_t \{r_{t+1}^k/r_t\})^{-\tilde{a}_{rr}} (y_t/y)^{a_y}$. We solved for the quadruplet of elasticities that yields the smallest welfare cost, which is given by $(a_\pi, \tilde{a}_{rr}, a_y, a_{rr}) = (1.2, 0.1, 0, 1.3)$. Interestingly, not responding to the output gap is optimal, and even with the separate financial subsidy rule, it is optimal for the monetary policy rule to respond to the credit spread. The welfare gains, however, are quite modest relative to what the dual rules regime attains (welfare, as measured by the ratio of compensating variations in consumption of the two regimes, is only 0.7 percent higher).

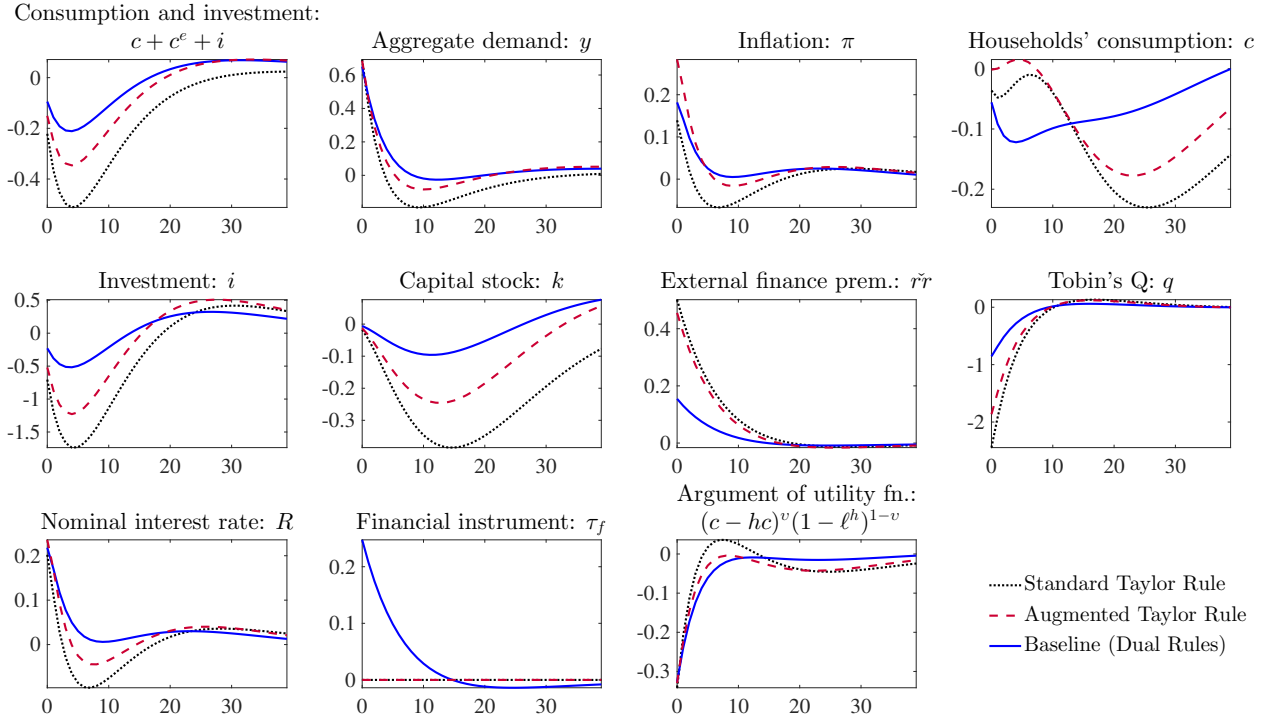


Note: The asterisks show the lowest welfare cost on each curve, which corresponds to the highest welfare that can be attained. The scale of the consumption equivalent measures have been calculated for a risk shock of size $1e^{-6}$, so the numbers in the figure are multiplied by $1e^6$. We computed the welfare costs for such a small shock in order to avoid pruning issues related to the second-order approximating algorithm. Our results are robust different pruning methods, including that proposed by Andreasen, Fernández-Villaverde and Rubio-Ramírez (2013).

Figure 4 illustrates the effects of a risk shock, equal to a 10-percent increase in the variance of the distribution of σ_{ω} , on key macroeconomic aggregates under the alternative policy regimes. The plots show impulse response functions computed using a first-order approximation method around the deterministic steady state. The blue curves correspond to the Baseline model with the dual policy rules set to their optimal elasticity values of $a_{\pi} = 1.22$ and $a_{rr} = 1.56$. The dashed, red curves pertain to the augmented Taylor rule with the optimal inflation and credit spread elasticities of $a_{\pi} = 1.25$ and $\check{a}_{rr} = 0.26$ respectively. The dashed, dotted black curves correspond to the standard Taylor rule with its optimal inflation elasticity $a_{\pi} = 1.45$, and by definition $a_{rr} = 0$.

