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Unpleasant Monetarist Arithmetic: Macroprudential Edition

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Abstract

The 2008 crisis highlighted the linkages between the financial sector and the real economy, as well as between the corresponding stabilization policies: macroprudential and monetary (M&Ms). Our game-theoretic analysis focuses on the increasingly adopted separation setup, in which M&Ms are conducted by two different institutions (e.g. in Australia, Canada, Eurozone, Sweden, Switzerland and the United States). We show that separated policy M&Ms are not as sweet as their chocolate counterparts, in fact they may turn sour. The main reason is that a strategic conflict is likely to arise between the autonomous prudential authority and the central bank in addressing exuberant credit booms, such as those during 1998-2000, 2003-2006 and 2011-2016. In this conflict - that manifests as the Game of Chicken under some parameter values - each institution prefers a different policy regime. In particular, both the prudential authority and the central bank prefer to do nothing about the credit boom and induce the other institution to respond instead; arguably the case of Sweden, Norway and other countries post-2010. To allow for richer strategic interactions, we postulate the concept of Stochastic leadership, which generalizes Stackelberg leadership and simultaneous move game by allowing for Calvo-type probabilistic revisions of policy actions. We show that the most likely outcomes are Policy Deadlock, Regime Switching and Macroprudential Dominance, but all three are socially undesirable. This is not only because of excessive financial and economic cycles, but also because monetary policy coerced into leaning against the wind loses full control over price inflation. The separation setup of M&Ms is thus subject to a macroprudential version of unpleasant monetarist arithmetic.

Keywords

Macroprudential policy, monetary policy, strategic interactions, Game of Chicken, financial stability, exuberant credit, leaning against the wind, unpleasant monetarist arithmetic.

JEL Classification

E61, G28

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Abstract

The 2008 crisis highlighted the linkages between the financial sector and the real economy, as well as between the corresponding stabilization policies: macroprudential and monetary (M&Ms). Our game-theoretic analysis focuses on the increasingly adopted separation setup, in which M&Ms are conducted by two different institutions (e.g. in Australia, Canada, Eurozone, Sweden, Switzerland and the United States). We show that separated policy M&Ms are not as sweet as their chocolate counterparts, in fact they may turn sour. The main reason is that a *strategic conflict* is likely to arise between the autonomous prudential authority and the central bank in addressing exuberant credit booms, such as those during 1998-2000, 2003-2006 and 2011-2016. In this conflict - that manifests as the Game of Chicken under some parameter values - each institution prefers a different policy regime. In particular, both the prudential authority and the central bank prefer to do nothing about the credit boom and induce the other institution to respond instead; arguably the case of Sweden, Norway and other countries post-2010. To allow for richer strategic interactions, we postulate the concept of Stochastic leadership, which generalizes Stackelberg leadership and simultaneous move game by allowing for Calvo-type probabilistic revisions of policy actions. We show that the most likely outcomes are *Policy Deadlock*, *Regime Switching* and *Macroprudential Dominance*, but all three are socially undesirable. This is not only because of excessive financial and economic cycles, but also because monetary policy coerced into leaning against the wind loses full control over price inflation. The separation setup of M&Ms is thus subject to a macroprudential version of unpleasant monetarist arithmetic.

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1. Introduction

A key lesson from the 2008 global crisis is that the financial sector and the real economy are like twins: intimately connected. The two associated policies, macroprudential and monetary (M&Ms), can hence be compared to intertwined umbilical cords through which policymakers ensure a healthy development of both segments of the economy.

Like actual umbilical cords that stem from a common placenta, both M&Ms have traditionally been assigned to one institution: the central bank. Recently, however, we have seen a move away from this 'integration setup'. In many economies (e.g. Australia, Canada, Chile, Denmark, Eurozone, Norway, Sweden, Switzerland and the United States) macroprudential policy has been separated from the central bank, and delegated to an autonomous institution or committee. This paper's key question is whether such 'separation setup' of M&Ms is desirable. *Its answer is (a resounding) 'No'.*

Unlike most studies, we do not assume that the policymakers in charge of M&Ms are necessarily willing and capable of coordinating their instruments. This is because, while plausible in the integration setup, such assumption is unrealistic in the separation setup. Instead, we examine the *strategic* (game-theoretic) aspect of interactions between independent macroprudential and monetary policies. Our framework provides insights for various combinations of financial and macroeconomic shocks, but our main focus is on M&Ms' responses to exuberant credit shocks - such as those observed in many countries during 1998-2000, 2003-2006 and 2011-2016. The strategic perspective means that we no longer ask the normative question 'How *should* a credit boom be addressed under optimally cooperating benevolent policymakers?' We ask the positive question 'How *will* a credit boom be addressed if the separated M&Ms interact strategically?'[2]

To examine the richness of strategic policy interactions we use a novel game-theoretic framework with more general information/timing. It extends the idea of Calvo's (1983) rigidity, used widely in macroeconomics, to policy actions. M&Ms' instruments may no longer be adjusted with certainty, but only with some (known) probability that can differ across the policies. Such Stochastic leadership framework nests the special cases of Stackelberg leadership and simultaneous move as well as everything in between them, enabling us to capture various real-world institutional and logistic features of M&Ms. Moreover, it endogenizes policy regimes - commonly assumed as exogenous.

Our exploration highlights two main reasons for the undesirability of separating macroprudential and monetary policies into two autonomous institutions. First, without the shield of (hard-earned) central bank independence, macroprudential policy may struggle to stay immune to political and financial lobby pressures (see IMF, 2013a). Second, even if this is not the case, social welfare may decline in the separation setup due to a *strategic conflict* between M&Ms in responding to exuberant credit shocks. In particular, we derive six main policy scenarios that can occur under some values of the underlying

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[2]There are a number of valuable recent contributions exploring the interactions of M&Ms, see Silvo (2016), Kiley and Sim (2015), Alpanda et al. (2014), Angelini et al. (2014), Beau et al. (2014), Cecchetti and Kohler (2014), Gelain and Ilbas (2014), Ueda and Valencia (2014), and Kannan et al. (2012). But none of these papers formally considers the strategic considerations between M&Ms, i.e. the integration setup is assumed. The main exceptions are Carrillo et al. (2017), Dennis and Ilbas (2016), Bodenstein et al. (2014) and De Paoli and Paustian (2013), who use the conventional simultaneous or sequential games to compare the non-cooperative Nash solution with the cooperative and/or Stackelberg outcomes.

macroeconomic and policy preference parameters. In five of them, including the Game of Chicken, a strategic conflict arises because the central bank and the prudential authority prefer a different regime. Each institution wants *the other* to deal with credit booms in order to minimize the variability of its own instrument.[3]

Our analysis shows that three outcomes of such policy conflict are likely to occur, and all are socially undesirable. The first one is a Policy Deadlock in which neither policy stabilizes exuberant credit growth. As a consequence, asset bubbles develop and financial instability subsequently spills over to the real economy, causing macroeconomic instability. Intuitively, the prudential authority may be hesitant to increase minimum reserve requirements, capital buffers, loan-to-value or loan-to-income ratios in the hope that the central bank leans against the wind by increasing interest rates. The central bank may however be apprehensive to do so hoping for the prudential authority to address the credit boom by (better-suited) macroprudential measures.

An alternative type of outcome is Regime Switching, whereby M&Ms randomize between various instrument settings in an uncoordinated fashion (play a mixed-strategy equilibrium). This again results in greater variability of financial and economic variables.

Finally, we may observe Macroprudential Dominance over monetary policy. Due to lower flexibility and greater adjustment costs of macroprudential measures, the prudential authority is the likely Stochastic leader, whereas the central bank is relegated to the back seat - the role of the Stochastic follower. It is strategically maneuvered by the prudential authority's inaction into becoming the 'chicken', i.e. leaning against the wind by raising interest rates. While this reduces the size of the asset bubble compared to a Policy Deadlock, socially optimal outcomes are not achieved. The central bank's attention to financial stability imperils price stability - due to one instrument chasing two objectives monetary policy loses full control over consumer price inflation.[4]

All of the three likely outcomes point to a *macroprudential version of an unpleasant monetarist arithmetic.* In the original work of Sargent and Wallace (1981) the culprit was the government ignoring fiscal imbalances, in our analysis it is the prudential authority ignoring financial imbalances. In either case, the Tinbergen rule is not observed so monetary outcomes are jeopardized and social welfare reduced. Recent real-world developments show that such strategic conflict between M&Ms is not just a theoretic peculiarity, but a pressing problem already observed in some countries. Ubide (2015) provides the following description in a report to the European Parliament:

> 'The experience of Sweden is a very good case study of the conflict between price stability and financial stability, and the risk of using monetary policy to address both rather than using macro-prudential policies. In recent years, Sweden's economy has experienced robust growth combined with still high unemployment and low inflation. At the same time, household debt has grown rapidly and house prices have remained buoyant. In response, as the Swedish FSA (Financial Supervisory Authority)

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[3]Instrument variability aversion for one of both M&Ms appears in an increasing number of papers, e.g. Carrillo et al. (2017), Angelini et al. (2014), Florio (2009) and Svensson (2000).

[4]This regime parallels Brunnermeier and Sannikov's (2014a) 'Financial Dominance'. They describe it as a situation in which 'the financial industry corners central banks, forcing them to take measures that restrict their freedom to conduct the proper monetary policy'.

was resisting repeated calls from the Riksbank [Sweden's central bank] for
the adoption of macro-prudential policies, the Riksbank adopted a tighter
monetary policy stance than purely macroeconomic considerations would
have called for. De facto, near term inflation and unemployment goals be-
came subordinated to reduce the risks to financial stability that stemmed
from Sweden's high level of household debt... Sweden's dilemma is not
an isolated example.'

In the same spirit, Svensson (2012) argued that the Riksbank's interest rate increases
between mid-2010 and mid-2011 (from 0.25% to 2%), driven by an attempt to lean
against the wind, were 'not consistent with its mandate'. The fact that he was Deputy
Governor of the Riksbank at the time, and effectively resigned over this episode, high-
lights the tension between M&Ms in the separation setup. Similarly, the Vice Chairman
of the Fed, Fischer (2015), argued: 'the need for coordination across different regulators
with distinct mandates creates challenges to the timely deployment of macroprudential
measures in the United States.'

Given the increasing magnitude of costly financial cycles over the past four decades
(see Drehmann et al., 2012), and recent wide adoption of the separation setup, an in-
depth investigation of strategic interactions between autonomous M&Ms seems highly
desirable. Our main contribution lies in: *(i) identifying circumstances under which
Policy Deadlock, Regime Switching and Macroprudential Dominance can occur following
credit booms, as well as (ii) formally examining institutional arrangements that may help
to avoid these socially-inferior outcomes by improving policy coordination.*

2. Map of the Paper and Main Results

In its focus on strategic policy interactions within the separation setup our analysis
differs from the literature, so it is worthwhile to outline how things fit together.

Policy Preference Assumptions. Our social welfare and policy objective func-
tions, postulated in Sections 3.1-3.2, are uncontroversial. As the primary objective, (i)
monetary policy cares about price stability and the macroprudential policy cares about
financial stability. As a secondary objective, (ii) both M&Ms prefer to stabilize (smooth)
their instrument, i.e. they are averse to its variability. For exuberant credit shocks, this
can be interpreted as *aversion to leaning against the wind.*[5]

Macroeconomic Assumptions. In regards to the economy, our general setting
of Section 3.3 only assumes that (iii) the financial sector and the macroeconomy are
interlinked ('twins' assumption); and (iv) macroprudential and monetary policies are
partial substitutes in dealing with financial and macroeconomic shocks ('intertwined
cords' assumption). These two generic features are present in virtually all recent papers
on M&Ms and widely accepted in the policy circles (for a discussion based on the views
of the International Monetary Fund prior- and post-2008 see Appendix A).

To focus on the game-theoretic aspect and keep its links to the macroeconomy trans-
parent, Section 3.4 spells out the simplest reduced-form model capturing the twins and

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[5]Despite such secondary objective, our benchmark M&Ms in Sections 5-9 can be interpreted as
(at least partly) benevolent, because they do *not* attempt to boost leverage/output above the natural
level. Section 10 considers the opposite case of an idiosyncratic prudential authority that is not fully
independent from the government or the financial lobby.

intertwined cords assumptions. It is however important to note that *our findings regarding strategic policy interactions are general*; their nature applies to any macro framework featuring assumptions (i)-(iv) with separated M&Ms. To document that, we closely relate our specification and results to the microfounded setting of Carrillo et al. (2017).

Linking Macro and Game Theory. Upon Section 4 summarizing the various combinations of financial and aggregate demand shocks and the implied types of conflict, Section 5 uses an intuitive method of Backus and Driffill (1985) to map our macro model into a game-theoretic representation. Each policy can, in response to an exuberant credit shock, perform *No-tightening N* (leaving its instrument unchanged - implying a loose stance), *Strong-tightening S* (addressing the shock alone - implying a tight stance), and *Joint-tightening J* (anything in between N and S). The latter includes two outcomes of interest used in most analyses. One is the *non-cooperative Nash solution* $\left(J^{NASH}, J^{NASH}\right)$, i.e. the intersection of the policies' reaction functions. The other is the *Cooperative solution* $\left(J^{COOP}, J^{COOP}\right)$ that would obtain if the central bank was in charge of both M&Ms.

Policy Scenarios. While the integration setup of M&Ms implies a constrained optimization problem, the separation setup needs to be examined as a non-cooperative game between the central bank and the prudential authority (for more on the institutional setups around the globe see Appendix B). In Section 6 we derive the fundamental scenarios that M&Ms may experience following an exuberant credit shock: Policy Deadlock, Macroprudential Dominance, Monetary Dominance, Focal Compromise, Symbiosis and the Game of Chicken (within the latter three Regime Switching can occur). All of these except Symbiosis feature a strategic conflict between M&Ms regarding stabilization of credit booms. The scenario of most interest is the Game of Chicken, because its equilibrium can reproduce equilibrium outcomes of all the other scenarios.

Stochastic Policy Leadership. To explore how institutional differences between the separated M&Ms may help to avoid socially undesirable regimes, we postulate in Section 7 a framework featuring Stochastic leadership. It builds on Libich and Nguyen (2013) and allows for a richer examination of strategic conflict and implicit coordination. The framework extends conventional Stackelberg leadership and the simultaneous move game by letting the policies revise their actions. For comparability with Stackelberg leadership, the revision opportunity arrives immediately and is made upon observing the opponent's initial action. But the revision occurs with some (known) probability as in Calvo (1983), not necessarily with certainty. Furthermore, the revision probability may differ across the policies to reflect their institutional and logistic heterogeneities.[6]

To give one possible interpretation of the probabilistic revisions, changes in the monetary policy setting are considered at least eight times a year at the regular central bank board meeting, whereas new macroprudential measures at most once or twice a year due to their associated costs and rigidities. This implies that a revision of previous macroprudential measures is expected with a much lower probability than a monetary revision. These characteristics put the prudential authority in the position of the Stochastic leader, whereas the central bank becomes the Stochastic follower.

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[6]To capture real-world uncertainty, the policymakers are unable to observe whether the opponent has also been given a revision opportunity. That means that the revisions are, like the policies' initial decisions, simultaneous.

Equilibrium Policy Regimes in the Game of Chicken. To illustrate the mechanics of Stochastic leadership, Sections 8.1-8.2 first examine the 2×2 Game of Chicken without the Joint-tightening options. Sections 8.3 and 8.4 then report results for the 3×3 game featuring $\left\{ N, S, J^{COOP} \right\}$ and for its larger $n \times n$ versions respectively.[7] They demonstrate that all the strategic-type findings of the 2×2 game carry over to the larger games, which is why a truncation to a 2×2 game has been performed with little loss of generality (for more see e.g. Backus and Driffill, 1985). We show under what circumstances macroprudential policy's Stochastic leadership helps to avoid Regime Switching and Policy Deadlock, because the central bank is incentivized to respond to the exuberant credit boom. However, such Macroprudential Dominance does not deliver society's first-best, it only delivers the third-best. This is because it only partly reduces credit imbalances and, importantly, it leads to unpleasant monetarist arithmetic.

Theoretic Insights. These results suggest that monetary policy flexibility, which is socially advantageous in the integration setup, becomes a *strategic disadvantage* in the separation setup. Our analysis implies other monetary policy features that similarly turn from sweet to sour for society when M&Ms are separated into two autonomous institutions. It is the central banker's patience (low level of discounting), its lack of aversion to leaning against the wind, and its possession of a highly potent interest rate instrument. All three features are socially desirable in the aftermath of exuberant credit shocks when the central bank is in charge of both M&Ms. But this is not the case in the separation setup, as they give a strategic advantage to the prudential authority and make unpleasant monetarist arithmetic more likely.

Our examination in Section 8 offers several additional messages about strategic interactions between policy M&Ms. For example, it shows that Stochastic leadership is neither necessary nor sufficient for a policy's dominance - unlike Stackelberg leadership, which is both necessary and sufficient. Further, we demonstrate that adding joint options into the 2×2 game such as J^{NASH}, or even the compromise-prone level J^{COOP}, does not necessarily alleviate the strategic policy conflict. In fact, these options may make a Policy Deadlock and Regime Switching more likely. This surprising finding that a '*compromise may compromise coordination*' implies that conventional models, automatically focusing on the non-cooperative Nash solution or cooperative outcome in a fully continuous framework, may provide an incomplete picture. Our analysis thus demonstrates that allowing for more dynamics on the game-theoretic level and some discreteness in the policy actions may be vital in designing policy institutions.