With the except of the consumption response, which differs both quantitatively and qualitatively in the dual rules regime, the responses of the other variables are qualitatively similar across all three regimes but sharply different quantitatively. In all three cases, the risk shock increases the probability of default on impact, and thus increases the credit spread, and as the risk shock fades monotonically the increase in the spread also reverses monotonically. The spreads are about the same under the standard and augmented Taylor rules, but with the dual rules regime the spreads increase much less. Inflation rises on impact because, although aggregate demand excluding monitoring costs falls, once monitoring costs are added total demand rises and exerts upward pressure on prices.

Figure 4: Impulse Response Functions: Dual Rules v. Standard and Augmented Taylor Rules



Note: Impulse responses after an increase of 10 percent in σ_ω , computed using a first-order approximation method. The y axis represents deviations from the deterministic steady state, the x axis are quarters.

The higher inflation and higher spreads trigger policy responses determined by the policy rules corresponding to each regime. Despite significant differences in the impact response in inflation, the impact response of the policy interest rate is similar with the standard Taylor rule and the dual rules regime, because the former has a slightly higher inflation elasticity but experiences a slightly smaller change in inflation than the latter when the risk shock hits. In contrast, the policy interest rate rises slightly more on impact with the augmented Taylor rule, reflecting the tight money-tight credit nature of this regime: The inflation elasticity and the impact change in inflation caused by the risk shock are both higher than with the dual rules, and even though the increase in the credit spread contributes to lower the policy interest rate with the augmented Taylor rule, the spread elasticity under this rule is not big enough to prevent the policy rate from increasing more than with the dual rules.

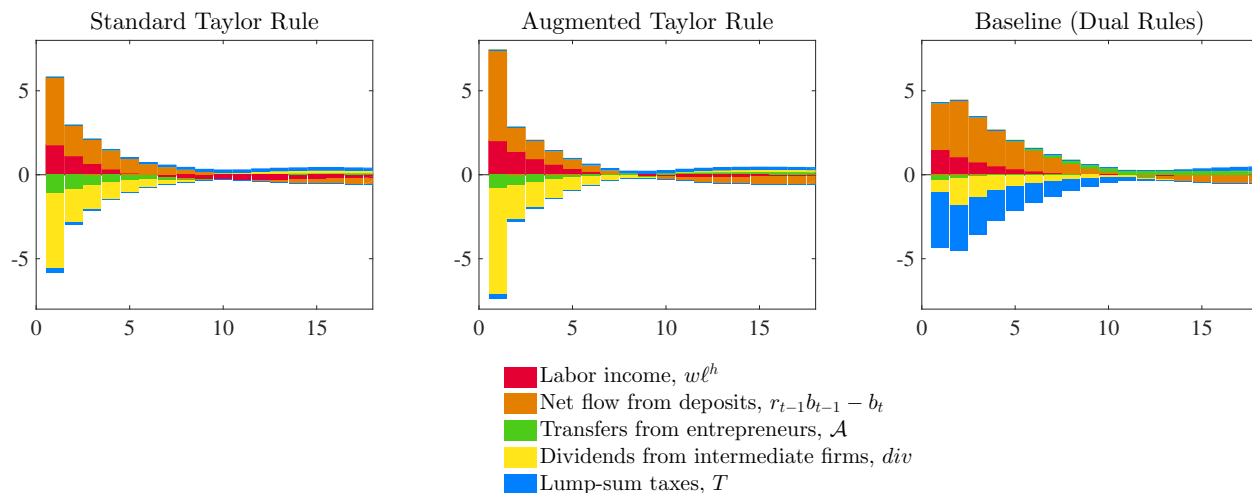
In the dual rules regime, the financial subsidy displays the same monotonic reversion as the credit spread, so 20 quarters after the risk shock hits both are back at their steady-state levels. Interestingly, the nearly identical credit spread responses under the standard and augmented Taylor rule regimes indicates that, although the policy interest rate responds to the credit spread in

the latter but not in the former (producing uniformly weakly higher policy interest rates with the augmented than with the standard Taylor rule, which thus affect the lender's participation constraints differently), the resulting equilibrium credit spreads do not differ much. In contrast, with the dual rules regime, the financial subsidy results in significantly lower spreads than in the other two regimes.

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, which associated gradual declines in the capital stock, aggregate demand, and inflation. Investment and demand reach their troughs around the 5th quarter, and the capital stock around the 12th to 14th quarter, followed by gradual recoveries in all three regimes. These recoveries are driven by the reversal of the increase in spreads and the temporarily lower interest rates. These fluctuations in investment, capital and aggregate demand are significantly smoother under the dual rules regime than under the other two regimes, and those under the augmented Taylor rule are in turn smaller than with the standard Taylor rule. This is due to the higher spreads under the regimes with the augmented and standard Taylor rules, both of which lack a separate instrument to respond to the effect of risk shocks on spreads (i.e. due to the violations of Tinbergen's rule under those two regimes). Note that interest rates after the impact effect are in fact higher under the dual rules regime, 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.