Policy Insights and Recommendations. Upon linking our game-theoretic results back to the macro model (Section 9), and exploring various modifications (Section 10), Sections 11-12 discuss in detail the policy recommendations and frame our findings within the literature. It is shown that they are consistent with results of many diverse analyses. In particular, our key finding about the superiority of the integration setup over the separation setup of M&Ms is in line with e.g. Carrillo et al. (2017), Silvo (2016), Melecky and Podpiera (2015), Angelini et al. (2014), Cecchetti and Kohler (2014) and Lim et al. (2013). All these papers highlight the importance of *explicit policy coordination*, and point to various problems with separating M&Ms into two institutions.

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[7]This extends Libich and Nguyen (2013) where only a 2×2 game is solved (in a different context).

Our additional insights relate to institutional measures that may enhance *implicit policy coordination* within the separation setup, and they are also consistent with the literature. They include: (i) the benefits of M&Ms' heterogeneity resulting in one policy's leadership (De Paoli and Paustian, 2013), (ii) the positive commitment effect of explicit numerical targets for macroprudential policy (Svensson, 2016a), (iii) the desirability of the macroprudential authority's objective function to also include an output stabilization objective (Gelain and Ilbas, 2014), and (iv) the importance of disentangling financial from macroeconomic shocks (Kannan et al., 2012). Sections 11-12 discuss how all these measures tend to lessen financial and business cycles by reducing the scope for a strategic conflict between M&Ms.

3. The Macroeconomic Framework

3.1. **Social Welfare.** We assume that society dislikes price and financial variability

$$(1) \qquad U^S = -\overbrace{\psi\left(\pi - \bar{\pi}\right)^2}^{\text{price stability}} - \overbrace{\lambda\left(L - \bar{L}\right)^2}^{\text{financial stability}} ; \qquad \psi > 0, \lambda > 0.$$

In the social welfare function U^S, π denotes (consumer price) inflation and $\bar{\pi}$ is the central bank's inflation target. The conditions in the financial sector are summarized by leverage, L. It is interpretable as the amount of credit in the financial sector, where $\bar{L}$ is some natural level reflecting the fundamentals.

3.2. **Policymakers' Objectives and Types.** Given the separation setup, our framework considers two institutions independent of each other. The central bank (C) conducts monetary policy whereas the prudential authority (P) conducts macroprudential policy (adding fiscal policy will be discussed in Section 10). The policies have a primary and a secondary objective as described by assumptions (i)-(ii) in Section 2:

$$(2) \qquad U^C = -\overbrace{\psi\left(\pi - \bar{\pi}\right)^2}^{\text{price stability}} - \overbrace{\rho_i\left(r - \bar{r}\right)^2}^{\text{instrument stability}} ; \qquad \psi > 0, \rho \geq 0,$$

$$(3) \qquad U^P = -\overbrace{\lambda\left(L - L^*\right)^2}^{\text{financial stability}} - \overbrace{\kappa_i\left(l - \bar{l}\right)^2}^{\text{instrument stability}} ; \qquad \lambda > 0, \kappa \geq 0.$$

The variable r is the real interest rate - the monetary policy instrument, and $\bar{r}$ is its natural level. Similarly, l denotes a composite macroprudential instrument including reserve requirements, capital buffers and loan-to-value ratios, whereby $\bar{l}$ represents its natural level. The 'secondary' aversion to instrument variability appears e.g. in Carrillo et al. (2017), Angelini et al. (2014) and Svensson (2000).[8] The subscript i indicates that the secondary weights depend on the type of shock i, but as we will focus below on exuberant financial shocks the subscript will be dropped for parsimony. The variable L^* denotes P's leverage target, and we will distinguish two types. In the benchmark analysis we assume the macroprudential authority in (3) to be, like the central bank in

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[8]For parsimony, (2)-(3) assume the policymakers' weights on the primary objectives to mirror society's weights, but this will have no qualitative effect on any of the results. The same can be said about a possible inclusion of society's instrument variability aversion, as well as about society's and policymakers' aversion to output variability (which will be discussed in Section 10).

(2), *benevolent*, i.e. independent from the government and financial lobby. Formally, its leverage target equals society's

(4) $$L^* = \bar{L}.$$

Section 10 then considers an *idiosyncratic* (dependent) prudential authority, featuring $L^* > \bar{L}$ in the spirit of the Barro and Gordon (1983) time-inconsistency literature.

3.3. **General Macroeconomy.**

The 'twins' and 'intertwined cords' assumptions of Section 2 can be written in general terms for example as follows

(5) $$\pi = f\left(l, r, \varepsilon, \varepsilon^D, ...\right) \quad \text{and} \quad L = f\left(l, r, \varepsilon, \varepsilon^D, ...\right).$$

This postulates that financial and inflation outcomes are, in addition to other variables (represented by the ... notation), a function f of the setting of both M&Ms, r and l, as well as of the respective shocks, ε^D and ε. The former represents a macroeconomic (aggregate demand) shock, whereas ε expresses a financial (credit) shock.

We will work below with the simplest setup capturing (5), which has both pros and cons. On the plus side, a reduced-form macro model can be mapped into a game-theoretic representation while keeping the policy interaction channels transparent. A disadvantage is that our auxiliary macroeconomic results, namely Proposition 6 and Remark 3, should be interpreted with caution and their relevance considered in alternative frameworks.

Nevertheless, the simplified nature of our economy in the next section does *not* affect our headline game-theoretic results on the strategic interaction of M&Ms, namely Propositions 1-5 and Remarks 1-2 & 4-6. These are robust as they do not rest on the specific macroeconomic model. Their nature generalizes to any microfounded framework in which the interlinkages in (5) apply, including Carrillo et al. (2017).[9]

3.4. **Specific Macroeconomy.**

Like in Ajello et al. (2015), there are three equations: the Phillips curve and IS curve express the supply and demand side respectively, whereas a leverage/credit equation represents the financial side of the economy. In the short term the leverage gap can be affected by both M&Ms and the financial shock

(6) $$L - \bar{L} = -\delta\left(l - \bar{l}\right) - \mu\left(r - \bar{r}\right) + \varepsilon; \qquad \delta > 0, \mu > 0.$$

Both monetary contraction $(r > \bar{r})$ and macroprudential contraction $(l > \bar{l})$ lead to reductions in credit and leverage, which is desirable under an exuberant credit shock $(\varepsilon > 0)$ to prevent asset bubbles $(L > \bar{L})$.[10] This shock can be interpreted as a 'negative risk shock' in Carrillo et al. (2017), i.e. a sudden decrease in the variability of entrepreneurs' returns. The IS curve is postulated as follows:

(7) $$y - \bar{y} = \gamma\left(L - \bar{L}\right) - \beta\left(r - \bar{r}\right) + \varepsilon^D; \qquad \gamma > 0, \beta > 0,$$

where y is real output and $\bar{y}$ denotes its natural level. This equation should be, like the rest of the macro setup, interpreted from a short-term perspective. It expresses that

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[9]Their microfounded framework (and similar ones) however cannot be directly mapped into a game-theoretic representation as it does not yield closed-form solutions for the aggregate (supply and demand) relationships.

[10]For an insightful discussion of the problems of the efficient market hypothesis see Barberis and Thaler (2003). Recent literature provides a growing number of avenues that can formalize excessive credit booms and asset bubbles, see e.g. Leduc and Natal (2016), Boz and Mendoza (2014), Brunnermeier and Sannikov (2014b), Klaus et al. (2014) and Gali (2014).

financial conditions can temporarily affect the real economy, and the same is true for both policies.[11] The supply side is encapsulated in the following simple Phillips curve

$$(8) \qquad\qquad \pi - \overline{\pi} = \alpha\left(y - \bar{y}\right); \qquad \alpha > 0,$$

where output below (above) natural leads to deflationary (inflationary) pressures.

Despite its simplicity, our model captures the gist of the framework by Carrillo et al. (2017). First, their policy objective functions (and thus M&M's incentives) are virtually identical to ours, incorporating assumptions (i)-(ii). Second, their M&Ms' strategy spaces also allow for some discreteness. Third, as per the 'twin' assumption (iii), their financial shock also affects output and inflation - through a Bernanke-Gertler financial accelerator. This creates incentives for the central bank to respond to this shock even if it does not care about financial stability per se. Fourth, the central bank's response (alone) will not fully stabilize the financial shock, because the bank factors in the deflationary effect of its leaning against the wind. Fifth, in both Carrillo et al. (2017) and our setting the direct impact of macroprudential policy is restricted to financial variables, whereas the monetary instrument's transmission is broader. We capture this by r directly affecting both L and y in (6)-(7), whereas l only influencing the former. These features encapsulate the 'intertwined cords' assumption (iv). They further imply that M&Ms are *partial (but not perfect) substitutes* in reducing cyclical swings; each still has a comparative advantage in stabilizing its 'own' shock (for more see Cecchetti and Kohler, 2014, and Leduc and Natal, 2016).[12]

Given this reduced-form 'correspondence' with Carrillo et al. (2017), it is unsurprising that their key result regarding the Tinbergen rule applies in our model too. In particular:

Remark 1. *Having both the macroprudential and monetary instruments is socially superior to only using the interest rates to stabilize financial shocks.*[13]

3.5. **Closing the Model.** The conventional approach is to use the optimal targeting rules derived from the policies' objective functions or ad-hoc instrument rules. We do not follow these approaches, because they only allow for the polar cases of a simultaneous move (the non-cooperative Nash solution) and Stackelberg leadership.[14] Instead,

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[11]Greater leverage and lower real interest rates tend to increase real output in the short term through many channels, e.g. consumption, investment, exchange rates, wealth and private expectations. The magnitude of these effects is determined by various imperfections, the economy's openness etc.

[12]The only feature of Carrillo et al. (2017) relevant for strategic interactions we do not capture is the fact that M&Ms may turn from substitutes to complements under some circumstances. But this simplification has no qualitative effect on our game-theoretic results, in fact it would strengthen our message, because in the complementarity region the policy conflict is intensified (more costly).

[13]The baseline calibration of Carrillo et al. (2017) implies the associated welfare gain to be 15 percent.

[14]Using the constraints in (6)-(8) with the preferences (2)-(3), from $\frac{\partial U^C}{\partial r} = 0$ and $\frac{\partial U^P}{\partial l} = 0$ we obtain M&Ms' reaction functions (the targeting rules):

$$r = \bar{r} + \frac{\alpha^2 \gamma \psi \left(\gamma\mu + \beta\right)}{\rho + \alpha^2 \psi \left(\gamma\mu + \beta\right)^2} \left[-\delta\left(l - \bar{l}\right) + \varepsilon\right] \quad \text{and} \quad l = \bar{l} + \frac{\lambda\delta}{\kappa + \lambda\delta^2} \left[-\mu\left(r - \bar{r}\right) + \varepsilon\right].$$

Solving them jointly yields the non-cooperative Nash solution

$$r^* = \bar{r} + \frac{\kappa\gamma\psi\alpha^2\left(\gamma\mu + \beta\right)\varepsilon}{\left(\kappa + \lambda\delta^2\right)\left[\rho + \alpha^2\psi\left(\gamma\mu + \beta\right)^2\right] - \mu\gamma\psi\lambda\alpha^2\delta^2\left(\gamma\mu + \beta\right)} \quad \text{and} \quad l^* = \bar{l} + \frac{\lambda\delta\varepsilon\left[1 - \mu\left(r^* - \bar{r}\right)\right]}{\kappa + \lambda\delta^2}.$$

we explore a more general (Stochastic) leadership concept that considers everything in between these special cases to capture strategic interactions.

4. Combinations of Shocks and Resulting Types of Policy Conflict

Table 1 summarizes nine main situations in terms of the shocks ε and ε^D. The fact that the length of financial and business cycles generally differs, see Drehmann et al. (2012), implies that the combinations tend to change quite frequently.

		Aggregate demand shock		
		Positive ($\varepsilon^D > 0$)	None ($\varepsilon^D = 0$)	Negative ($\varepsilon^D < 0$)
Credit shock	Positive ($\varepsilon > 0$)	Strategic conflict only	Strategic & tradeoffs-driven conflict (minor)	Strategic & tradeoffs-driven conflict (major)
	None ($\varepsilon = 0$)	Strategic & tradeoffs-driven conflict (minor)	No conflict	Strategic & tradeoffs-driven conflict (minor)
	Negative ($\varepsilon < 0$)	Strategic & tradeoffs-driven conflict (major)	Strategic & tradeoffs-driven conflict (minor)	Strategic conflict only

TABLE 1. Types of potential conflict between M&Ms based on conditions in the financial sector (rows) and the macroeconomy (columns).

Two main types of macroprudential-monetary conflict can arise. A tradeoffs-driven conflict relates to the normative question of which policy *should* respond to a particular shock based on society's cost/benefit considerations. In contrast, a strategic conflict relates to the positive question of which policy *will* respond to the shock based on their utility maximization and strategic considerations. Importantly:

Remark 2. *A tradeoffs-driven conflict implies a strategic policy conflict, but not vice versa. Hence inefficient outcomes may arise even if the economy poses no constraints to reaching efficient outcomes.*

Our benchmark analysis will focus on the case of an exuberant financial shock

$$(9) \qquad \qquad \varepsilon > 0 = \varepsilon^D.$$

This means that we will explore the top middle cell of Table 1.[15] Our focus on exuberant financial shocks (such as during 2003-2006 or 2011-2016 in some countries) has several implications. First, ρ can be interpreted as monetary policy's aversion to leaning against the wind. Second, under the socially optimal 'division of labour' monetary policy leaves responses to credit shocks solely to macroprudential policy, i.e. the social optimum is (N, S) rather than $\left(J^{COOP}, J^{COOP}\right)$ or $\left(J^{NASH}, J^{NASH}\right)$.[16] Third, and because of

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[15]In Section 10 and Appendix H.4 we discuss policy interactions for all other combinations of shocks.

[16]This feature that financial shocks should be treated by macroprudential rather than monetary policy is consistent with most of the literature, e.g. Alpanda and Zubairy (2017), Paul (2017), Svensson (2016b), Leduc and Natal (2016), IMF (2015), Kiley and Sim (2015) and Gali's (2014). For more see Appendix A.

that, the central bank is fully-benevolent for any $\rho \geq 0$, whereas the prudential authority (with $L^* = \bar{L}$) can be differentiated as *fully-benevolent* ($\kappa = 0$) and *partially-benevolent* ($\kappa > 0$).

It is important to note that Carrillo et al. (2017) focus on the opposite case of *adverse* financial shocks (e.g. the 2000-2002 and 2007-2009 periods). Their headline finding of 'Tight Money-Tight Credit' therefore needs to be reinterpreted under an exuberant shock as 'Loose Money-Loose Credit'.

5. The Macroprudential-Monetary Interaction as a Game

5.1. **M&Ms Actions.** For the considered credit boom $\varepsilon > 0$, we can label each policy's options intuitively as follows. *No-tightening*, N, refers to a policy not responding at all - leaving its instrument at the neutral level

$$(10) \qquad r^N = \bar{r} \quad \text{and} \quad l^N = \bar{l}.$$

The opposite extreme is *Strong-tightening*, S, whereby the policy responds assuming that the other policy does not respond at all. It is natural to define S as the optimal degree of tightening (i.e. one that maximizes the policy's utility from the primary objective) under the opponent's N. Formally, to obtain l^S we use (6) and impose $L = \bar{L}$ with $r = \bar{r}$. To get r^S we use (7) and impose $l = \bar{l}$ and $y = \bar{y}$, because the latter ensures $\pi = \bar{\pi}$ in (8). Doing so yields

$$(11) \qquad r^S = \bar{r} + \frac{\varepsilon}{\mu + \frac{\beta}{\gamma}} \quad \text{and} \quad l^S = \bar{l} + \frac{\varepsilon}{\delta}.$$

All other responses in between N and S can be grouped under *Joint-tightening, J*

$$(12) \qquad r^J \in \left(r^N, r^S\right) \quad \text{and} \quad l^J \in \left(l^N, l^S\right).$$

In this continuous action set there are our macro model's *non-cooperative Nash solution* $\left(J^{NASH}, J^{NASH}\right)$ as well as the *Cooperative solution* $\left(J^{COOP}, J^{COOP}\right)$.[17] As both are, even in our simple model, non-monotone functions of the underlying parameters, we will not use them explicitly in our game-theoretic analysis. Instead, we will below interpret $\left(J^{COOP}, J^{COOP}\right)$ more broadly as a 'compromise outcome' - the reader can think of the intuitive symmetric case of both policies' primary objectives having the same weight (as reported in Carrillo et al., 2017), or alternatively the case of both policies tightening half way between N and S.

5.2. **Macroeconomic Outcomes.** Using the definitions of $\{N, S, J\}$ in (10)-(12) together with the economy postulated in (6)-(8) yields leverage, output, and inflation for all possible combinations of M&Ms' responses to the exuberant credit shock $\varepsilon > 0$. The strategy profile (N, N) denotes the lack of response (the first action will throughout denote the row player, i.e. the central bank). It leads to a large asset bubble, an overheating of the real economy and inflationary pressures. In contrast, (S, S) represents an excessive uncoordinated tightening that leads to a credit bust, an output contraction and deflationary pressures.

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[17]For the former see footnote 14, the latter obtains when one institution conducts both M&Ms by solving jointly $\partial \left(U^C + U^P\right)/\partial r = 0$ and $\partial \left(U^C + U^P\right)/\partial l = 0$.

The regimes (N,S), (S,N) and a subset of (J,J) represent a coordinated policy response, leading to improved outcomes. Nevertheless, the latter two still feature a positive leverage gap as the credit shock is not fully stabilized.[18] The outcomes can be summarized as follows.