Consumption is not only smoother under the dual rules, it also moves in opposite directions. On impact, it falls more than in the other two regimes, then continues to decline while it rises slightly in the other two regimes, and then rises steadily starting around the fifth period, while in the other two regimes declines steadily until the 25th period and then begins to recover. The larger initial drop in consumption and the gradual decline until the 5th period under the dual rules is due to the large increase in lump-sum taxes needed to pay for the financial subsidy that the financial authority is using to smooth the effects of the financial shock on spreads and investment. 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 5th period, consumption rises and grows higher than in the other two regimes as the financial subsidy and lump-sum taxes fall, and in fact the financial subsidy becomes a small tax and the lump-sum

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 households' budget constraint, given in equation (2.2), after a risk shock. The y axis represents weighted deviations from the deterministic steady state such that the bars add up to the percent deviation of consumption for a given period. The x axis are quarters.

tax becomes a small subsidy. This occurs in turn because around period 15 the spread moves below its deterministic steady state, and the financial policy rule then lowers the subsidy below its steady state level.

The different consumption patterns reflect equivalent differences in disposable income net of savings. Figure 5 shows the contributions of the various components of disposable income net of savings to the consumption dynamics shown in the impulse response functions. We break down these contributions into five components: labor income $w_t \ell_t$, the net 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 . The patterns and the impact effects under the standard and augmented Taylor rules are very similar, except that after the impact effect we see smaller changes in all the income components under the augmented Taylor rule. In contrast, the components of income evolve very differently under the dual rules regime. In particular, on impact lump-sum taxes rise more than in the other two cases, which is needed to pay for the financial subsidy, but notice this leads to significantly smaller declines in dividends and entrepreneurs' transfers, and the effect of these outweighs the effect of the higher taxes, resulting in a smaller net income reduction on account of these components. In turn, agents use these higher income to smooth and hence increase bank deposits more than in the other

two regimes. Since the real interest rate is higher, the higher deposits with higher real returns yield significantly higher net income from deposits under the dual rules regime as time passes, which helps offset the lump-sum taxes.

These results are important because they show that, even though the first-order effect of the financial policy instrument is only on the participation constraint of lenders, it has nontrivial effects on consumption and income dynamics via the effects described above. In computing the welfare-maximizing elasticities of the dual rules, the financial authority is implicitly trading off the effects of the financial subsidy tilting the consumption profile over time, reducing consumption initially but increasing it steadily in future periods through the above income effects. The last plot of Figure 4 shows that period utility is about the same in all three regimes initially, then from the third period to the 12th to 14th period is lower with the dual rules, but after that it is higher under the dual rules, and this time profile of utility flows yields higher welfare than under the standard and augmented Taylor rules, as we documented earlier.¹³ Hence, if utility and welfare are the payoff functions of policymakers, clearly there are important effects resulting from financial policy. Moreover, if the payoff functions are standard quadratic loss functions, the inflation and interest rate responses are affected by introducing the financial subsidy (compare their impulse responses with the standard Taylor rule v. the dual rules), so the spillover effects between monetary and financial policies described graphically in the previous Section are quantitatively large.

In summary, the results reported in this Section show that the implications of violating Tinbergen's rule in the design of monetary and financial stability policies are quantitatively significant. A regime with dual rules for monetary and financial policies yields higher welfare 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 standard Taylor rule. 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 dual rules regime ex-

¹³The utility flows in the impulse response functions do not match exactly the welfare estimates used to compute compensating consumption variations because the former are constructed using a first-order approximation solution method and the latter are based on a second-order method, which is more accurate for capturing the inefficiencies due to price dispersion.

amined here sidesteps this issue by implicitly assuming cooperation by the two policy authorities and/or agreement to use social welfare as a common payoff function to evaluate alternative pairs of policy rule elasticities. In the next Section we study the implications of relaxing these assumptions.

4.3 Strategic Interaction

This Section examines the implications of strategic interaction between the two policy authorities under alternative payoff functions. We construct the authorities' reaction curves and solve and compare the outcomes of Nash and Cooperative equilibria.

4.3.1 Payoffs and reaction functions

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. We consider two formulations of payoff functions. First, a case in which both policymakers have as a common payoff function the household's expected lifetime utility function (i.e. social welfare): $L_m = \mathbb{W}(a_\pi, a_{rr}; \boldsymbol{\varrho})$ for $m \in \{CB, F\}$. Second, a case in which each authority has a payoff defined by a loss function that depends on the sum of the variances of their own policy instrument and target: $L_{CB} = -[\text{Var}(\pi_t) + \text{Var}(R_t)]$ and $L_F = -[\text{Var}(r_t^k/r_t) + \text{Var}(\tau_{f,t})]$, where $\text{Var}(x)$ denotes the unconditional variance of x_t in the economy's stochastic steady state. This type of payoff function is in line with those often used in quantitative studies of monetary policy (see Taylor and Williams, 2010; Williams, 2010). As explained in the Introduction, quadratic loss functions of this class can be used to derive log-linear policy rules like the ones we are using as optimal rules. Log-linear policy rules and quadratic loss functions are also widely used in practice at central banks for the quantitative evaluation of inflation targeting with DSGE models.

On the side of monetary policy, including the variance of inflation in the loss function can be justified by the widely-agreed consensus on inflation targeting. In turn, given the structure of the model, inflation targeting can be justified because of the welfare losses caused by inefficient price dispersion with sticky prices, as explained in Section 2. For the financial authority, institutions such as the BIS and the IMF advocate the use of financial policy to counter financial instability (see IMF, 2013; Galati and Moessner, 2013). When studying this issue using DSGE models, financial policy is often formulated as targeting the credit-output ratio, credit growth, or the volatility of the credit spread, as in the model we proposed (see also Angelini *et al.* (2014), Bodenstein *et al.*

(2014), De Paoli and Paustian (2013)). Again, given the model's structure, this makes sense because fluctuations in the credit spread create inefficient fluctuations in investment and output, and hence cause also welfare losses.¹⁴

We construct reaction functions that map the optimal (payoff maximizing) choice of one authority's policy rule elasticity for a given value of the other authority's rule elasticity.¹⁵ Denote the reaction function of the monetary authority as the best choice of the elasticity of the monetary rule for a given value of the elasticity of the financial policy rule, $a_\pi^*(a_{rr})$, and the reaction function of the financial authority as the best choice of the elasticity of the financial subsidy rule for a given value of the elasticity of the monetary policy rule, $a_{rr}^*(a_\pi)$, both defined over discrete grids of admissible values of elasticities, such that $A_\pi = \{a_\pi^1, a_\pi^2 \dots a_\pi^M\}$ and $A_{rr} = \{a_{rr}^1, a_{rr}^2 \dots a_{rr}^F\}$ with M and F elements respectively. Hence, the strategy space is defined by the $M \times F$ 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:

$$a_\pi^*(a_{rr}) = \left\{ (a_\pi^*, a_{rr}^s) : a_\pi^* = \arg \max_{a_\pi \in A_\pi} E \{L_{CB}\}, \text{ s.t. } \boldsymbol{\varrho}(a_\pi^*, a_{rr}) \text{ and } a_{rr} = a_{rr}^s \right\}_{a_{rr}^s \in A_{rr}},$$

$$a_{rr}^*(a_\pi) = \left\{ (a_\pi^s, a_{rr}^*) : a_{rr}^* = \arg \max_{a_{rr} \in A_{rr}} E \{L_F\}, \text{ s.t. } \boldsymbol{\varrho}(a_\pi, a_{rr}^*) \text{ and } a_\pi = a_\pi^s \right\}_{a_\pi^s \in A_\pi}.$$

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 the non-cooperative game between the policy authorities is defined by the intersection of the two reaction curves: $N = \{(a_\pi^N, a_{rr}^N) : a_\pi^N = a_\pi^*(a_{rr}^N), a_{rr}^N = a_{rr}^*(a_\pi^N)\}$. A Cooperative equilibrium is defined by a pair of policy elasticities picked by a planner who maximizes a linear combination of L_{CB} and L_F , with a weight of φ on the monetary authority's payoff, subject to the constraint that the cooperative equilibrium must be a Pareto improvement over the Nash equilibrium (i.e. each player must weakly prefer the Cooperative outcome). Since there can be more than one solution depending on the value of φ (i.e. the set of Cooperative equilibria corresponds to the contract curve of the two authorities), we define the Cooperative

¹⁴De Paoli and Paustian (2013) 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).

¹⁵In doing this, and given the pre-determined log-linear formulation of the policy rules, we are implicitly assuming commitment to these rules and abstract from studying strategic interaction under discretion (see also De Paoli and Paustian, 2013; Bodenstein *et al.*, 2014).

equilibrium in the following way:

$$C(\varphi) = \left\{ (a_{\pi}^C, a_{rr}^C) \in \arg \max_{a_{\pi}^s, a_{rr}^s \in A_{\pi} \times A_{rr}} E \{ \varphi L_{CB} + (1 - \varphi) L_F \}, \text{ s.t. } \varrho(a_{\pi}^s, a_{rr}^s) \right\}.$$