(13)

		P		
		S	N	J
C	S	**major bust** $L = \bar{L} - \dfrac{\varepsilon\mu}{\mu+\frac{\beta}{\gamma}}$ $y = \bar{y} - \dfrac{\varepsilon(\gamma\mu+\beta)}{\mu+\frac{\beta}{\gamma}}$ $\pi = \bar{\pi} - \dfrac{\alpha\varepsilon(\gamma\mu+\beta)}{\mu+\frac{\beta}{\gamma}}$	**small bubble** $L = \bar{L} + \varepsilon - \dfrac{\varepsilon\mu}{\mu+\frac{\beta}{\gamma}}$ $y = \bar{y}$ $\pi = \bar{\pi}$	$L \in \left(L^{SS}, L^{SN}\right)$ $y \in \left(y^{SS}, y^{SN}\right)$ $\pi \in \left(\pi^{SS}, \pi^{SN}\right)$
	N	**stability** $L = \bar{L}$ $y = \bar{y}$ $\pi = \bar{\pi}$	**large bubble** $L = \bar{L} + \varepsilon$ $y = \bar{y} + \gamma\varepsilon$ $\pi = \bar{\pi} + \alpha\gamma\varepsilon$	$L \in \left(L^{NS}, L^{NN}\right)$ $y \in \left(y^{NS}, y^{NN}\right)$ $\pi \in \left(\pi^{NS}, \pi^{NN}\right)$
	J	$L \in \left(L^{SS}, L^{NS}\right)$ $y \in \left(y^{SS}, y^{NS}\right)$ $\pi \in \left(\pi^{SS}, \pi^{NS}\right)$	$L \in \left(L^{SN}, L^{NN}\right)$ $y \in \left(y^{SN}, y^{NN}\right)$ $\pi \in \left(\pi^{SN}, \pi^{NN}\right)$	$L \in \left(L^{SS}, L^{NN}\right)$ $y \in \left(y^{SS}, y^{NN}\right)$ $\pi \in \left(\pi^{SS}, \pi^{NN}\right)$

5.3. **Policy Payoffs.** Substituting the economic outcomes in (13) into the policy objective functions in (2)-(3) yields the following payoffs of M&Ms

(14)

		P		
		S	N	J
C	S	$\overbrace{-\left\{\psi\left[\dfrac{\alpha(\gamma\mu+\beta)}{\mu+\frac{\beta}{\gamma}}\right]^2 + \rho\left(\dfrac{1}{\mu+\frac{\beta}{\gamma}}\right)^2\right\}\varepsilon^2}^{a};$ $\underbrace{-\left[\lambda\left(\dfrac{\mu}{\mu+\frac{\beta}{\gamma}}\right)^2 + \kappa\left(\dfrac{1}{\delta}\right)^2\right]\varepsilon^2}_{v}$	$\overbrace{-\rho\left(\dfrac{\varepsilon}{\mu+\frac{\beta}{\gamma}}\right)^2}^{b};$ $\underbrace{-\lambda\left[\left(1-\dfrac{\mu}{\mu+\frac{\beta}{\gamma}}\right)\varepsilon\right]^2}_{w}$	$e; m$
	N	$\overbrace{0}^{c};\overbrace{-\kappa\left(\dfrac{\varepsilon}{\delta}\right)^2}^{x}$	$\overbrace{-\psi(\alpha\gamma\varepsilon)^2}^{d};\overbrace{-\lambda\varepsilon^2}^{z}$	$f; n$
	J	$g; o$	$h; s$	$k; u$

The newly introduced parameters $\{a, ..., z\}$ in (14) denote the general payoffs that will be used below to streamline the notation, and then linked back to the underlying parameters. There is no benefit in attempting to calibrate our simple macro model; its

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[18]Intuitively, if the central bank plays S or J it knows that raising interest rates to lean against the wind lowers y below $\bar{y}$ and π below $\bar{\pi}$. In pursuing price stability the bank finds it optimal to offset this contractionary effect by aiming for an appropriate positive level of the leverage gap, which is expansionary. Section 12 discusses how our short-term analysis can be related to a long-term perspective, in which there are second round effects due to L and y correcting towards their natural levels.

aim is to provide some intuition for our qualitative strategic insights. For quantitative insights regarding the macroeconomic side we throughout turn to Carrillo et al. (2017). For further illustration, we will accompany the general payoffs with specific payoffs obtained by setting all parameters (except the secondary objectives' weights ρ and κ) to unity:

$$(15a) \qquad \alpha = \beta = \gamma = \delta = \varepsilon = \lambda = \mu = \psi = 1,$$

$$(15b) \qquad \rho = \kappa = \frac{1}{2}.$$

5.4. **Social Welfare.** To obtain society's payoffs in the various policy mixes following exuberant credit shocks, substitute the economic outcomes in (13) into (1). Using the specific payoffs in (15) yields the following social welfare:[19]

(16)

		P			
		S	N	J^{COOP}	J
C	S	major bust -10 *(second-worst)*	small bubble -2 *(third-best)*	minor bust -6 *(fifth-best)*	$(-10, -2)$
	N	**stability** **0** *(first-best)*	large bubble -16 *(worst)*	medium bubble -8 *(sixth-best)*	$(-16, 0)$
	J^{COOP}	minor bust -5 *(fourth-best)*	medium bubble -9 *(seventh-best)*	near stability -1 *(second-best)*	$(-9, -5)$
	J	$(-10, 0)$	$(-16, -2)$	$(-8, -6)$	$(-16, 0)$

It is clear that, for all parameter values, (N, S) delivers the social *first-best* and (N, N) delivers the *worst* outcome. The joint options (J, J) can replicate the full range of outcomes and social welfare values in between these, which is why the other regimes cannot be uniquely ranked. Nevertheless, if we focus on the compromise cooperative option, then under reasonable parameters of most models, including ours, $\left(J^{COOP}, J^{COOP}\right)$ yields the *second-best*, (S, N) yields the *third-best* and (S, S) yields the *second-worst* outcome for society. The combinations of J^{COOP} with N or S yield the fourth-best through to the seventh-best, and the same generally applies to the mixed-strategy Nash equilibrium as well as the macro model's $\left(J^{NASH}, J^{NASH}\right)$ outcome. To document, in Carrillo et al. (2017) the social loss is seven times higher under the non-cooperative Nash solution than under the Cooperative solution.

6. Possible Scenarios Under Benevolent M&Ms

Even our simplified macroeconomy can yield a variety of scenarios (classes of games). Socially undesirable outcomes may obtain in equilibrium in all but one of them.

Proposition 1. *Consider the macroprudential-monetary interaction following an exuberant credit shock $\varepsilon > 0$ as summarized in (13)-(14). In the 2×2 game featuring $\{N, S\}$ five fundamental scenarios can occur in the simultaneous game - depending on the underlying parameters. The social optimum (N, S) occurs with:*

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[19]The J row and column report the full continuous range in (12), the J^{COOP} option has been postulated intuitively as yielding social welfare exactly in between that achieved by S and N. All payoffs in (16) have been multiplied by 8 for clarity, and the same normalization applies to (17) and Figure 1.

*(i) certainty in the **Monetary Dominance** scenario;*
*(ii) some probability ('high' and 'low' respectively) in the **Symbiosis** and **Game of Chicken** scenarios;*
*(iii) zero probability in the **Policy Deadlock** and **Macroprudential Dominance** scenarios.*

*The scenarios of the 3×3 and larger versions of the policy game are mere variations of the 2×2 scenarios, such that the J option(s) may appear in equilibrium with N and/or S. The only distinct case is the **Focal Compromise Game of Chicken** scenario, in which $\left(J^{COOP}, J^{COOP}\right)$ is the Nash equilibrium selected by the focal point argument.*

The proof deriving the thresholds between the scenarios in the 2×2 game is provided in Appendix C, except for the Game of Chicken, which is included in the main text. Before doing so it is worthwhile to summarize Proposition 1 in two intuitive ways, using the specific parameters in (15a) while varying the secondary aversions ρ and κ. In (17) the scenarios' payoff matrices are presented (with the Nash equilibria highlighted in bold), whereas Figure 1 offers their graphical depiction in the $\rho \times \kappa$ space.
(17)

		P	
		S	N
C	S	$-18; -6$	$-10; -2$
	N	stability **0**; -4	$-8; -8$

Monetary Dominance
(for $\rho = 5, \kappa = \frac{1}{2}$)

		P	
		S	N
C	S	$-18; -18$	$-10; -2$
	N	$0; -16$	large bubble $-\mathbf{8}; -\mathbf{8}$

Policy Deadlock
(for $\rho = 5, \kappa = 2$)

		P	
		S	N
C	S	$-9; -3$	small bubble $-\mathbf{1}; -\mathbf{2}$
	N	stability **0**; $-\mathbf{1}$	$-8; -8$

Symbiosis
(for $\rho = \frac{1}{2}, \kappa = \frac{1}{8}$)

		P	
		S	N
C	S	$-9; -6$	small bubble $-\mathbf{1}; -\mathbf{2}$
	N	stability **0**; -4	$-8; -8$

Game of Chicken
(for $\rho = \frac{1}{2} = \kappa$)

		P	
		S	N
C	S	$-9; -18$	small bubble $-\mathbf{1}; -\mathbf{2}$
	N	$0; -16$	$-8; -8$

Macroprudential Dominance
(for $\rho = \frac{1}{2}, \kappa = 2$)

Symbiosis is the only scenario in which a strategic conflict does not occur. Both M&Ms prefer the same outcome, the social optimum (N, S), because P's aversion to instrument variability is sufficiently low. This scenario only features a coordination problem between the policies, but it can be alleviated using Schelling's (1960) focal point argument.[20]

All other scenarios in (17) feature a strategic conflict because each policy prefers a different regime - each would like the other policy to stabilize the shock. Resolution of such conflict depends on the values of ρ and κ as well as on other parameters. Under Monetary Dominance, the central bank has the upper hand strategically. Due to high ρ, N is strictly dominant over S for monetary policy, and hence the prudential authority is induced to deal with the credit boom. This uniquely leads to the social optimum, and unpleasant monetarist arithmetic is surely avoided. Under Macroprudential Dominance, the opposite is true (due to high κ), and the central bank is induced to lean against

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[20]This is true for the Pure Coordination game in (17), but somewhat less so for the Stag Hunt game that can also arise under the Symbiosis scenario. The reason is that its Pareto-inferior Nash equilibrium is risk-dominant.
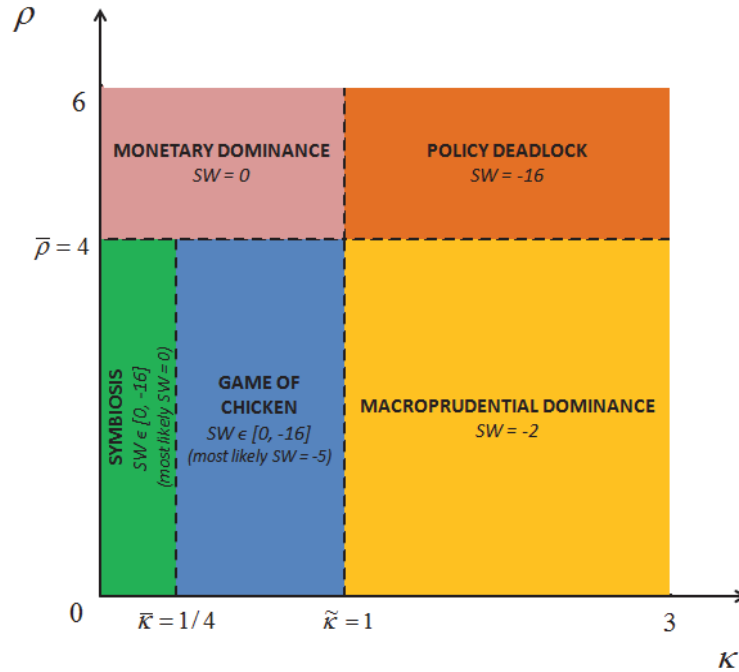
FIGURE 1. Scenarios of the 2×2 interaction between M&Ms - as functions of the secondary objectives' weights (relative to primary). Social welfare (SW) and all thresholds are reported for the parameters in (15a).

the wind. In the Policy Deadlock scenario neither policy can outmaneuver the other - due to high ρ and κ action N is strictly dominant over S for both policymakers. Hence financial market exuberance is not dealt with, which leads to a large asset bubble that spills over to the real economy and causes macroeconomic imbalances.[21]

All of the above outcomes can obtain - in equilibrium - in the Game of Chicken. This scenario is analogous to the Hawk and Dove game, as well as to the Battle of the Sexes in which the actions are re-labeled. It occurs if the weight on the secondary objective is sufficiently small for C, but in an intermediate interval for P. Using the payoffs in (14) the Game of Chicken applies iff

$$(18) \qquad c > b > \max\{a, d\} \quad \text{and} \quad w > x > \max\{v, z\}.$$

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[21] A different version of the Policy Deadlock scenario that could in principle arise in some models of M&Ms is a Prisoner's Dilemma. In such case (N, N) is the unique Nash equilibrium, but it is Pareto-inferior to the (S, S) outcome. It cannot occur in our game, because for both players N is the unique best response to S. A Matching Pennies scenario, in which the inferior mixed-strategy Nash equilibrium is the unique equilibrium, cannot occur in our setting for the same reason.

Using the macro model's (general and specific) parameters, these can be re-written as[22]

$$(19) \quad \rho < \bar{\rho} = \psi \alpha^2 \left(\gamma \mu + \beta \right)^2 \stackrel{(15a)}{=} 4 \;\; \text{and} \;\; \kappa \in (\bar{\kappa}, \tilde{\kappa}) = \left(\frac{\lambda \left(\delta \beta \right)^2}{\left(\beta + \gamma \mu \right)^2}, \lambda \delta^2 \right) \stackrel{(15a)}{=} \left(\frac{1}{4}, 1 \right).$$

The Game of Chicken has two pure-strategy Nash equilibria, (S, N) and (N, S), but because each player prefers a different one standard game-theoretic methods are unable to select between them in a one-shot game (for use of uncorrelated asymmetries in an evolutionary setting see Smith, 1982). Therefore the mixed-strategy Nash equilibrium, in which the policies randomize between S and N, is a likely outcome. The problem is that such uncoordinated Regime Switching is Pareto-inferior.[23]

In the extended games containing some J option(s) the five scenarios of the 2×2 game still occur, but each has additional variations. For example, in the 3×3 game with the compromise option J^{COOP} there are two additional versions of the Symbiosis scenario; one featuring three pure-strategy Nash equilibria, (N, S), $\left(J^{COOP}, J^{COOP} \right)$ and (S, N), and the other only featuring the former two. In both cases the focal point argument selects the social optimum (N, S) as it is Pareto-dominant. Other examples of the variations are Partial Macroprudential Dominance, in which $\left(J^{COOP}, N \right)$ is the unique Nash equilibrium, and Partial Monetary Dominance, in which $\left(N, J^{COOP} \right)$ is the unique Nash equilibrium. The only somewhat different scenario that emerges in the 3×3 game can be called Focal Compromise Game of Chicken. It features multiple (pure- and mixed-strategy) equilibria, but the focal argument selects the compromise $\left(J^{COOP}, J^{COOP} \right)$ outcome due to its symmetry.

It is apparent that while the 4×4 and larger versions of the policy game can feature additional Nash equilibria (with different J levels including J^{NASH}), the intuition is unchanged as no fundamentally different scenario arises. In the rest of the paper we will focus on the Game of Chicken scenario (both with and without J^{COOP}) for three main reasons. First, it is the most interesting case from the game-theoretic perspective due to equilibrium multiplicity and selection problems. Second, it applies for a large range of ρ and κ. Third, the Game of Chicken is general in the sense that *in equilibrium* it can produce the equilibrium outcomes of all the other scenarios, and it can thus provide insights relevant for all of them.

7. GAME-THEORETIC FRAMEWORK OF STOCHASTIC LEADERSHIP

7.1. **Stackelberg Leadership.** The conflict and coordination problems inherent in the Game of Chicken can be eliminated by applying Stackelberg leadership (for its use in

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[22]The right-hand-side of the $\stackrel{(15a)}{=}$ notation reports values for the specific payoffs postulated in (15a).

[23]To demonstrate, under the Game of Chicken payoffs in (17) the mixed-strategy Nash equilibrium consists of C playing both S and N with probability 0.5, whereas P playing them with probabilities 0.4375 and 0.5625. That means that the two worst social outcomes occur with roughly 50% probability - Policy Deadlock (N, N) with 28% and a major bust (S, S) with 22% probability. The expected payoffs of the mixed equilibrium for C, P and society are -4.5, -5 and -5 respectively, which is less than in both pure-strategy Nash equilibria. While the experimental evidence on mixed-strategy Nash equilibria is inconclusive, there are findings suggesting that this sort of behaviour is used in some contexts, see e.g. Chiappori et al. (2002). In regards to policy evidence, the estimates of Davig and Leeper (2010) identify over a dozen switches in the U.S. monetary-fiscal regime since 1950.

the M&Ms game see Dennis and Ilbas, 2016 and De Paoli and Paustian, 2013, in the fiscal-monetary game Foresti, 2017, Dixit and Lambertini, 2003, or Sargent and Wallace, 1981). It consists of a change in the information/timing whereby one player becomes the Stackelberg leader and moves first. Solving by backwards induction, upon observing the leader's action the Stackelberg follower plays its static best response, which allows the leader to induce the follower to cooperate.