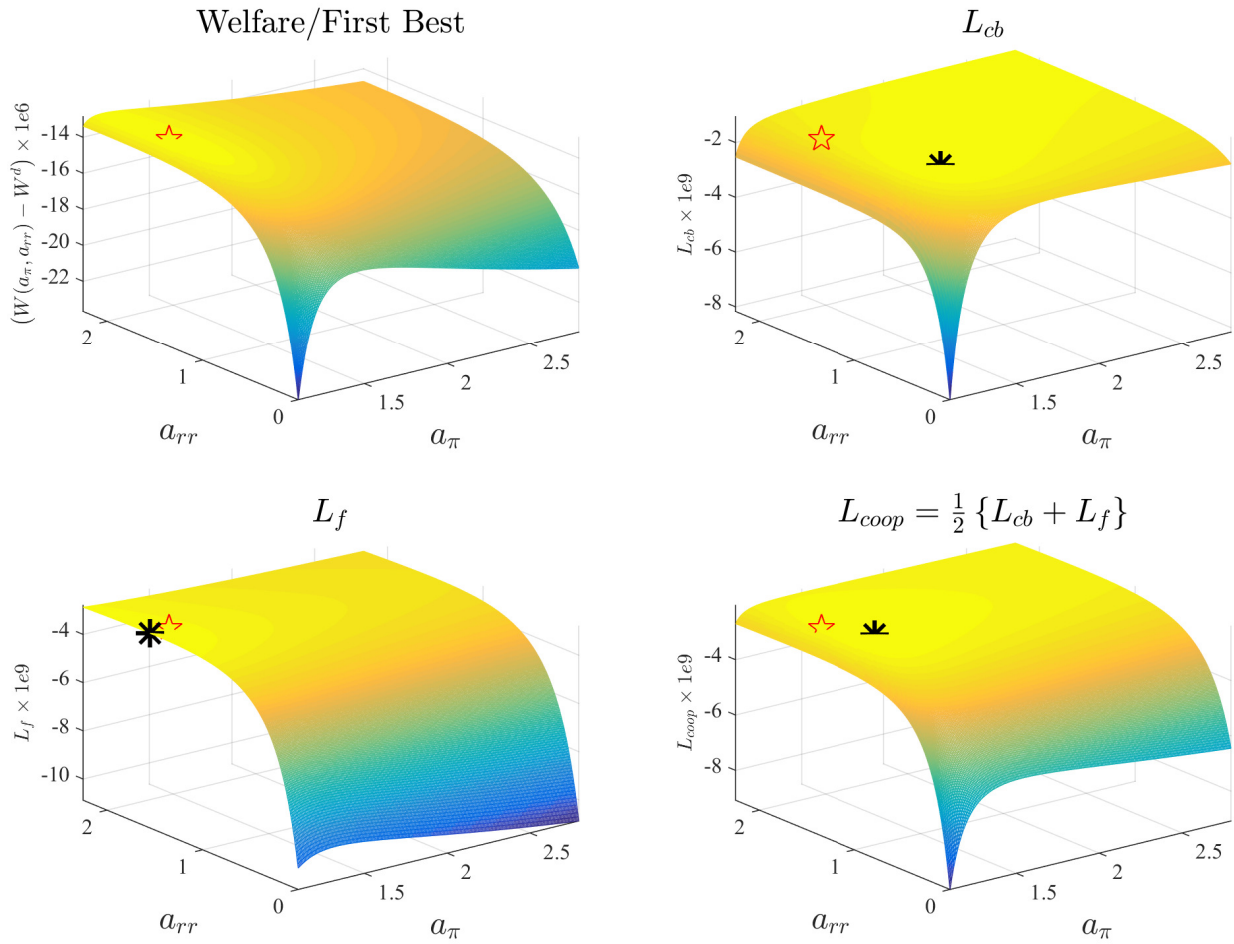
4.3.2 Welfare as a common payoff

The upper-left panel of Figure 6 shows a surface plot of the difference in social welfare under a given pair of policy elasticities minus welfare in the deterministic steady state, which is independent of the policy rule elasticities by construction. The maximum of this plot (identified with a star) determines the pair of elasticities that yields the highest social welfare, which we label the “first best.”¹⁶ The elasticities that support the first best are $(a_{\pi}^*, a_{rr}^*) = (1.22, 1.56)$. Since the surface plot is single peaked, any other pair of elasticities is suboptimal relative to this pair. Moreover, by construction, this first-best outcome corresponds to the Cooperative equilibrium when both authorities have social welfare as a common payoff, for any value of φ .

The upper-left panel of Figure 7 shows the reaction curves and the Nash and Cooperative equilibria when both policy authorities have welfare as a common payoff. The solid-blue line is the reaction function of the financial authority and the dashed-red line is the reaction function of the monetary authority. Two results are worth noting: First, the reaction curves are non-linear. The strong non-linearity of these reaction curves highlights the importance of the incentives for strategic interaction. In particular, the financial authority’s reaction curve shifts from treating its best elasticity choice as a strategic substitute for the choice of the monetary authority to treating it as a strategic complement. For low a_{π} , the policies interact as strategic substitutes in the financial authority’s reaction curve: The financial authority lowers its elasticity choice as the elasticity of the monetary rule rises. At sufficiently high values of a_{π} , however, the opposite happens, so that policies become strategic complements in the financial authority’s reaction curve. The monetary authority’s reaction curve is also nonlinear, but in this case the policies are always strategic substitutes. Hence, as the elasticity of the financial policy rule rises, the best choice of the elasticity of the monetary rule falls, first sharply when the elasticity of the financial rule is close to zero, and then very little as the financial rule elasticity rises above 1.

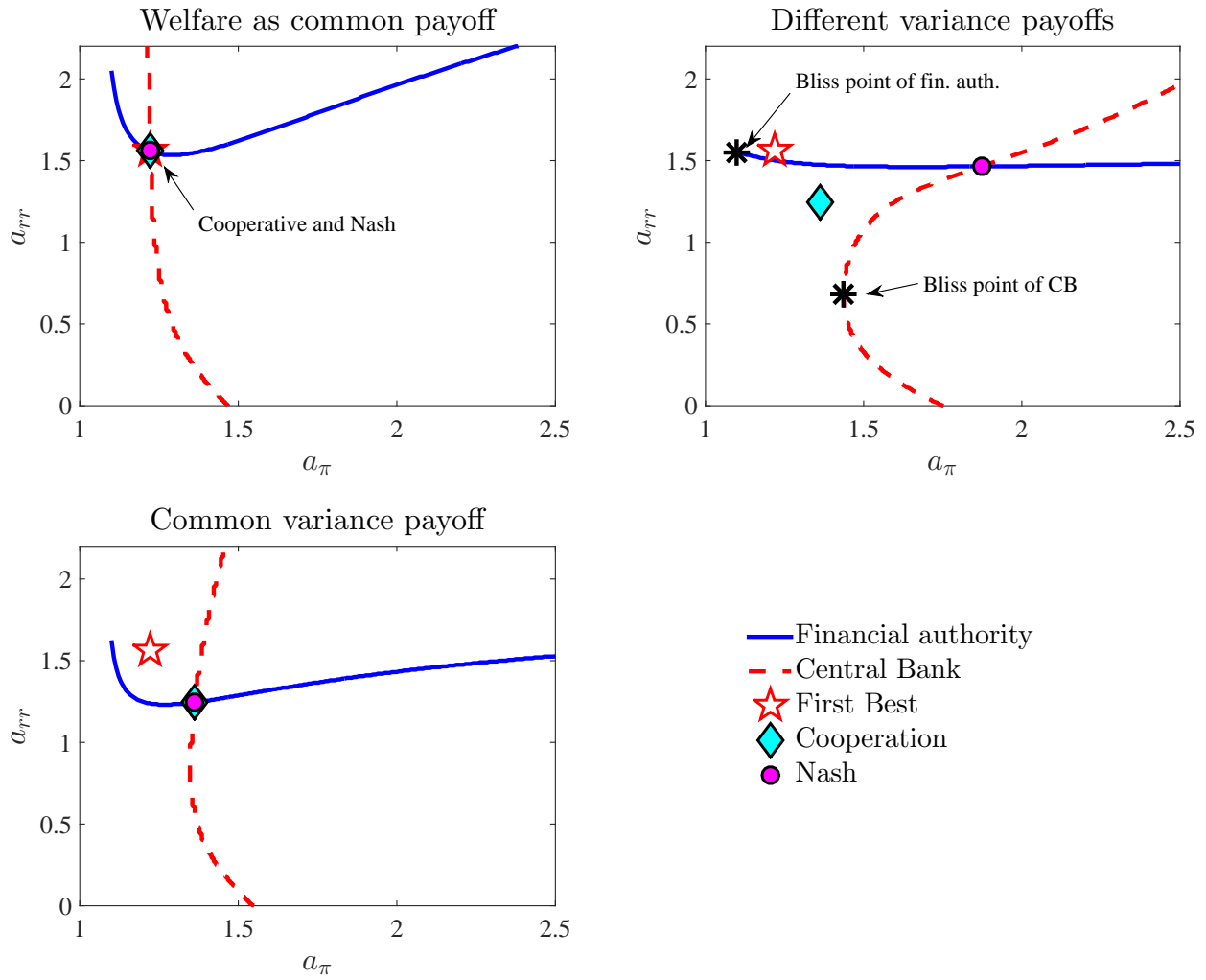
¹⁶This plot is analogous to the right-side panel in Figure 2, except that in that figure we plotted compensating consumption variations to measure welfare effects, and here we show differences in lifetime utility itself.

Figure 6: Payoffs and Policy Rule Elasticities



Note: The stars in the figures show the first best (the maximum welfare), while the asterisks are the maximum for each case.

Figure 7: Reaction Curves, Cooperative and Nash Equilibria



The nonlinear nature of the reaction curves also reflects the relative importance of the effects of monetary and financial policies described in Section 3. A higher elasticity of the financial rule for a given elasticity of the monetary rule implies that the effects of the financial policy response illustrated in Panel (B) of Figure 1 are stronger. Similarly, a higher elasticity of the monetary rule for a given elasticity of the financial rule implies that the effects of the monetary policy response shown in Panel (C) of the Figure are stronger. Each authority takes this into account when choosing its optimal response to a given value of the elasticity of the other authority.

The second result observed in Figure 7 is that, with welfare as common payoff, the Cooperative and Nash equilibria coincide, so there is no coordination failure and there are no gains from policy coordination. 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. Hence, the same result holds for any other specification of a common payoff function that depends on equilibrium allocations or prices. What changes, however, is that with social welfare as the payoff, the Nash and Cooperative equilibria also match the first-best outcome that maximizes social welfare, while with other common payoff functions the Nash and Cooperative equilibria are still the same but do not match the first-best outcome.

It is worth noting that the above result implies that assuming a common payoff is equivalent to assuming cooperation in the setup we are studying. Hence, the notion that coordination failure could be removed with the seemingly simple step of giving the two authorities the same payoff is in fact as complex as asking them to coordinate fully.

The result that Nash and Cooperative equilibria are the same with common payoff functions is not new in the monetary policy literature. For example, Dixit and Lambertini (2001) found in a monetary-union model that, when all countries and the central bank have the same objective, the ideal outcomes can be achieved in cooperative and non-cooperative games. Blake and Kirsanova (2011) show in a model with a monetary-fiscal interaction that the Nash equilibrium with a common payoff coincides with the Cooperative equilibrium, because the optimality conditions of the two problems are identical. Bodenstein *et al.* (2014) show a similar result in a model with monetary-financial interactions with open-loop Nash strategies.