Four simplifying features of the Stackelberg framework are apparent: (a) the leader's initial move can be observed prior to the follower's revision, (b) the follower's 'revision' takes place immediately after the leader's initial move, (c) it occurs with certainty, and (d) the leader has zero probability of revision. This means that there is never any conflict or mis-coordination *by assumption* - there is no cost to the leader of inducing the follower to cooperate in the Game of Chicken. In other words, Stackelberg leadership is too static to fully capture strategic interactions.

7.2. **Stochastic Leadership: Timing and Real-World Policy Interpretation.** For comparability with Stackelberg leadership we keep assumptions (a)-(b) and only relax assumptions (c)-(d). And we do so in a way familiar to macroeconomists - using the Calvo (1983) probabilistic revision opportunities. The game starts at time $t = 0$ with M&Ms making the standard simultaneous move. Upon *observing* the initial action of the opponent, each institution j can make an immediate revision at $t = 0$, but only with (exogenous and known) probability q^j. The revisions are simultaneous so the policymakers can observe neither the revision of the opponent, nor the move of nature determining whether the opponent actually got a revision opportunity. The (stage) game finishes at time $t = 1$ - see Figure 2 for a graphical depiction in which the initial and revision moves are denoted by subscripts 1 and 2 respectively.[24]
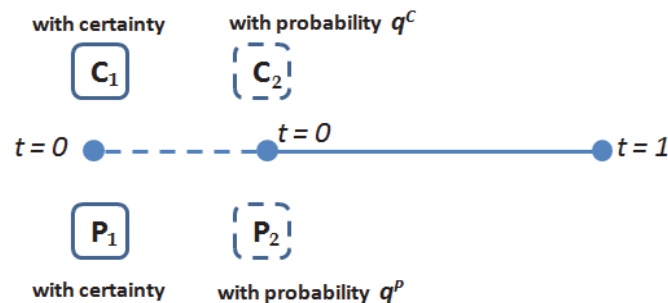

FIGURE 2. The timing of moves featuring (immediate and simultaneous) stochastic revisions with probabilities q^C and q^P.

There are a number of real-world institutional and logistic features that the revision probability q can capture. It expresses a policymaker's ability to change its mind, i.e. to alter its previous policy stance at will. This ability (and hence q) is decreased by,

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[24]Since (infinite) repetition of the stage game has the standard effects of facilitating coordination, see Mailath and Samuelson (2006) or Barro and Gordon (1983), we do not examine it here.

for example: (i) a lower frequency of policy meetings, (ii) longer recognition and implementation lags, (iii) more complex decision making, (iv) more costly implementation processes, (v) less independence from external idiosyncratic pressures, and (vi) a higher level of pre-commitment to past decisions. All these characteristics put a policy into a Stochastic leadership position, reducing its chances of a revision. All features (i)-(vi) suggest that:

Claim 1. *In the real world the macroprudential authority is the likely Stochastic leader in the strategic game against the monetary authority, $q^P < q^C$.*

Intuitively, while monetary policy decisions occur 8-12 times a year at the regular meeting of the central bank board/committee, macroprudential decisions are considered at most once or twice a year due to their complicated implementation process and adjustment costs. This is one of the reasons for P being more rigid than C.

8. Implicit Coordination of M&Ms

In order to develop the intuition of Stochastic leadership, we will first examine the standard 2×2 Game of Chicken, and then consider larger versions of the policy game.[25]

8.1. 2×2 **Game of Chicken.** We can now formulate a result regarding implicit coordination between M&Ms.

Proposition 2. *Consider the Game of Chicken in (14) and (18) between the macroprudential and monetary authorities under Stochastic leadership and an exuberant credit shock. Costly Regime Switching and Policy Deadlock will surely be avoided if and only if the probability of revisions is **below** a certain threshold for one (dominating) policy, and **above** a certain threshold for the other policy.*

Proof. The proof consists of deriving the necessary and sufficient conditions for the three equilibrium regions within the Game of Chicken scenario (depicted graphically in Figure 3). It is Monetary Dominance, Macroprudential Dominance, and Multiplicity; and only in the latter region Regime Switching (with Policy Deadlock within it) can occur.

Due to Claim 1 we will start with the case in which the prudential authority dominates ('surely wins') the game, i.e. its preferred outcome $\left(C_1^S C_2^S, P_1^N P_2^N\right)$ is the unique subgame perfect equilibrium. In order to eliminate the central bank's preferred outcome $\left(C_1^N C_2^N, P_1^S P_2^S\right)$ and the mixed-strategy equilibrium from the set of subgame perfect equilibria, it is required that P finds it uniquely optimal to open with N and not revise, regardless of C's initial action. In other words, $P_1^N P_2^N$ is P's strictly dominant strategy.

Three types of conditions need to be satisfied for such Macroprudential Dominance to occur. We will only provide their intuition here and relegate the details to Appendix D. Solving backwards, the first is a 'yielding condition'. It guarantees that C, the opponent of the dominating player, plays in its revision the static best response to P's

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[25]Our truncation of the continuous action space to a 2×2 game is analogous to allowing monetary and fiscal policies in Leeper's (1991) framework to choose between some (representative) level of the 'active' and 'passive' stance. In both frameworks four possible regimes, as well as switching between them, can occur. In fact, even the Game of Chicken applies in Leeper's model (as well as in Sargent and Wallace's, 1981). This is because the central bank and government prefer a different policy regime, but both institutions would like to avoid mis-coordination/conflict and explosively growing imbalances.
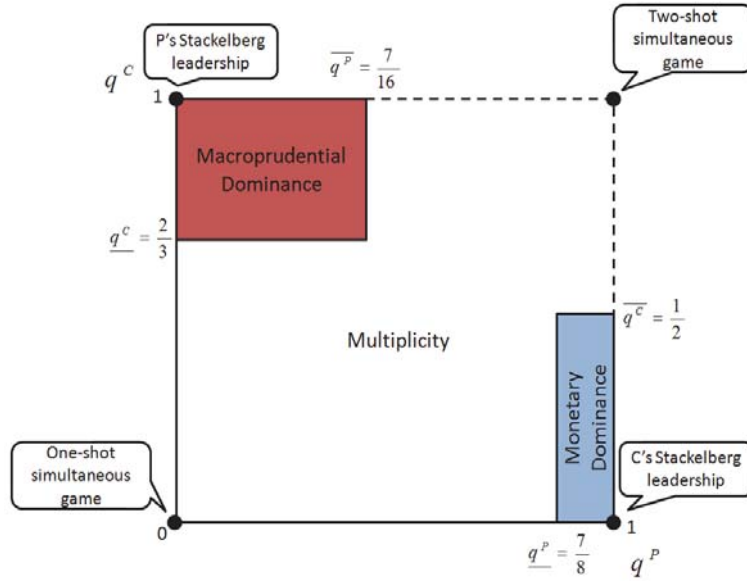
FIGURE 3. Equilibrium regions in the 2×2 Game of Chicken with revisionprobabilities q^P and q^C; for the specific parameters in (15).

initial action, not to P's anticipated revision. This ensures that if the central bank observes the prudential authority ignoring the shock initially (playing P_1^N), the bank will surely, albeit grudgingly, step in and lean against the wind (play C_2^S) if given a revision opportunity. Naturally, the central bank will become the chicken in its revision if the prudential authority is very rigid (pre-committed), i.e. it has a sufficiently low probability of being able to revise. Appendix D shows that occurs iff

$$(20) \qquad q^P < \overline{q^P} = \frac{\overbrace{b-d}^{\text{C's yielding gain (avoiding deadlock)}}}{\underbrace{c-a}_{\text{C's yielding loss (missing out on preferred outcome)}}+b-d} \overset{(15)}{=} \frac{7}{16}.$$

Assuming the yielding condition holds, a 'sticking condition' is then required. It guarantees that if the prudential authority starts with P_1^N, it will find it optimal to keep ignoring the credit boom in its revision (play P_2^N); even if it observes the central bank had also ignored the shock initially (played C_1^N). The prudential authority will surely do so if and only if monetary policy is sufficiently flexible, i.e. the central bank is likely to start dealing with the credit exuberance in its revision (play C_2^S).

Assuming the sticking condition is satisfied and moving backwards, the final requirement is a 'victory condition'. It ensures that the prudential authority finds it optimal to ignore the credit boom already in its initial move (play P_1^N) - even in the worst case scenario of knowing with certainty that the central bank will do the same (play C_1^N). The intuition is analogous to the sticking condition; for P the threat of a Policy Deadlock has to be outweighed by the likelihood of C stepping in and leaning against the wind in

its revision (switching from C_1^N to C_2^S). Intuitively, P's expected cost of conflict must be sufficiently low relative to its expected gain from 'victory'. The relevant threshold derived in Appendix D is

$$(21) \qquad q^C > \underline{q}^C = \frac{\overbrace{x-z}^{P\text{'s yielding gain}}}{\underbrace{w-z}_{P\text{'s victory gain}}} \overset{(15)}{=} \frac{2}{3}.$$

This victory condition is stronger than the sticking condition for all general Game of Chicken parameter values in (18). In summary, if (20) and (21) hold then ignoring the exuberant credit shock $(P_1^N P_2^N)$ strictly dominates all other strategies for the prudential authority. Knowing this, the central bank - reluctantly but surely - leans against the wind from the start and never revises. Put differently, it becomes the chicken already in its initial move (plays $C_1^S C_2^S$). Hence we have a Macroprudential Dominance regime where P's preferred outcome $\left(C_1^S C_2^S, P_1^N P_2^N\right)$, the third-best from society's point of view, is the unique subgame perfect equilibrium.

The conditions for the opposite Monetary Dominance, in which the central bank surely wins and P becomes the chicken, can be derived by symmetry. The relevant parameter values ensuring society's first-best $\left(C_1^N C_2^N, P_1^S P_2^S\right)$ as the unique subgame perfect equilibrium are

$$(22) \qquad q^C < \overline{q}^C = \frac{x-z}{w-v+x-z} \overset{(15)}{=} \frac{1}{2} \quad \text{and} \quad q^P > \underline{q}^P = \frac{b-d}{c-d} \overset{(15)}{=} \frac{7}{8}.$$

As (20)-(22) show, both Macroprudential Dominance and Monetary Dominance require one policy's q to be sufficiently low and the other's q sufficiently high, relative to other parameters. The proof also implies that while in neither of these Dominance regions Regime Switching and Policy Deadlock can arise, such undesirable outcomes can occur within the whole Multiplicity region.[26] $\qquad\qquad\square$

From a social welfare perspective, for exuberant credit shocks Monetary Dominance is preferred, but the other two regions cannot be uniquely ranked. Macroprudential Dominance is socially superior to the Multiplicity region based on the Maximin criterion as policy conflict and mis-coordination are surely avoided, but it is socially inferior based on the Maximax criterion since the first-best can never occur. It is worth highlighting that both the Multiplicity and Macroprudential Dominance regions imply an unpleasant monetarist arithmetic. This is because monetary policy is (with some probability and certainty respectively) induced to deal with developments that are outside

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[26]The whole Multiplicity region contains all three types of equilibria, two in pure-strategies and one in mixed-strategies. There arguably exist sub-regions in which the likelihood of the three equilibria may differ somewhat in a real-world/experimental setting, but standard game-theoretic techniques do not provide clear conclusions in this respect in a one-shot game. It can be argued that Regime Switching and Policy Deadlock are most likely in the fully symmetric case with $q^C = q^P$ and identical payoffs across the policymakers. It is further possible that in an experimental setting the chances of avoiding these undesirable outcomes would improve as policy heterogeneity in the revision probabilities increases, i.e. as the game moves closer towards one of the Dominance regions. In such case the leadership (asymmetry) argument may start to outweigh the focal point (symmetry) argument.

its scope; even if a better-suited instrument is available. Such deviation from the Tinbergen rule jeopardizes, sooner or later, monetary policy's primary objective of price stability. The following result provides further details, and shows that Stochastic leadership may augment the intuition of Stackelberg leadership in ways that have important policy implications.

Proposition 3. *The macroprudential or monetary policymaker may* **dominate** *the Game of Chicken even from the position of* **the Stochastic follower***.*

Proof. The equilibrium conditions in (20)-(22) show that the probability thresholds are functions of the various costs of policy conflict and mis-coordination as well as the coordination and victory gains. To prove the claim it suffices to provide an example of parameter values under which a dominance region crosses the 45 degree line (the full range of circumstances will be implied in Section 9). One example is offered in Figure 4. It uses the same specific parameters as Figure 3, just the central bank's aversion to leaning against the wind is increased. Such change shrinks the Macroprudential Dominance region and enlarges the Monetary Dominance region, so the latter can obtain even for values $q^C > q^P$. ☐
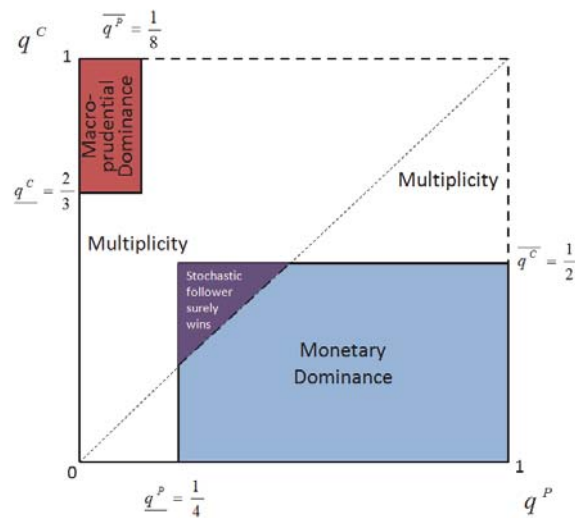

FIGURE 4. Equilibrium regions in the 2×2 Game of Chicken under stochastic revisions q^C and q^P for the specific parameters in (15); except for ρ, which is changed from 0.5 to 3. P's and C's Stochastic leadership occur in the large triangles above/below the 45 degree line, hence the Stochastic follower C dominates in the top left triangle of the Monetary Dominance region.

8.2. **Contrasting Stochastic and Stackelberg Leadership.** Both Stackelberg and Stochastic leadership are an advantage in the Game of Chicken as they help to put pressure on the follower to coordinate on the leader's preferred outcome. However, under

Stackelberg leadership this pressure is sufficient - there is never any conflict in equilibrium due to an unrealistic combination of assumptions (a)-(d) spelled out in Section 7.1.

Our analysis of Stochastic leadership implies that relaxing just one of these four assumptions introduces a possibility of a strategic conflict in equilibrium. It is unsurprising that Stochastic leadership is no longer sufficient for the leader to 'surely win' (dominate) the Game of Chicken, unlike Stackelberg leadership. However, what may seem surprising is that the Stochastic leader will 'surely lose' the Game of Chicken under some circumstances (i.e. the Stochastic follower dominates). Hence Stochastic leadership is neither necessary nor sufficient for a player's dominance. This is in stark contrast to Stackelberg leadership, which is both necessary and sufficient. The reason is that under Stochastic leadership the exact payoffs capturing the various costs/benefits of conflict and coordination determine the set of equilibria, unlike under Stackelberg leadership. So a sufficient asymmetry in the payoffs can offset the effect of the players' leadership.

8.3. 3×3 **Game of Chicken Featuring a Compromise Option.**

It is important to address the potential concern that truncating the continuous action space of the macro model to a 2×2 game without the joint options may overstate the threat of a strategic conflict. This section (together with the next) shows that it is not necessarily the case, in fact the opposite is more likely. In our 3×3 game J^{COOP} can be interpreted as a compromise; the most coordination-prone joint option. The game can be summarized by the following general constraints on the payoffs in (14)

$$(23) \quad c > k > b > f > h = g > e > d > a \quad \text{and} \quad w > u > x > s > n = m > o > z > v.$$

For illustration, we will accompany them by the following specific (symmetric) payoffs:

		P		
		S	N	J^{COOP}
(24)	S	major bust $a = 0, v = 0$	**small bubble** $\mathbf{b = 6, w = 10}$	minor bust $e = 2, m = 3$
C	N	**stability** $\mathbf{c = 10, x = 6}$	large bubble $d = 1, z = 1$	medium bubble $f = 4, n = 3$
	J^{COOP}	minor bust $g = 3, o = 2$	medium bubble $h = 3, s = 4$	**near stability** $\mathbf{k = 8, u = 8}$

There are three pure-strategy Nash equilibria: $(S, N), (N, S)$ and $\left(J^{COOP}, J^{COOP}\right)$. In the standard simultaneous move game, the focal point argument can be used to favour the compromise outcome - due to its symmetry.[27] Under Stochastic leadership, however, one cannot rely on this focal argument as revisions inject asymmetry in the game.

To see this, note that the types of equilibrium regions in the 3×3 Game of Chicken are the same as in the 2×2 version, namely Macroprudential Dominance, Monetary Dominance and Multiplicity. In fact, our Proposition 2 about unique equilibrium selection was postulated to hold in the 3×3 (and larger) Games of Chicken without any alterations. Nevertheless, there are three features of the 3×3 game worth noting that have implications for implicit policy coordination. Two (weaker ones) suggest that the

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[27]Let us note that the 3×3 game in (24) also features four mixed-strategy Nash equilibria, in which both players randomize between two or three options. Nevertheless, their expected payoffs (between 3.8 and 6.2) are lower than those of $\left(J^{COOP}, J^{COOP}\right)$ for both players, so they are less likely.

introduction of the compromise option J^{COOP} may help M&Ms to coordinate, whereas the third (and strongest) implies the opposite.