We examined the robustness of these findings to changes in the degree of price stickiness ($\vartheta = 0.85$ v. 0.74 in the baseline calibration) and the magnitude of monitoring costs ($\mu = 0.25$ v. 0.12 in the baseline calibration). Qualitatively the results described above are preserved, but quantitatively there are differences. With stronger nominal rigidities, the central bank has incentives to react more to inflation, so for a given a_{rr} , the central bank chooses a higher a_{π} . Given this more aggressive reaction function, the financial authority is less aggressive than in the baseline model. When the financial frictions are stronger, the monetary authority is marginally more aggressive than in the baseline, because the policy interest rate has first-order effects on both the inflation (via aggregate demand) and the credit market (via the lender's participation constraint). Because there is a stronger reaction of the central bank, again the financial authority is less aggressive. The detailed results are shown in the online Appendix.

4.3.3 Different payoff functions

We now consider strategic interaction when the monetary and financial authorities have different payoff functions, given by the sum-of-variance loss functions defined earlier. For simplicity, for the cooperative case we focus on the average of the individual payoffs, that is $\frac{1}{2} \{L_{CB} + L_F\}$, which corresponds to the case in which $\varphi = 1/2$.

The upper-right and bottom-left panel of Figure 6 show surface plots of the individual payoff functions of the monetary and financial authorities as functions of the two policy rule elasticities, and the bottom-right panel shows the payoff function under cooperation. Note that all of these plots are again single peaked, and more importantly, the elasticity pairs that maximize each payoff unconditionally (i.e. the bliss points) differ for the monetary and financial authorities, and both also differ from the first-best pair of elasticities. These differences reflect the conflict of objectives of the two authorities and their incentives for engaging in strategic behavior, which in turn result in a Nash equilibrium that is inferior to the Cooperative equilibrium, as we show next.

The upper-right panel of Figure 7 displays the reaction functions of the central bank and the financial authority when their payoff functions are given by the sum-of-variances loss functions. The graph also identifies the Nash and Cooperative equilibria, and includes for comparison the first-best outcome and the authorities' bliss points. Qualitatively, the plot is consistent with standard results when coordination failure is present, in terms of the relative location of the Nash and Cooperative equilibria and the bliss points.

As in the case with a common payoff, the reaction functions are nonlinear, but the features of the two curves are swapped. Now, the financial authority's reaction curve is nonlinear but does not change the sign of the slope, while that of the monetary authority is U-shaped. In the financial authority's reaction curve, as the elasticity of the monetary rule rises, the elasticity of the monetary rule falls slightly, and the two elasticities always remain strategic substitutes. In the monetary authority's reaction curve, when the elasticity of the financial taxes starts increasing from near zero, the elasticity of the monetary rule falls, but after the financial subsidy elasticity rises above 0.7, the elasticity of the monetary rule rises sharply. Thus, in the eyes of the monetary authority, the elasticities change from strategic substitutes to complements.

The Nash equilibrium features a higher inflation elasticity than both the Cooperative and first-best outcomes (1.9 v. 1.35 and 1.25 respectively). The spread elasticity in the Nash equilibrium is higher than in the Cooperative equilibrium (1.45 v. 1.2) but slightly lower than in the first-best outcome (1.45 v. 1.55). Hence, relative to the first-best pair of elasticities, the Nash equilibrium produces a tight money-tight credit regime: The policy interest rate rises too much when inflation is above target, and the financial subsidy does not rise enough when the spread is above target. Compared with the Cooperative equilibrium, the Nash equilibrium is again a tight money regime, but is also slightly easy in terms of credit, because the elasticity with respect to the spread is a notch higher.

In terms of welfare, the Nash equilibrium is a "third-best" outcome, in the sense that it is inferior to both the first-best and the Cooperative outcomes. Hence, in this case there is coordination failure and there are gains from policy coordination. In terms of welfare costs relative to the deterministic (and Pareto efficient) steady state, the Nash equilibrium has a 7 percent higher cost than the first best, while the cost of the Cooperative equilibrium is only 1 percent higher than in the first best. Hence, the cost of the coordination failure is about 6 percentage points in terms of a compensating consumption variation. Furthermore, there are Cooperative equilibria that dominate

the one with 50-50 weights on the two policy authorities, and thus are closer to the first best. In particular, the Cooperative equilibrium that is closest to the first best is attained with $\varphi = 0.13$ (i.e. with most of the weight on the financial authority). In this case, the welfare cost under the Cooperative equilibrium is only 0.03 percent points in terms of consumption equivalent, and thus the welfare gain of policy coordination rises to almost 7 percent.

Finally, we consider an alternative scenario in which we use a common payoff function but formulated in terms of a loss function instead of social welfare. In particular, we assume that the common payoff is the sum of the variances of all policy instruments and targets: $\tilde{L}_{CB} = \tilde{L}_F = -[\text{Var}(\pi_t) + \text{Var}(R_t) + \text{Var}(r_t^k/r_t) + \text{Var}(\tau_{f,t})]$. The bottom-left panel of Figure 7 displays the outcome of this alternative scenario. Since the payoff is common, the Nash and Cooperative equilibria coincide, but now the solution is second-best, because the objective is not to maximize social welfare. Notice that the policy elasticities at the Cooperative equilibrium are very similar to those in the Cooperative equilibrium of the game with different payoffs. The difference is that now the Nash equilibrium also supports this outcome, since the common payoff removes the coordination failure. The resulting policy regime is again tight money-tight credit relative to the first-best outcome.

5 Conclusions

This paper studies coordination failure in the implementation of monetary and financial policies in a New Keynesian model with risk shocks. Calvo-style staggered pricing and the Bernanke-Gertler costly monitoring of borrowers cause economic distortions that induce inefficient business cycle fluctuations. 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 the variables that each authority targets depends on the policy instruments controlled by both authorities, and these spillovers incentivize strategic behavior.

The theoretical principles behind these two aspects 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 three key results: First, violations of Tinbergen's rule are quantitatively significant. A regime in which the Taylor rule for monetary policy is augmented with financial stability considerations is significantly inferior to a regime in which monetary policy follows a standard Taylor rule to set the nominal interest rate and financial policy follows a log-linear 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. Second, the reaction curves that describe the optimal choice of policy rule elasticities of the monetary and financial authorities are nonlinear, and display switches from strategic substitutes to strategic complements in the adjustment of those elasticities. Third, with standard loss functions defining the payoffs of monetary and financial authorities, a non-cooperative Nash equilibrium in the setting of policy rule elasticities is significantly inferior to a cooperative equilibrium and to a first-best outcome that maximizes social welfare. Both the Nash and the Cooperative equilibria are also tight money-tight credit regimes in which the interest rate rises too much when inflation rises and the financial subsidy does not rise enough when the credit spread widens.

Table 3 provides a summary of this paper's quantitative findings that highlights the large welfare implications of coordination failure in monetary and financial policies. The Table compares the welfare costs of the various policy regimes we studied, and their associated policy rule elasticities.

The top half of the Table shows the implications of violating Tinbergen's rule by comparing the baseline dual rules regime with the standard and the augmented Taylor rule, and also compares the latter two between themselves. The dual rules regime increases welfare by the equivalent of a 14.7 percent compensating variation in consumption relative to the augmented Taylor rule, and 34.5 percent relative to the standard Taylor rule. If the dual rules are unfeasible, the augmented Taylor rule yields 17.3 percent higher welfare than the standard Taylor rule. Hence, disregarding the strong incentives for strategic interaction, the dual rules regime clearly dominates (i.e. Tinbergen's rule is quantitatively significant).

Table 3: Summary of Quantitative Results

Regime x v. regime y	% diff. in ce	Param. values of regime x		
		a_π	a_{rr}	\tilde{a}_{rr}
<i>Violations of Tinbergen's rule (payoff is welfare)</i>				
Dual rules v. First best	0%	1.22	1.56	-
Augmented Taylor rule v. Dual rules	14.7%	1.25	-	0.26
Standard Taylor rule v. Dual rules	34.5%	1.45	-	-
Standard Taylor rule v. Augmented Taylor rule	17.3%	1.45	-	-
<i>Costs of strategic interaction (payoffs are quadratic loss functions, except for the first best)</i>				
Nash v. First best	7.3%	1.87	1.47	-
Cooperative with equal weights v. First best	1.3%	1.37	1.25	-
Cooperative with optimal weights v. First best	$\frac{3}{100}\%$	1.22	1.45	-
Standard Taylor rule v. Nash	25.3%	1.45	-	-

Note: ce corresponds to the consumption equivalent welfare measure defined in equation (2.22). A given ce figure in the comparison of regimes x v. y means that regime x has a welfare cost equivalent to ce percent in terms of a compensating consumption variation that would be needed for an agent living in regime x to be as well off as under regime y .

The bottom half of the Table shows the effects of strategic interaction. It compares the Nash and Cooperative equilibria v. the welfare-maximizing outcome (denoted the first best), assuming that the payoff function of each authority is formulated in terms of the sum of the variances of policy instruments and targets. The Nash and a Cooperative equilibrium with equal weights yield welfare costs of 7.3 and 1.3 percent in terms of compensating variation in consumption relative to the first best, respectively. This implies that welfare under cooperation is about 6 percent higher than under the Nash equilibrium, and thus the welfare gains of coordination of monetary and financial policies are large. If the weights in the Cooperative payoff function are optimized to yield the smallest welfare cost, the Cooperative equilibrium approximates the first best closely, and the gain of policy coordination rise to nearly 7.3 percent.

The Table also shows that if the choice is between a regime with a standard Taylor rule and no financial policy, and a non-cooperative Nash equilibrium in the setting of monetary and financial policy rules, the latter is preferred by a large margin, with a welfare gain of 25.3 percent. Hence, while our results show that coordination failure in monetary and financial policy has large effects, they also suggest that a dynamic financial policy aiming to smooth fluctuations in credit spreads is worth undertaking even if policy coordination is unattainable.

This analysis has two important limitations. First, for tractability, we use perturbation methods to quantify the amplification effects of risk shocks in the Bernanke-Gertler financial accelerator. As explained by Mendoza (2016), the perturbation methods are likely to 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, the analysis only includes 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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