First, within the Multiplicity region there is a *Focal Compromise* sub-region along the 45 degree line, in which the focal point argument favours (J^{COOP}, J^{COOP}) due to its symmetry. Second, also within the Multiplicity region there are up to two *Compromise Semi-Dominance* sub-regions that wrap around the Macroprudential and Monetary Dominance regions. The label Semi-Dominance expresses that playing J^{COOP} in both the opening move and revision is strictly dominant over the S action - for the player whose Dominance region is wrapped around.[28] Essentially, the Compromise Semi-Dominance sub-regions of the 3×3 game are, from the perspective of equilibrium outcomes, analogous to the whole Multiplicity region of the 2×2 Game of Chicken.

The existence of the Focal Compromise and Compromise Semi-Dominance sub-regions however does *not* guarantee an improvement in M&Ms' coordination upon the introduction of J^{COOP}; for several reasons. One is that the Focal Compromise sub-region applies with full force only for the special fully symmetric case, in which the revision probabilities are equal $(q^C = q^P)$ and also the payoffs are the same across the players. Another reason is that under a wide range of circumstances the Compromise Semi-Dominance sub-regions do not occur at all.[29] And even if they do exist, the fact that each player prefers a different equilibrium in the Compromise Semi-Dominance sub-regions implies that the mixed-strategy equilibrium (Regime Switching) is the likely outcome.[30]

The third new feature of the 3×3 game, and the most important reason for the potential failure of the compromise option J^{COOP} to improve M&Ms' implicit coordination, is that the Macroprudential and Monetary Dominance regions may get smaller in the 3×3 game compared to the 2×2 game. This implies the following.

Proposition 4. *A mere existence of a macroprudential-monetary policy* **compromise may compromise implicit coordination** *achieved through heterogeneity in the policies' leadership. Introduction of J^{COOP} and/or J^{NASH} may therefore increase the likelihood of Regime Switching and Policy Deadlock, and worsen rather than improve macroprudential and monetary outcomes compared to the 2×2 game.*

Proof. The proof is analogous to the 2×2 Game of Chicken; the same three types of (yielding, sticking and victory) conditions need to be satisfied for each Dominance region. The main difference is that in the 3×3 game there may be up to four inequalities rather than one for each condition, because there are two actions to start with and switch into.

We will only provide the intuition in the main text, and offer the derivation of the three types of conditions in Appendix E. They are captured in Figure 5, in which the 2×2 and 3×3 games' thresholds are denoted by subscripts 2 and 3 respectively, and

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[28]This is commonly the Stochastic leader, but recall from Proposition 3 that it can be the Stochastic follower under some circumstances. Naturally, choosing J^{COOP} in the initial move cannot be dominant over the N action, so a full-fledged Compromise Dominance region featuring $\left(C_1^J C_2^J, P_1^J P_2^J\right)$ as the unique subgame perfect equilibrium does not exist.

[29]To offer one such example, there are no Compromise Semi-Dominance regions if c and w in (24) both change from 10 to 9 and i and u both change from 8 to 7.

[30]In this equilibrium the semi-dominant player randomizes between N and J^{COOP}, whereas the opponent randomizes between S and J^{COOP}.

the yielding and victory thresholds of the Compromise Semi-Dominance sub-regions are denoted by $\widehat{q_3}$ and $\widetilde{q_3}$ respectively.
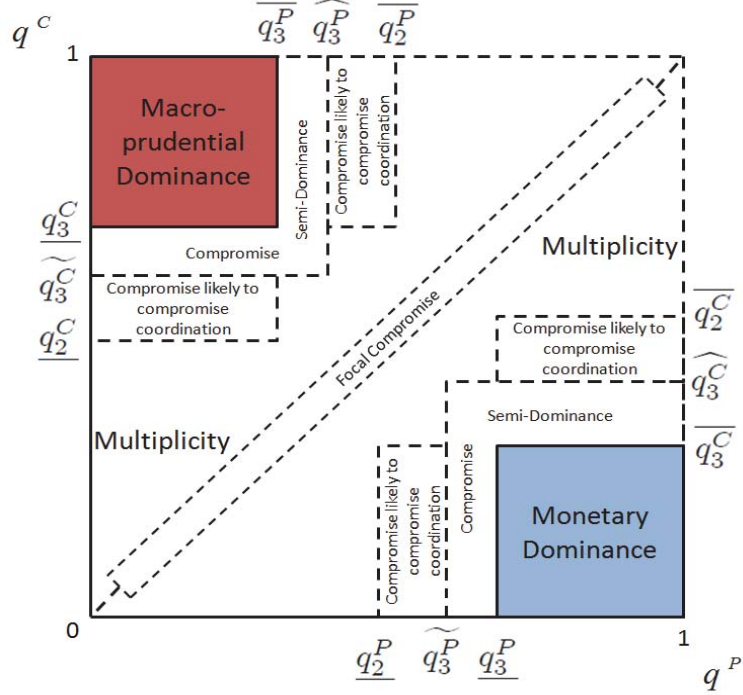

FIGURE 5. Equilibrium regions in the 3×3 Game of Chicken under Stochastic leadership.

Appendix E shows that the reduction in the size of the players' Dominance regions occurs for most parameter values; for a small range their size is unchanged, but J^{COOP} (or any other J) never enlarges these regions. In terms of the Macroprudential Dominance region, its size is not reduced in the 3×3 game if and only if two conditions are jointly satisfied: $\frac{b-d}{b-d+c-a} \leq \frac{b-h}{b-h+k-e}$ (ensuring $\overline{q_2^P} = \overline{q_3^P}$) and $\frac{x-z}{w-z} \geq \frac{u-s}{w-s}$ (ensuring $\underline{q_2^C} = \underline{q_3^C}$). By symmetry, the Monetary Dominance region does not shrink iff $\frac{x-z}{x-z+w-v} \leq \frac{x-n}{x-n+u-o}$ (ensuring $\overline{q_2^C} = \overline{q_3^C}$) and $\frac{b-d}{c-d} \geq \frac{k-f}{c-f}$ (ensuring $\underline{q_2^P} = \underline{q_3^P}$). If any one of these for inequalities does not hold then the Multiplicity region is enlarged, so unique policy coordination of the 2×2 game is threatened in the 3×3 game.

Under some of these values M&Ms are *inside* the new Compromise-Semi Dominance sub-region, so deterioration of policy outcomes is less likely and less severe. But under some parameters M&Ms end up *outside* this sub-region, which means that the introduction of J^{COOP} may move the game from an efficient outcome (N, S) or (S, N) to the players' worst outcome (N, N). Appendix E implies that this may in principle occur under four different sets of parameter values, indicated in Figure 5 as 'Compromise likely to compromise coordination'. For example, in the neighbourhood of Macroprudential

Dominance such case occurs if either $\underline{q_2^C} < \min\left\{\underline{q_2^C}, \widetilde{q_3^C}\right\}$, namely

$$(25) \qquad \frac{b-d}{b-d+c-a} > \max\left\{\frac{b-h}{b-h+k-e}, \frac{k-e}{k-e+b-h}, \frac{k-f}{k-f+c-g}\right\},$$

and/or if $\overline{q_2^P} > \max\left\{\overline{q_3^P}, \widehat{q_3^P}\right\}$, that is if

$$(26) \qquad \frac{x-z}{w-z} < \min\left\{\frac{u-s}{w-s}, \frac{x-n}{u-n}\right\}.$$

$\square$

How can a compromise option be counter-productive, and jeopardize the players' coordination? Intuitively, the Stochastic leader's second best option in the 3×3 game (coordinating with the opponent on jointly playing J^{COOP}) is relatively more attractive than in the 2×2 game (being induced to play S). As such, the Stochastic leader faces a *higher opportunity cost* of attempting to enforce its preferred outcome through a threat of a deadlock. To compensate for this, the Stochastic follower's revision probability has to be sufficiently higher in the 3×3 game. If not, existence of the J^{COOP} option may lead to Pareto-inferior outcomes such as Regime Switching and Policy Deadlock.

From the game-theoretic perspective, it happens because *the focal point argument and the leadership argument clash.* The former - favouring the compromise outcome - is based on the policymakers' symmetry, whereas the latter - favouring the Stochastic leader's preferred outcome - is based on their asymmetry. In conventional macro analyses this clash is assumed away by using *either* the simultaneous move *or* Stackelberg leadership. Our analysis shows that the wide range of possibilities in between these two polar cases needs to be considered also.

8.4. **Extended Versions of the Policy Game.** Adding more policy options to M&Ms could in principle change the policy scenario, as well as outcomes within a certain scenario. To capture the gist of all the scenarios, let us extend the 3×3 Focal Compromise Game of Chicken in (24) into its 4×4 version by adding some J' for each policy. If J' is far from the policies' reaction functions than (J', J') does not constitute a Nash equilibrium, and such extension has no effect on equilibrium outcomes. In the opposite case it may become a Nash equilibrium. In a game with symmetric revision probabilities such additional Nash equilibrium - featuring for example payoffs $(9, 7)$ in (24) - would not be selected since the focal point argument would favour the symmetric $\left(J^{COOP}, J^{COOP}\right)$ outcome yielding payoffs $(8, 8)$. If, however, the policies' degrees of leadership differ, the likelihood of (J', J') may increase. Further, Compromise Semi-Dominance sub-region(s) of (J', J') may arise; placed in between the Compromise Semi-Dominance sub-region of $\left(J^{COOP}, J^{COOP}\right)$ and the relevant Dominance region.

It is important to note that existence of a larger number of Nash equilibria generally makes implicit coordination between separated M&Ms more challenging, and socially optimal outcomes less likely. This is also because, in line with Proposition 4, the Macro-prudential Dominance and Monetary Dominance regions may again be reduced in size. The same intuition applies to further extensions of the game through additional discrete policy options between N and S, because they would tend to increase the number of

Nash equilibria in the game. This is the case even if we allow for (some parts of) the J action space to be continuous, i.e. even in an $n \times n$ game, where $n \in \mathbb{R}$.

Only if we move to a fully continuous and unbounded action space the nature of the underlying game changes. There is a unique Nash equilibrium $\left(J^{NASH}, J^{NASH}\right)$, which is the non-cooperative Nash solution used in conventional analyses. It however suffers from some problems that make it unsuitable for examination of the separation setup of M&Ms - in addition to its potentially large welfare losses (see Carrillo et al., 2017). First, it disregards real-world constraints and bounds that generate some discreteness in the policymakers' action space. Second, it does not explain how two autonomous institutions would reach this (time-varying) Nash solution without explicit coordination. Third, it only applies under the simultaneous move, i.e. logistic heterogeneities leading to one policy's leadership are not factored in.

We are certainly not the first to point out the potential problems of fully continuous settings. In applied mathematics it has long been recognized that various dynamic properties differ substantially in continuous and discrete settings. It has been shown extensively that discrete settings may exhibit richer behaviour and be more relevant for many real-world applications, see e.g. Epperlein et al. (2015). Our analysis provides one such example in the area of macroeconomics, showing that even a small degree of discreteness may qualify conventional findings substantially. This is by allowing for richer strategic policy interactions, which can give rise not only to multiple policy scenarios, but also to multiple equilibria (policy regimes) within each scenario.[31]

9. Linking the Game-Theoretic Results to the Macro Model

Two distinct perspectives on our macroeconomic results lend themselves. One is 'local', and only considers the parameter values under which the Game of Chicken obtains. The other perspective is 'global', featuring all possible parameters and thus other scenarios. Our results highlight the fact that in the presence of strategic policy interactions the global perspective is essential as it may augment the findings of the local perspective. Specifically, once we allow for changes *across* different classes of games (scenarios) rather than just *within* a certain class of game, the effect of policy and structural parameters becomes a lot more complex. We will therefore relegate the local perspective to Appendix F, and discuss only the global perspective in the main text.

Proposition 5. *Consider the general game (14) between the macroprudential and monetary authorities under Stochastic leadership. Due to strategic policy interactions, the individual effect of any of the macroeconomic parameters $(\alpha, \beta, \gamma, \delta, \mu)$, policy preferences $(\kappa, \lambda, \rho, \psi)$ and revision probabilities (q^C, q^P) on financial and macroeconomic outcomes, and hence on the policymakers' payoffs and social welfare, is* **non-monotone**. *For example, a rise in $\frac{\rho}{\psi}$ and/or a fall in $\frac{\kappa}{\lambda}$ (ceteris paribus) may increase, not change or decrease the policies' expected payoffs and social welfare.*

Proof. See Appendix G. $\qquad\square$

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[31]For a framework using time-scales calculus, which nests continuous and discrete settings as special cases, see Libich and Stehlík (2008) in the context of monetary-fiscal interactions.

The finding of Proposition 5 applies not only to the 2×2 game but also to the larger games. It suggests that if strategic interactions are taken into account we need to exercise caution in reporting comparative statics; even in a very simple macro model. This is because changes in various parameters may lead to changes (i) in the class of game, as well as (ii) in the set and likelihood of equilibrium regimes within a certain class of game.

A growing body of the macroeconomic literature has argued that the existence of various (fundamentally different) policy regimes, and switching between them, should be investigated. A prominent example is Davig and Leeper (2008), in which policy regimes are made endogenous. This is also the case in our analysis (albeit using a different approach), showing how policy scenarios and equilibrium regimes depend on institutional, macroeconomic and policy preference parameters.

10. Modifications and Extensions

Our focus has been on strategic policy interactions that cannot be captured in existing microfounded models. In a sense, we provide a strategic-perspective extension of analyses such as Carrillo et al. (2017), who use a one-shot simultaneous game. But while our analysis allows for rich dynamics on the game-theoretic level, they provide its important economic and financial underpinnings, and a rich dynamics at the macro level.

Considering the robustness of our strategic findings, it is apparent that their nature would be unchanged under *alternative timing/information* assumptions. It would apply under Semi-stochastic leadership, whereby the probabilistic revisions occur with some delay (Libich and Nguyen, 2013), as well as under Deterministic leadership, where revisions arrive with certainty at fixed player-specific frequencies (Libich, 2011). This is because by introducing a more dynamic leadership concept, all these frameworks allow for a continuum of cases between the simultaneous move and Stackelberg leadership.

In regards to the simplifications made to the macroeconomic side of our analysis, we will briefly discuss them here and offer more details in Appendix H. Starting with the society's and policymakers' preferences in Sections 3.1-3.2, one can consider adding a *desire to stabilize output* at $\bar{y}$ for one or both institutions. For the central bank this would only have a minor quantitative impact, but for the prudential authority this could have a more substantial impact. It would make P more willing to respond to the credit shock, preferring the socially optimal (N, S) outcome to (S, N) for a greater range of instrument variability aversion κ. As such, the set of parameters yielding the Symbiosis scenario would enlarge, implying the following:

Remark 3. *If the macroprudential authority is also assigned an output target at the natural level, a strategic conflict with monetary policy is less likely.*

This finding is in line with Gelain and Ilbas (2014), whose results suggest that 'there can be considerable gains from coordination if the macroprudential regulator has been assigned a sufficiently high weight on output gap stabilization'.

Another possible modification is the case of an *idiosyncratic macroprudential authority* that is not fully independent from the government and/or the financial sector. It faces a time-inconsistency problem in the spirit of Kydland and Prescott (1977) - arising from a short-term temptation to boost credit, leverage and asset prices beyond the natural level, $L^* > \bar{L}$. This case is discussed in Appendix H.1, which suggests that:

Remark 4. *Lack of macroprudential authority's independence from the government or financial lobby makes a deadlock with the (benevolent) central bank more likely.*

This is essentially because an excessive target L^* makes the policy objectives of M&Ms even more distinct, so a strategic conflict can arise even if $\rho = \kappa = 0$ and $\varepsilon = \varepsilon^D = 0$. In terms of additional modifications to the policy side of the model, Appendix H.2 discusses how (and why) *fiscal policy* can be brought into the strategic analysis.[32] The discussion relates Macroprudential Dominance to Leeper's (1991) Fiscal theory of the price level, and then highlights the resulting policy coordination problem:

Remark 5. *Use of an additional stabilization instrument by an autonomous institution (such as fiscal policy by the government) makes policy mis-coordination and socially inferior outcomes more likely - even if all institutions are benevolent.*

Intuitively, a greater number of substitute stabilization options (i.e. intertwined umbilical cords) increases the complexity and the number of possible policy regimes. It can thus make potential implicit coordination in the separation setup harder to achieve. The same conclusion in principle applies to other modelling features, e.g. introducing *private expectations* (see Appendix H.3), as well as to the case of *multiple shocks*. Table 1 provided their summary, and Appendix H.4 discusses all the eight combinations of credit and aggregate demand shocks not examined above. It implies that:

Remark 6. *The benefits of the integration setup vis-à-vis the separation setup vary over the course of the business and financial cycles. Explicit policy coordination is most crucial when credit and demand shocks with opposite signs co-occur (such as during 2011-2016), because a strategic policy conflict is amplified by a tradeoffs-driven conflict.*

This confirms our conclusion that the integration setup's ability to have decisions of M&Ms decided jointly by one institution, based on cost/benefit considerations for both the financial and real sectors of the economy, is highly desirable.

A related issue is an extension of our analysis to the longer term, which was abstracted from to focus on short-term stabilization of credit shocks. Incorporating longer horizons, together with the policymakers' discounting (impatience), is discussed in Appendix H.5. It suggests the following:

Remark 7. *The central bank's patience can become a strategic disadvantage from a medium- and long-term perspective, potentially increasing the likelihood of Macroprudential Dominance. The prudential authority's patience can have the opposite effect and thus be socially beneficial.*

11. Policy Implications: Superiority of the Integration Setup

Apart from offering novel (game-theoretic) results regarding strategic policy interaction, the paper's aim was to contribute to the policy debate. Our recommendations are

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[32]For strategic interactions between fiscal and monetary policy see Foresti (2017), Leeper and Leith (2016), Libich et al. (2015), Blake and Kirsanova (2011), and Fragetta and Kirsanova (2010). Adding fiscal policy would make our agenda even more in line with the recently established Trinity network at Princeton University (operating under the auspices of several major central banks), coordinated by leading scholars Markus Brunnermeier and Eric Leeper. The network strives to deepen our understanding of 'the interactions among monetary, financial and fiscal stabilization policies'.

divided into two parts: this section focuses on the comparison of the integration and separation setups, whereas Section 12 discusses possible improvements of the latter.

11.1. **Likely Regimes in the Separation Setup.** Conventional approaches generally compare the non-cooperative Nash solution with the cooperative and/or Stackelberg leadership outcomes. Our step forward is to show how under richer strategic interactions a number of additional policy scenarios and regimes may occur, and to endogenously identify those that are likely to obtain. The growing financial cycles in the past four decades and lack of macroprudential actions in recent credit booms seem to suggest that the values of leaning against the wind aversion ρ, and even more so κ, may be high in the real world. In such case our analysis (see Figure 1) implies that the two best scenarios from the social welfare point of view, Monetary Dominance and Symbiosis, are unlikely. In contrast, the inferior Policy Deadlock, Macroprudential Dominance and Game of Chicken scenarios are likely in the aftermath of an exuberant financial shock.

We can use the 2011-2016 period as a tentative example. Many prudential authorities have been worried that continued monetary policy of (near) zero interest rates might result in growing financial imbalances, but they generally did not adjust their macroprudential settings.[33] The same is true for the global regulatory measures of Basel III, which were not implemented in 2013-2015 as scheduled but postponed until 2019. On the other hand, most monetary policymakers did not see it as their job in the separation setup to address financial imbalances; they have been focused on stimulating the weak economy (hit by $\varepsilon^D < 0$) to achieve macroeconomic stability. They either did not respond to the credit boom at all, implying a Policy Deadlock (N, N), or were induced to lean against the wind, implying Macroprudential Dominance (S, N). For the latter see Ubide's (2015) and Svensson's (2012) narrative of the Swedish case; Norway offers a similar example. This is in line with the calibration of Carrillo et al. (2017) to US data, in which an exuberant credit shock would yield the 'Loose Money-Loose Credit' regime in the absence of policy cooperation.

Within the Game of Chicken scenario, the outcomes were shown to crucially depend on the policies' flexibility determining their relative Stochastic leadership.[34] In a symmetric Game of Chicken the most likely (focal) outcome is Regime Switching, whereas under the likely leadership of the prudential authority our analysis again points to Macroprudential Dominance. Both are socially undesirable.

What are the chances of the Cooperative outcome and the non-cooperative Nash solution in the separation setup? We have discussed above some theoretic reasons why they are unlikely to obtain under heterogeneous policies. But there are also practical reasons related to uncertainty, making it difficult for autonomous M&Ms to coordinate on $\left(J^{COOP}, J^{COOP} \right)$ or $\left(J^{NASH}, J^{NASH} \right)$.

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[33]In the 1998-2000 and 2003-2006 periods, absence of macroprudential responses may have been due to the policymakers underestimating systemic risk and their lack of experience with macroprudential instruments. Such explanation is however much less plausible in the 2011-2016 period.

[34]This is in contrast to the Policy Deadlock and the two Dominance scenarios in which leadership plays no role - both feature a unique equilibrium by strict dominance. In the Symbiosis scenario the effect of leadership is the same as in the Game of Chicken, but it is of lesser importance since the socially optimal outcome can be selected by the focal point argument.

First, in the real world the policymakers have incomplete information about economic conditions. It may not be clear what these joint-tightening outcomes actually are; they obviously vary over time with new economic developments (see footnote 14) and changes in policy leadership (see Section 8). It may therefore be impossible for separated M&Ms to share the necessary tightening without explicit coordination embedded in the integration setup; also because optimal decisions must be based on *joint* forecasts featuring an endogenously determined future path of both policies' instruments.

The second type of uncertainty relates to reputational considerations under incomplete information about the opponent's type. The M&Ms' policymakers do not know the opponent's instrument variability aversion, and they may try to build reputation (for a high ρ and κ respectively) to gain a strategic advantage; see Backus and Driffill (1985) for this in a different context. Real-world central banks may thus be worried that if they start 'cooperatively' leaning against the wind (play J^{COOP}) they will signal a low ρ, and will be more easily induced by the macroprudential authority's inaction to do more in the future (play S). In effect, central banks may be afraid that aiming for a compromise will make the monetarist arithmetic even more unpleasant in the future.

11.2. **Integration vs Separation of M&Ms.** The previous sub-section implies that in the separation setup the socially optimal and cooperative outcomes are rather unlikely whereas the Policy Deadlock, Regime Switching and Macroprudential Dominance are likely. In contrast, in the integration setup absent of strategic interactions these costly outcomes are surely avoided.[35] This implies our key recommendation.

1) The recent trend of separating macroprudential policy from the central bank into a different institution should be reconsidered. Our analysis points to three main reasons for the superiority of the integration setup over the separation setup. The first one is that under the separation setup macroprudential policy loses the shelter of central bank independence, which has proved to be crucial in enhancing monetary policy outcomes post-1970s. This need is highlighted by the fact that short-term incentives for idiosyncratic political and financial lobby pressures that favour an excessively loose stance are even stronger for macroprudential than for monetary policy.[36]

The second reason for the inferiority of the separation setup - in operation even if there are no external pressures - is the lack of an explicit coordination channel between

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[35]As discussed above, $\left(J^{COOP}, J^{COOP}\right)$ yields society's first best under $\kappa = 0$ and society's second-best otherwise. It should however be acknowledged that strategic considerations could (to a smaller extent) also apply in the integration setup. For example Carrillo et al. (2017) argue that '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.'

[36]As IMF (2013a) argue: 'the benefits of [macroprudential] action accrue in the future and are highly uncertain, while the costs of imposing macroprudential constraints are felt immediately, by both borrowers and providers of funds. As a result, macroprudential policy is subject to strong lobbying and political pressures.' Brunnermeier and Sannikov use the term 'financial dominance' to describe this situation. It should be noted that our policy implication 1) assumes that the central bank is benevolent. The integration setup may no longer be superior if the central bank itself lacks independence from the government or has idiosyncratic objectives for some other reason. Ueda and Valencia (2014) show that in such case a new type of time-inconsistency may arise when the central bank conducts both monetary and macroprudential policy. This is because interest rates 'may be abused to reduce the private sector's real debt burden after a financial shock materializes'.

autonomous M&Ms. We formally show that the resulting mis-coordination or strategic conflict may lead to unnecessary financial instability (asset bubbles), price instability (deviations from the inflation target) as well as real instability (output gaps).

This finding is consistent with several studies using microfounded models. In Carrillo et al. (2017) the gains from coordination arise because, like in our model, different M&Ms' objectives imply 'strategic incentives faced by each authority acting unilaterally'. Their welfare gain of policy coordination, compared to a non-cooperative Nash solution, is 6-7 percent. Similarly, Bodenstein et al. (2014) show that 'lack of coordination [between M&Ms] leads to large welfare losses even if technology shocks are the only source of fluctuations'. Angelini et al. (2014) show that insufficient cooperation of M&Ms 'may result in excessive volatility of the monetary policy rate and capital requirements'. In line with our results, Silvo's (2016) analysis finds that the social optimum can only be achieved if macroprudential and monetary policy are optimized jointly. For similar findings regarding 'a need to coordinate the use of macroprudential and traditional monetary policy tools' see Cecchetti and Kohler (2014).

These theoretic insights are further consistent with the empirical results of Melecky and Podpiera (2015) about the desirability of the integration setup. Their analysis suggests that microprudential policy should be conducted - jointly with macroprudential and monetary policy - by the central bank rather than a separate prudential authority. Importantly, our results are also consistent with the empirical evidence of Lim et al. (2013) from a sample of 39 countries. The authors show that 'the macroprudential framework that gives the central bank an important role is associated with more timely use of macroprudential policy instruments'.

The third pro-integration reason relates to the credibility of both policies. Our results imply that the conventional argument for the separation setup, namely that it enhances credibility of both M&Ms by sharpening their respective mandates, may not be valid. The possibility of a strategic conflict and increased political pressures may in fact reduce the policies' credibility, not enhance it.[37] For example, if the central bank is subject to an unpleasant monetarist arithmetic its legislated accountability for the inflation target becomes problematic, and monetary policy's credibility is likely to suffer.

Svensson (2016a) favours the separation setup, arguing that: 'in normal times, it is best to conduct monetary policy and macroprudential policy independently, with each policy taking the conduct and effects of the other policy into account in order to best achieve its goals... In game-theory terms, it corresponds to a non-cooperative Nash equilibrium rather than a cooperative equilibrium.' Our analysis however shows some potential problems with this arrangement. First, M&Ms may not be willing to coordinate, even if one of them is fully-benevolent and one partly-benevolent (see e.g. the large welfare losses in Carrillo et al., 2017). Second, even if both institutions are fully-benevolent and willing to cooperate, for social optimality it is necessary that M&Ms make joint decisions based on joint forecasts conditional on the full (jointly optimal) paths of both policy instruments. Such required level of explicit coordination far exceeds the reality observed in countries using the separation setup.

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[37]The U.S. seems to be a case in point, given that the Financial Stability Oversight Council is chaired by the Secretary of the Treasury.

Another argument for the separation setup has been that financial stability and hence macroprudential policy should be the government's responsibility - given its fiscal backing through implicit guarantees to too-big-to-fail financial institutions. A related argument is that macroprudential policy has direct distributional effects, and unelected central bankers should not pick winners and losers. However, as we discussed in Section 10, if the government is in charge of financial stability a time-inconsistency problem is likely to arise. It tends to lead to excessive financial cycles that mirror political cycles, and a higher likelihood of a costly macroprudential-monetary deadlock.

12. Policy Implications: How to Improve the Separation Setup?

Many countries adopted the separation setup recently and seem unlikely to move away from it in the near future. We therefore discuss measures that may be able to ameliorate its outcomes (Section 12.2), as well as those that are unlikely to have traction (Section 12.1). Before we do so, let us however reiterate the implication of Proposition 5 that *all policy reforms within the separation setup need to be considered carefully because, due to strategic policy interactions, the effect of key parameters on financial/macroeconomic outcomes and social welfare may be non-monotone.* Such ambiguity generally does not occur in the integration setup, which constitutes another of its advantages.

12.1. **The Dead Ends.** Let us spell out two arrangements with dubious benefits.

2) A Memorandum of understanding between macroprudential and monetary policies is unlikely to resolve their strategic conflict and mis-coordination. Our analysis shows that effective cooperation of M&Ms requires a great deal more than just 'common understanding' and occasional sharing information about the economy.

3) The central bank's overstating (bluffing about) its aversion to leaning against the wind is a risky strategy that may worsen economic outcomes. We demonstrated that a sufficiently high level of ρ (as perceived by P) may help C to achieve Monetary Dominance, possibly improving its payoffs and social welfare. But the opposite is true if the prudential authority is sufficiently averse to changing its instrument setting ($\kappa > \tilde{\kappa}$), and/or it lacks independence from the government or the financial lobby ($L^* > \bar{L}$). Then a rise in ρ may be self-defeating and yield a costly Policy Deadlock.[38]

12.2. **Improvements of the Separation Setup.** Several institutional arrangements may partly enhance the outcomes of M&Ms in the absence of policy integration.

4) Differences in macroprudential and monetary policy flexibility and lags may improve implicit coordination and help to avoid a Policy Deadlock. Our analysis shows that if the policies' revision probabilities are sufficiently different the economy ends up in one of the Dominance regions, where Regime Switching and Policy Deadlock cannot occur. This finding is in line with De Paoli and Paustian (2013) who argue, using conventional Stackelberg leadership, that: 'having one of the authorities act as a leader can mitigate coordination problems. At the same time, choosing monetary and macroprudential tools that work in a similar fashion can increase such problems.'

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[38]In Carrillo et al. (2017) the strategic space of M&Ms consists of their choice of the policy rule elasticities, so it can be interpreted as the policies selecting their relative secondary weights ρ and κ.

5) To maximize social welfare each policy should be the Stochastic follower (i.e. sufficiently flexible) in terms of stabilizing its own shocks, and the Stochastic leader (sufficiently inflexible) in stabilizing the opponent's shocks. This is implied by the fact that the two Dominance regions do not yield identical outcomes. With respect to credit shocks, Monetary Dominance ensures society's first-best whereas Macroprudential Dominance only the third-best. Unfortunately, the latter seems more likely than the former due to the lower flexibility (and thus Stochastic leadership) of macroprudential policy. Designers of the institutional framework should therefore consider arrangements that promote specialization of M&Ms in the desired direction. Adopting some automatic mechanism for implementing macroprudential measures could increase P's flexibility (and q^P) as well as lower its implementation costs (and κ). This has been the case for monetary policy whereby the open market operations process for changing the interest rate setting has become more flexible and less costly over time. These have arguably increased the central bank's q^C and lowering ρ in regards to demand shocks.[39]

6) Analytical tools that better distinguish financial from other types of shocks in real time are likely to reduce scope for a strategic macroprudential-monetary policy conflict. Our analysis assumed that the policymakers in charge of M&Ms can tell the ε and ε^D shocks apart. In the real world, however, this is often not the case. Allowing for such uncertainty would make policy coordination in our model even more challenging and inferior outcomes due to a Policy Deadlock more likely. This is consistent with Kannan et al. (2012), who demonstrate that 'it is crucial to understand the source of house price booms for the design of monetary and macroprudential policy.' An implication is that adding other (e.g. commodity or productivity) shocks would further expand the scope for a policy mis-coordination and conflict.

7) Legislating some numerical medium-term target for macroprudential policy could in principle help to diminish its strategic conflict with monetary policy. This conclusion is inspired by the major reforms in monetary policy towards accountability and transparency (including numerical medium-term inflation targets) that have occurred in the 1990s; for more discussion see Appendix I. Our analysis implies, in line with Svensson (2016a), that research should explore the desirability and implementability of such legislated targets for macroprudential policy too. This is not only true for the separation setup but also for the integration setup - in both of them explicit targets are desirable to sharpen the policies' mandates and improve incentives.[40] A numerical target for credit growth seems like a natural starting point of such consideration, e.g. Ferreira and Nakane's (2015) estimated DSGE model implies credit growth to be a good macroprudential policy instrument.

Pursuing a numerical target for some financial variable would undoubtedly be more challenging than pursuing a numerical inflation target, also because it would most likely

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[39]International cooperation in setting global macroprudential standards is obviously of paramount importance in lowering κ due to cross-border financial flows, see e.g. Cecchetti and Tucker (2016).

[40]For example, Fed Vice Chairman Fischer (2015) points out the problems with unclear and inconsistent policy mandates/objectives. He notes that the members of the Financial Stability Oversight Council in the U.S. have 'different mandates, some of which do not include macroprudential regulation', and argues that this 'may hinder coordination'.

be specified as contingent on other variables (e.g. Angelini et al., 2014 argue for time-varying capital requirements). This is one of the reasons why the policymakers' understanding of financial stability is believed to be insufficient to go ahead with numerical macroprudential targets. But the introduction of explicit inflation targets was also met with major concerns about feasibility, and central banks' 'learning by doing' proved successful.

How can we think of P that is accountable for achieving some explicit macroprudential target? In our framework this would be represented by $L^* = \bar{L}$, in combination with a low κ in regards to credit shocks and a high κ in regards to aggregate demand shocks. Such goals would generally ensure either the Symbiosis scenario or the socially desirable Dominance scenario. Furthermore, explicit targets would arguably force the prudential authority and central bank to communicate and coordinate more transparently.

8) Arrangements that increase the macroprudential policymakers' optimizing horizon (such as extending the length of their mandate) are likely to improve their coordination with monetary policymakers. In our analysis we assumed the probabilistic revisions to arrive immediately after the initial actions. If we however interpret them in a deterministic sense as a possible delay in responding, the policymakers' patience (low degree of discounting) makes a Policy Deadlock between M&Ms less likely. This is because in their victory conditions more patient policymakers put a greater weight on the benefit of cooperation, which occurs *after* a period of costly mis-coordination. As such, the size of the Dominance regions that avoid a Policy Deadlock tends to increase under patient policymakers, and so does expected social welfare. Longer macroprudential mandates, like other recommendations in this section, may thus provide an avenue for the outcomes of policy M&Ms to taste sweeter even in the separation setup.

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(All appendices can be shortened or possibly deleted)

Appendix A. Emergence of Macroprudential Policy

The views on macroprudential policy instruments, their role in financial sector stabilization, and their linkages to monetary and fiscal policies, have evolved over time. Figure 6 presents a summary of the key changes as seen by the International Monetary Fund (IMF, 2013b). The top panel portrays the situation prior to the 2008 crisis. Essentially, no linkages were considered between the financial sector and the macroeconomy, and between M&Ms. In fact, there was no macroprudential policy to speak of. The IMF and most economists and policymakers saw a role for microprudential policy in minimizing idiosyncratic risk, but it did not link to the macroeconomic objectives of price and output stability. The current view by the IMF and others, shown in the bottom panel of Figure 6, is very different. Macroprudential policy is considered to play a key role in addressing systemic risk, and ensuring not only financial stability but indirectly also macroeconomic stability. Importantly, macroprudential policy is seen highly interlinked with monetary and fiscal policies.

Figure 6. The IMF (2013b) view of prudential and macroeconomic policies prior to the 2008 crisis (top panel) and post-2008 (bottom panel).

Despite the implied substitutability of M&Ms in addressing financial shocks, recent literature suggests that these should be addressed by macroprudential rather than monetary policy. For example, Svensson (2016b) offers a cost/benefit analysis of monetary policy's leaning against the wind, showing that the potential social costs far exceed its potential benefits. Paul's (2017) analysis suggests that these depend on the financial cycle, specifically: 'at the peak of the housing boom prior to the Great Recession, the

percentage change of output per percentage change in house prices - a measure in the spirit of the sacrifice ratio - quadrupled. He therefore calls into question the use of monetary policy to lean against the wind. Similarly, the estimated model of Kiley and Sim (2015) implies that monetary policy should not respond strongly to the credit cycle. In the same spirit, Leduc and Natal (2016) find that once they account for a macroprudential rule linked to credit growth, optimal monetary policy should only focus on price stability. Gali's (2014) analysis suggests that monetary policy's leaning against the wind policy may actually be counter-productive, and increase rather than decrease the volatility of asset prices. Alpanda and Zubairy (2017) show that certain macroprudential measures are 'the most effective and least costly in reducing household debt', and preferable to monetary policy. All these findings are in line with IMF (2015), which argues: 'Based on current knowledge, the case for leaning against the wind is limited, as in most circumstances costs outweigh benefits'.

Appendix B. Tools and Setups of Macroprudential Regulation

The Bank for International Settlements, specifically its Basel Committee on Banking Supervision, has been setting global standards for prudential regulation of the banking sector. Basel III is the latest set of prudential measures, originally scheduled to be implemented between 2013 and 2015, but postponed until 2019. The key pillars of Basel III are rules regarding capital and liquidity requirements, leverage, and capital buffers. Other macroprudential instruments have been in use as well, for example loan-to-value and loan-to-income ratios. Such measures have been accompanied by stress testing, a tool for regulators to examine the consequences of adverse developments on the banking system and the real economy.[41]

There exists three main setups of prudential regulation (for more details see Nier et al., 2011). In the *integration* setup, used e.g. in the Czech Republic, Ireland, New Zealand and Singapore, there is no separation of policy decisions and control between M&Ms. While there are generally two distinct units within the central bank devoted to macroprudential and monetary policy, the final decisions of both policies are made jointly by the central bank board/committee.

At the opposite end of the spectrum lies the *full-separation* setup. Its key feature is that (macro)prudential decisions are not made by the central bank but by a separate institution or committee, as in Australia, Canada, Chile, Denmark, Norway, Sweden, Switzerland, the United States and Eurozone. The specific details vary substantially, for example in regards to the government's involvement in macroprudential policy, existence of a third body coordinating M&Ms, terms of a Memorandum of understanding between M&Ms etc. The *partial-separation* setup, used e.g. in Belgium, the Netherlands, Thailand and the UK, lies somewhere in between the integration and full-separation setups. Macroprudential policy is conducted by the central bank or a committee related to the central bank, and while there are varying degrees of separation of policy decisions in some areas, there is generally no role of the government.[42]

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[41]Ceruttia et al. (2016), Tillmann (2015), Geršl and Jašová (2014), and Claessens et al. (2013) offer an empirical assessment of the effectiveness of various macroprudential measures implemented since 2000.

[42]Nier et al. (2011) put the United States in the partial-separation category and Eurozone into its own category, but for our purposes both are best seen as examples of the full-separation setup. This

Appendix C. Proof of Proposition 1

In addition to the Game of Chicken derived in the main text, there is a policy Symbiosis and three scenarios featuring a unique Nash equilibrium.

C.1. **Symbiosis.** If the weight on both secondary policy objectives ρ and κ is sufficiently small (relative to the primary objectives) then M&Ms prefer the same outcome in equilibrium, namely the social optimum (N, S). The macroprudential authority finds it optimal to tighten in response to the credit shock in order to avoid the minor credit boom that would occur under (S, N). Formally, using (14) for the general payoffs and (15a) for the specific payoffs this scenario obtains iff

$$(27) \qquad \rho < \bar{\rho} = \psi\alpha^2 (\gamma\mu + \beta)^2 \overset{(15a)}{=} 4 \quad \text{and} \quad \kappa < \bar{\kappa} = \lambda \left(\frac{\delta\beta}{\beta + \gamma\mu} \right)^2 \overset{(15a)}{=} \frac{1}{4}.$$

The game has two pure-strategy Nash equilibria, namely (S, N) and (N, S). The latter is Pareto-superior, which can be interpreted as a symbiosis between M&Ms.[43] Symbiosis is the only scenario in which a strategic policy conflict is absent. Despite this, the existence of multiple equilibria still implies a coordination problem facing the two policies. So while the socially optimal outcome can be selected by the focal point argument, it cannot be guaranteed with certainty. Note that this scenario nests the case of $\rho = \kappa = 0$, i.e. a policy mis-coordination may occur even if both institutions are fully-benevolent.

C.2. **Macroprudential Dominance.** If the weight on macroprudential policy's secondary objective is above a certain threshold then S becomes strictly dominated by N for the prudential authority. Therefore, C knows that P will never play S. If the weight on the secondary objective for C is sufficiently small, then C will be induced to play S and deal with the shock. Formally, this scenario occurs iff

$$(28) \qquad \rho < \bar{\rho} = \psi\alpha^2 (\gamma\mu + \beta)^2 \overset{(15a)}{=} 4 \quad \text{and} \quad \kappa > \tilde{\kappa} = \lambda\delta^2 \overset{(15a)}{=} 1.$$

The unique equilibrium (S, N) features a smaller-scale short-term bubble as C is strategically maneuvered by the dominating P to respond to the exuberant shock and raise interest rates. While the worst outcomes are averted, the first-best is not achieved.

C.3. **Monetary Dominance.** This scenario is the opposite of Macroprudential Dominance. It is now the weight on C's secondary objective that is above a certain threshold, and such strong aversion of monetary policy to leaning against the wind means that, for the central bank, S becomes strictly dominated by N. Knowing this, the prudential authority is forced into stabilizing the shock - if (and only if) its weight on the secondary objective is below a certain threshold. In particular, using (14)-(15a) one obtains

$$(29) \qquad \rho > \bar{\rho} = \psi\alpha^2 (\gamma\mu + \beta)^2 \overset{(15a)}{=} 4 \quad \text{and} \quad \kappa < \tilde{\kappa} = \lambda\delta^2 \overset{(15a)}{=} 1.$$

is because monetary and macroprudential decisions are not made jointly by the same body/committee, and the latter policy is subject to non-negligible influence from the government. Specifically, in 2010 the Financial Stability Oversight Council and the European Systemic Risk Board were established to conduct macroprudential policy in the US and Eurozone respectively. While the relevant central banks play some role in both institutions, M&Ms' decisions are still separated institutionally (and largely politically too).

[43]For an analogous use of the term symbiosis in regards to monetary-fiscal interactions see Dixit and Lambertini (2003) and Foresti (2017).

It is now the central bank that dominates and induces P to respond to the credit boom via macroprudential measures. The socially optimal outcome (N, S) is therefore reached.

C.4. **Policy Deadlock.** This scenario combines strong instrument variability aversion for both policy institutions, so for both S is dominated by N. This implies that neither institution can be strategically induced into addressing the credit shock. Using (14) and (15a) this scenario occurs iff

$$(30) \qquad \rho > \bar{\rho} = \psi\alpha^2 \left(\gamma\mu + \beta\right)^2 \overset{(15a)}{=} 4 \quad \text{and} \quad \kappa > \tilde{\kappa} = \lambda\delta^2 \overset{(15a)}{=} 1.$$

The unique equilibrium (N, N) features a Policy Deadlock leading to a major short-term imbalance in both the financial and real sectors of the economy.

Appendix D. Proof of Proposition 2

Solving backwards, the yielding condition described in the main text is as follows

$$(31) \qquad \overbrace{\underbrace{b\left(1 - q^P\right)}_{P_2^N \text{ (P's victory)}} + \underbrace{aq^P}_{P_2^S \text{ (mis-coordination)}}}^{C_2^S} > \overbrace{\underbrace{d\left(1 - q^P\right)}_{P_2^N \text{ (deadlock)}} + \underbrace{cq^P}_{P_2^S \text{ (P's yielding)}}}^{C_2^N},$$

whereby the left-hand-side reports C's minimum payoff under C_2^S and the right-hand-side its maximum payoff under C_2^N, both assuming P_1^N. Intuitively, playing C_2^S will result in P's victory if the prudential authority does not get a revision opportunity (probability $1 - q^P$), but mis-coordination/conflict if P does (a switch to P_2^S is assumed, which is the worst case scenario for C). The opposite is true for C_2^N, which will result in a Policy Deadlock in the absence of P's revision opportunity, and coordination otherwise (assuming C's best case scenario with P's yielding, P_2^S). This implies that, upon observing P_1^N, playing C_2^S will be optimal for monetary policy if P's revision probability is sufficiently low, i.e. the conflict is unlikely. Rearranging (31) yields the corresponding threshold reported in (20) in the main text. Assuming it holds, the sticking condition then has the form

$$(32) \qquad \overbrace{\underbrace{z\left(1 - q^C\right)}_{C_2^N \text{ (deadlock)}} + \underbrace{wq^C}_{C_2^S \text{ (C's yielding)}}}^{P_2^N} > \overbrace{\underbrace{x\left(1 - q^C\right)}_{C_2^N \text{ (C's victory)}} + \underbrace{vq^C}_{C_2^S \text{ (mis-coordination)}}}^{P_2^S},$$

where the left-hand-side reports P's minimum payoff under P_2^N and the right-hand-side its maximum payoff under P_2^S. Both sides assume P_1^N, C_1^N and, as implied by the yielding condition, C_2^S. This can be rearranged into

$$(33) \qquad q^C > \frac{x - z}{x - z + w - v}.$$

Intuitively, for P to stick to N even upon observing C_1^N, the player must expect C to be able to revise its action with sufficiently high probability. This is because from the yielding condition P knows the revision would be from C_1^N to C_2^S, avoiding the deadlock. In such case P's expected conflict cost (occurring with probability $1 - q^C$) would be sufficiently small relative to its expected victory gain (probability q^C).

Assuming the sticking condition (33) is satisfied, move backwards to P's initial move. Its victory condition can be written as

$$(34) \qquad \overbrace{\underbrace{z\left(1-q^{C}\right)}_{C_{2}^{N} \text{ (deadlock)}} + \underbrace{wq^{C}}_{C_{2}^{S} \text{ (P's victory)}}}^{P_{1}^{N}} > \overbrace{\underbrace{x}_{C_{2}^{N} \text{ (P's yielding)}}}^{P_{1}^{S}},$$

where, assuming C_{1}^{N}, the left-hand-side reports P's minimum payoff under P_{1}^{N} and the right-hand-side its maximum payoff under P_{1}^{S}. Analogously to the sticking condition, the victory condition will be satisfied if P's expected victory gain is large enough, i.e. if C's revision to C_{2}^{S} (preventing the deadlock) is sufficiently likely. Rearranging yields (21) reported in the main text. This condition is stronger than the sticking condition in (33) for all general payoffs in (18).

APPENDIX E. PROOF OF PROPOSITION 4

E.1. **Macroprudential Dominance.** Solving backwards, C's yielding condition in (31) is generalized and consists of four sub-conditions

$$(35) \qquad \overbrace{\underbrace{b\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{aq^{P}}_{P_{2}^{S}}}^{C_{2}^{S}} > \max\left\{\overbrace{\underbrace{d\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{cq^{P}}_{P_{2}^{S}}}^{C_{2}^{N}}, \overbrace{\underbrace{h\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{gq^{P}}_{P_{2}^{S}}}^{C_{2}^{J}}\right\},$$

$$(36) \qquad \overbrace{\underbrace{b\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{eq^{P}}_{P_{2}^{J}}}^{C_{2}^{S}} > \max\left\{\overbrace{\underbrace{d\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{fq^{P}}_{P_{2}^{J}}}^{C_{2}^{N}}, \overbrace{\underbrace{h\left(1-q^{P}\right)}_{P_{2}^{N}} + \underbrace{kq^{P}}_{P_{2}^{J}}}^{C_{2}^{J}}\right\}.$$

Rearranging these, one obtains
$$(37)$$
$$q^{P} < \overline{q_{3}^{P}} = \min\left\{\overline{q_{2}^{P}} = \frac{b-d}{b-d+c-a}, \frac{b-h}{b-h+g-a}, \frac{b-d}{b-d+f-e}, \frac{b-h}{b-h+k-e}\right\}.$$

Using the general payoffs in (23) one can verify that all fractions on the right-hand-side of (37) except the third one may be the smallest, and thus binding. The fact that the first fraction is the yielding condition of the 2×2 game implies that in the 3×3 game the threshold is smaller or the same, i.e. $\overline{q_{3}^{P}} \leq \overline{q_{2}^{P}}$. Assuming that the yielding condition in (37) holds, the prudential authority's sticking condition obtains iff

$$(38) \qquad \overbrace{\underbrace{z\left(1-q^{C}\right)}_{C_{2}^{N}} + \underbrace{wq^{C}}_{C_{2}^{S}}}^{P_{2}^{N}} > \max\left\{\overbrace{\underbrace{x\left(1-q^{C}\right)}_{C_{2}^{N}} + \underbrace{vq^{C}}_{C_{2}^{S}}}^{P_{2}^{S}}, \overbrace{\underbrace{n\left(1-q^{C}\right)}_{C_{2}^{N}} + \underbrace{mq^{C}}_{C_{2}^{S}}}^{P_{2}^{J}}\right\},$$

$$(39) \qquad \overbrace{\underbrace{s\left(1-q^{C}\right)}_{C_{2}^{J}} + \underbrace{wq^{C}}_{C_{2}^{S}}}^{P_{2}^{N}} > \max\left\{\overbrace{\underbrace{o\left(1-q^{C}\right)}_{C_{2}^{J}} + \underbrace{vq^{C}}_{C_{2}^{S}}}^{P_{2}^{S}}, \overbrace{\underbrace{u\left(1-q^{C}\right)}_{C_{2}^{J}} + \underbrace{mq^{C}}_{C_{2}^{S}}}^{P_{2}^{J}}\right\}.$$

Rearranging and combining these conditions yields

$$(40) \qquad q^C > \max\left\{\frac{x-z}{x-z+w-v}, \frac{n-z}{n-z+w-m}, \frac{o-s}{o-s+w-v}, \frac{u-s}{u-s+w-m}\right\}.$$

Using the general constraints (23), all fractions on the right-hand-side of (40) except the third one may be the largest in value. The fact that the first fraction is the yielding condition of the 2×2 game implies that in the 3×3 game the threshold is bigger or the same. Assuming both the yielding and sticking conditions in (37) and (40) hold, the victory condition is composed of

$$(41) \qquad \overbrace{\underbrace{z\left(1-q^C\right)}_{C_1^N C_2^N} + \underbrace{wq^C}_{C_1^N C_2^S}}^{P_1^N P_2^N} > \overbrace{\underbrace{x}_{C_1^N C_2^N}}^{P_1^S P_2^S} \quad \text{and} \quad \overbrace{\underbrace{s\left(1-q^C\right)}_{C_1^J C_2^N} + \underbrace{wq^C}_{C_1^N C_2^S}}^{P_1^N P_2^N} > \overbrace{\underbrace{u}_{C_1^J C_2^J}}^{P_1^J P_2^J}.$$

Rearranging yields

$$(42) \qquad q^C > \underline{q_3^C} = \max\left\{\underline{q_2^C} = \frac{x-z}{w-z}, \frac{u-s}{w-s}\right\}.$$

It is straightforward to see that the victory condition in (42) is, for all general parameter values in (23), stronger than the sticking condition in (40). We can therefore conclude that the $\left(C_1^S C_2^S, P_1^N P_2^N\right)$ outcome constitutes the unique subgame perfect equilibrium if and only if the conditions in (37) and (42) hold, i.e. they are (jointly) necessary and sufficient for P's dominance. Note that the victory condition in (42) is at least as strong as in the 2×2 game, i.e. $\underline{q_3^C} \geq \underline{q_2^C}$.

E.2. **Monetary Dominance.** The necessary and sufficient conditions can be derived by symmetry. The yielding and victory conditions are

$$(43) \qquad q^C < \overline{q_3^C} = \min\left\{\overline{q_2^C} = \frac{x-z}{x-z+w-v}, \frac{x-n}{x-n+m-v}, \frac{x-n}{x-n+u-o}\right\}.$$

$$(44) \qquad q^P > \underline{q_3^P} = \max\left\{\underline{q_2^P} = \frac{b-d}{c-d}, \frac{k-f}{c-f}\right\}.$$

Naturally, we have $\overline{q_3^C} \leq \overline{q_2^C}$ and $\underline{q_3^P} \geq \underline{q_2^P}$.

E.3. **Compromise Semi-Dominance.** Let us derive the conditions under which J^{COOP} strictly dominates S for one player, while the $\left(C_1^J C_2^J, P_1^J P_2^J\right)$ outcome still remains in the set of subgame perfect equilibria. We will do so for the case in which P is the semi-dominating player, i.e. the Compromise Semi-Dominance sub-region wrapping the Macroprudential Dominance region in Figure 5. Solving backwards, it is required that the central bank chooses C_2^J upon observing P_1^J - even if it knows with certainty that the prudential authority would switch to P_2^N or P_2^S if able to. This first component of the yielding condition is satisfied iff

$$\overbrace{\underbrace{k\left(1-q^P\right)}_{P_2^J} + \underbrace{hq^P}_{P_2^N}}^{C_2^J} > \max\left\{\overbrace{\underbrace{f\left(1-q^P\right)}_{P_2^J} + \underbrace{dq^P}_{P_2^N}}^{C_2^N}, \overbrace{\underbrace{e\left(1-q^P\right)}_{P_2^J} + \underbrace{bq^P}_{P_2^N}}^{C_2^S}\right\},$$

$$\overbrace{\underbrace{k\left(1-q^P\right)}_{P_2^J}+\underbrace{gq^P}_{P_2^S}}^{C_2^J} > \max\left\{\overbrace{\underbrace{f\left(1-q^P\right)}_{P_2^J}+\underbrace{cq^P}_{P_2^S}}^{C_2^N},\overbrace{\underbrace{e\left(1-q^P\right)}_{P_2^J}+\underbrace{aq^P}_{P_2^S}}^{C_2^S}\right\},$$

and upon rearranging

$$(45) \quad q^P < \widehat{q_3^P} = \min\left\{\frac{k-f}{k-f+d-h},\frac{k-e}{k-e+b-h},\frac{k-f}{k-f+c-g},\frac{k-e}{k-e+a-g}\right\}.$$

The second and third fractions on the right-hand-side can be the smallest ones and hence binding. Another component of C's yielding within the Compromise Semi-Dominance region is that the yielding condition for Macroprudential Dominance, (37), is *not* satisfied (with strict inequality). Assuming both components hold, the sticking condition then requires that P prefers sticking to J^{COOP} rather than switching to S in its revision. This is even in the worst case of observing C_1^N, namely if

$$(46) \qquad \overbrace{\underbrace{n\left(1-q^C\right)}_{C_2^N}+\underbrace{uq^C}_{C_2^J}}^{P_2^J} > \overbrace{\underbrace{x\left(1-q^C\right)}_{C_2^N}+\underbrace{oq^C}_{C_2^J}}^{P_2^S}.$$

Rearranging implies

$$(47) \qquad q^C > \frac{x-n}{x-n+u-o}.$$

Assuming it holds, the 'semi-victory condition' is

$$(48) \qquad \overbrace{\underbrace{n\left(1-q^C\right)}_{C_1^N C_2^N}+\underbrace{uq^C}_{C_1^N C_2^J}}^{P_1^J P_2^J} > \overbrace{\underbrace{x}_{C_1^N C_2^N}}^{P_1^S P_2^S},$$

which, upon rearranging, yields

$$(49) \qquad q^C > \widetilde{q_3^C} = \frac{x-n}{u-n}.$$

This is again stronger than the Sticking condition in (47). Nevertheless, it is also required that the victory condition for Macroprudential Dominance, (42), is *not* satisfied (with strict inequality). Hence the interval for P's Compromise Semi-Dominance is

$$(50) \qquad q^C \in \left(\widetilde{q_3^C},\underline{q_3^C}\right) = \left(\frac{x-n}{u-n},\frac{u-s}{w-s}\right).$$

For illustration, under the specific parameters in (24) we obtain $\underline{q_3^C} = \frac{2}{3} > \widetilde{q_3^C} = \frac{3}{5} > \underline{q_2^C} = \frac{5}{9}$ and $\widehat{q_3^P} = \frac{4}{11} > \overline{q_3^P} = \overline{q_2^P} = \frac{1}{3}$. This implies that in the specific game the compromise-compromising sub-region in Figure 5 below the Macroprudential Dominance region exists, whereas the one to the right of this region does not. The conditions for the opposite Compromise Semi-Dominance sub-region, in which C is the semi-dominating player, can be obtained by symmetry.

APPENDIX F. LINKING THE GAME OF CHICKEN TO THE MACRO PARAMETERS

The game-theoretic results of Section 8 imply many macroeconomic interlinkages. While they are only 'local' (apply within the Game of Chicken), and may not be fully robust in a richer macro model, they may provide potentially interesting insights.

Proposition 6. *Consider the Game of Chicken (18)-(19) between the macroprudential and monetary authorities under stochastic revisions and a exuberant credit shock. The relative size of the Monetary Dominance region increases, i.e.* **the social optimum** (N, S) **becomes 'more likely'***, if:*
(i) the central bank becomes more averse to leaning against the wind - relative to inflation variability (a rise in $\frac{\rho}{\psi}$);
(ii) the prudential authority becomes less averse to variability in its instrument - relative to financial variability (a fall in $\frac{\kappa}{\lambda}$);
(iii) macroprudential policy becomes more potent in stabilizing leverage (a rise in δ);
(iv) real output's effect on inflation decreases (a fall in α).

Proof. Using the necessary and sufficient conditions for uniqueness of the Monetary Dominance region, (22), together with the macro model in (2)-(6), yields

$$(51) \qquad q^C < \overline{q_2^C} = \frac{(\beta + \gamma\mu)\left(\lambda\delta^2 - \kappa\right)}{2\lambda\gamma\mu\delta^2} \quad \text{and} \quad q^P > \underline{q_2^P} = \frac{\alpha^2\psi\left(\beta + \gamma\mu\right)^2 - \rho}{\alpha^2\psi\left(\beta + \gamma\mu\right)^2}.$$

We can see that $\overline{q^C}$ is increasing in λ, δ, β and decreasing in κ, γ, μ, whereas $\underline{q^P}$ is increasing in $\alpha, \psi, \beta, \gamma, \mu$ and decreasing in ρ. Combining these relationships implies that the size of the Monetary Dominance region is increasing in ρ, δ, λ and decreasing in $\kappa, \alpha, \psi, \gamma, \mu$ (the effect of β is ambiguous). Analogously, the conditions in (20) and (21) for the Macroprudential Dominance region become

$$(52) \qquad\qquad q^P < \overline{q_2^P} = \frac{1}{2}\underline{q_2^P} \quad \text{and} \quad q^C > \underline{q_2^C} = \left(\frac{2\beta + 2\gamma\mu}{2\beta + \gamma\mu}\right)\overline{q_2^C}.$$

The size of the Macroprudential Dominance region is influenced by all the variables in the opposite direction to the Monetary Dominance region. This means that a change in a certain parameter affects the size of the Monetary region relative to the Macroprudential Dominance region, but not necessarily the combined size of the two dominance regions relative to the Multiplicity region (and if so, only to a smaller extent). $\qquad\square$

The thresholds in (51)-(52) allow us to see the exact conditions under which the Stochastic follower's dominance of Proposition 3 can occur, as well as those under which a player's Dominance region does not occur at all. In discussing the intuition of Proposition 6, let us first highlight a consequence of the offsetting effect of a parameter change on the Macroprudential and Monetary Dominance regions. This property is apparent when comparing Figures 3 and 4. It implies that a change in a macroeconomic or policy preference parameter may in principle increase, decrease or not change the size of the Multiplicity region and the likelihood of a Policy Deadlock.

In regards to claims (i)-(ii), if a certain policy becomes more averse to its instrument variability (relative to its primary objective) then a given response to the credit shock becomes more costly to that policy. As such, yielding by playing S becomes comparatively less attractive than before, and the policy is less willing to cooperate on the opponent's

preferred outcome. This makes the policy's victory condition weaker - enlarging its dominance region. In effect, *low aversion to instrument variability is a strategic disadvantage in the Game of Chicken.*

The intuition of claim (iv) is similar. If output has a smaller effect on inflation then a given level of the leverage and/or output gap translates into a smaller deviation of inflation from the target. This means a Policy Deadlock is less costly for the central bank, and therefore a lower expected victory gain (i.e. a lower degree of leadership) is required for the central bank to uniquely play N. Formally, this makes the central bank's victory condition weaker and enlarges the size of the Monetary Dominance region.

In terms of claim (iii), if macroprudential policy becomes more effective in stabilizing leverage a less aggressive response (smaller change in P's instrument) is required to deal with a certain credit shock. This makes macroprudential measures less costly to P, which weakens P's yielding condition and makes the Monetary Dominance region bigger. This means that *being in charge of a highly potent instrument may turn out to be a strategic disadvantage, similarly to policy flexibility.*

Appendix G. Proof of Proposition 5

In the payoff matrix (14) each of the macroeconomic and policy preference parameters $\alpha, \beta, \gamma, \delta, \kappa, \lambda, \mu, \rho, \psi$ affects the payoffs of at least one policy. Furthermore, each parameter impacts at least one of the threshold levels between the scenarios reported in Section 6 and Appendix C, namely (19) and (27)-(30). The fact that expected payoffs and social welfare change across the scenarios in a non-monotone fashion, see Figure 1, implies the same about each of the underlying parameters. Proposition 2 shows the same to be true for the revision probabilities q^C and q^P.

The global claim that a given increase in $\frac{\rho}{\varphi}$ and/or $\frac{\kappa}{\lambda}$ may increase, not change or decrease the policies' expected payoffs and social welfare generalizes the local claims (i)-(ii) of Proposition 6. It can be proven by offering an example of such circumstances. For clarity we will focus on the specific parameter values in (15), and the case of P's Stochastic leadership such that $q^P = 0.1$ and $q^C = 0.5$. These values place the economy within the Multiplicity region of the Game of Chicken scenario in which the mixed-strategy Nash equilibrium is the most likely outcome. It yields expected payoffs of -4.5 and -5 for C and P respectively, and expected social welfare of -5. Keeping all other parameters in (15a) fixed, an increase in the central bank's aversion to lean against the wind ρ may have the following consequences:

(1) Expected social welfare *increases substantially*, from -5 to 0, if ρ increases sufficiently to convert the interaction into Monetary Dominance (either the scenario or the region within the Game of Chicken).

(2) Expected social welfare *increases somewhat,* from -5 to -2, if ρ does does not exceed a certain threshold whereas κ increases sufficiently. This is because Macroprudential Dominance arises (either the scenario itself or the region within the Game of Chicken).

(3) Expected social welfare *does not change* in principle if ρ changes in a way that still yields the Multiplicity region of the Game of Chicken scenario.

(4) Expected social welfare *decreases*, from -5 to -16, if both ρ and κ rise sufficiently to convert the interaction into the Policy Deadlock scenario.

APPENDIX H. FURTHER DETAILS ON MODIFICATIONS AND EXTENSIONS

H.1. **Idiosyncratic (Dependent) Macroprudential Authority.** In our benchmark specification we focused on the case of (partly or fully) benevolent macroprudential authority, $L^* = \bar{L}$. It was independent not only from the central bank, but also from the government and the financial sector lobby.[44] Because of that, our benchmark P did not face a time-inconsistency problem in the spirit of Kydland and Prescott (1977). Let us now consider the opposite case of a dependent macroprudential authority. This case should not be disregarded, also because the incentives for political and financial lobby interference to achieve short-term gains are arguably even greater than in monetary policy (see IMF, 2013a).

A politically-driven macroprudential authority can be represented by $L^* > \bar{L}$. This gives the authority an additional, stronger motive *not* to respond to the exuberant credit shock. By ignoring the shock P would not only avoid a loss from changing its instrument (due to $\kappa > 0$); it would in fact have a higher utility because excessively growing credit would bring leverage closer to its target L^*. The effect of $L^* > \bar{L}$ is (within a certain range) similar to a rise in κ. As such, the parameters' range that yields the Symbiosis and Monetary Dominance scenarios is reduced, and the other - socially undesirable - scenarios become more likely. In fact, if the difference $L^* - \bar{L}$ gets above a certain threshold then P starts preferring the minor bubble outcome (S, N) to the stability outcome (N, S) for *any* $\kappa \geq 0$. This implies that for credit shocks the Symbiosis scenario is unachievable even if the macroprudential authority does not mind changing its instrument, $\kappa = 0$.

Moreover, if the difference $L^* - \bar{L}$ increases above a different (higher) threshold then N becomes P's dominant strategy, and the normal-form game has a unique equilibrium. It features either a minor bubble (the Macroprudential Dominance scenario) or a major bubble (the Policy Deadlock scenario) - depending on whether ρ is below or above $\bar{\rho}$. In any case, the economy cannot reach its social optimum because the Symbiosis, Game of Chicken and Monetary Dominance scenarios can no longer occur. And this is the case even if the central bank is a strong Stochastic leader, i.e. for any timing of moves.

This implies Remark 4 in the main text, as well as another important advantage of the integration setup of M&Ms. Macroprudential policy benefits from central bank independence to shelter it from idiosyncratic political and financial influences. It took many years in the 1990s and early 2000s for central bank independence to fully develop - both de iure and de facto. Waiting that long for the separated macroprudential authority's independence to develop may be very costly.[45]

H.2. **Incorporating Fiscal Policy.** As we have focused on the short-run perspective of responding to financial shocks (excessive credit booms), fiscal policy was not included in the analysis. There is a consensus that fiscal policy is unsuitable for short-term stabilization of demand side shocks, unless they are very large (as in 2008-2009), and this is even more the case for credit shocks. Nevertheless, it needs to be acknowledged that

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[44]The results of Melecky and Podpiera (2013) imply that the institutional setup of macroprudential policy may be endogenous; the lobbying power of the financial sector may hinder policy integration and make the separation setup more likely.

[45]For an analysis of the effect of lacking central bank independence on monetary policy's responses to financial shocks see Berger and Kißmer (2013) and Ueda and Valencia (2014).

a fiscal aspect may still be present in the real world because the government provides fiscal backing for too-big-to-fail financial institutions as well as for the central bank's balance sheet (on the latter see Del Negro and Sims, 2015). Before we discuss how fiscal policy can be brought into the picture, let us first note some similarities of our macroprudential-monetary interactions to fiscal-monetary interactions.

Apart from Sargent and Wallace's (1981) unpleasant monetarist arithmetic, one way to interpret our analysis is a parallel to the work of Leeper (1991) and the Fiscal theory of the price level. This body of research has made the important point that we should not automatically *assume* the socially optimal policy regime, in which benevolent monetary and fiscal policymakers are capable and willing to perfectly coordinate their actions. Specifically, it is commonly assumed that fiscal policy is 'passive' and aims to balance the intertemporal budget constraint, which allows monetary policy to be 'active' and control the inflation rate. These authors have argued (see e.g. the papers discussed in Leeper and von Hagen, 2011) that such assumption may not be realistic - pointing to the unsustainable long-term stance of public finances in most countries. This literature implies that if fiscal policy is 'active' then monetary policy may be induced to be 'passive', and stabilize the real value of government debt.

We offer an analogous message with regards to an 'active' macroprudential policy. It can indirectly force monetary policy to be 'passive' on the macroeconomic front and stabilize credit shocks instead. Monetary policy dictated by financial stability however loses full control over price stability. This parallel with fiscal policy implies that, under some circumstances, the banking sector and macroprudential policy may in principle be determining the price level. Such possibility of a 'Macroprudential (or financial/banking) theory of the price level' should therefore be explored in microfounded models as well as in the data (for a valuable attempt see Kumhof and Benes, 2012).[46] Both mechanisms applying jointly would arguably make Tinbergen turn in his grave, because the central bank's interest rate instrument would be misused to stabilize three separate sets of objectives: monetary, fiscal and financial.

Formally, fiscal policy can be added into our reduced-form model as a partial substitute of M&Ms in stabilizing financial shocks. In the leverage equation (6) the considered exuberant credit shock $\varepsilon > 0$ would then be partly muted by contractionary fiscal policy in the form of government expenditure cuts or tax increases. Similarly to monetary policy, an element would also be included in the IS curve (7) to show fiscal policy's direct effect on output, and indirectly on inflation through the Phillips curve.[47]

In such setting the government's preferences include targets for leverage and output (as well as a possible aversion to variability of fiscal instruments). If the two targets are at the natural levels then the government is benevolent, and a similar interaction to the one examined in our benchmark specification applies. The difference would be that with three independent policies being able to stabilize financial and macroeconomic shocks,

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[46]In our Macroprudential Dominance regime the inflation target is achieved due to the specific choice of r^S. But recall that this only applies in the short run; the bursting of the resulting bubble would tend to jeopardize price stability over time - like under Sargent and Wallace's unpleasant arithmetic and Leeper's Fiscal theory.

[47]Hughes Hallett et al. (2011) do so in order to study monetary-fiscal interactions in regards to financial stabilization. However, autonomous macroprudential authority and instruments are absent in their framework.

the scope for mis-coordination and strategic conflict would be even greater than with just M&Ms (there would be three rather than two intertwined cords). This is summarized as Remark 5 in the main text. Assuming an idiosyncratic rather than a benevolent government would further magnify the challenges of a three-way policy coordination.

H.3. **Private Expectations.** Our specific macro model left out the expectational channel. This was necessary to disentangle the effect of strategic policy considerations from the effect of rational expectations of private agents. Intuitively, when strategic policy interactions affect leverage, output and inflation, as they do in our analysis, imposing rational expectations for these variables requires that agents also form expectations about the outcomes of this strategic policy interaction. But if we allow for such feedback effect between rational expectations of private agents and M&Ms outcomes (i.e. the S, N, and J actions to be functions of expectations), this becomes an infinite loop-type reasoning. So we could neither solve the game nor separate the impact of these two modelling features.

H.4. **Alternative Combinations of Credit and Demand Shocks.** We have throughout the paper focused on the case of an exuberant credit shock, $\varepsilon > 0 = \varepsilon^D$, i.e. the top middle cell of Table 1. It is however important to realize that the intuition of our analysis can be used for all other combinations of shocks.

H.4.1. *Negative Financial Shock.* This case of $\varepsilon < 0 = \varepsilon^D$ considered in Carrillo et al. (2017), referred to as a 'positive risk shock', is a mirror image of our benchmark situation. Under $\rho > 0$ and $\kappa > 0$ the central bank and prudential authority would again be reluctant to stabilize this shock via loosening their stance, and thus a virtually identical strategic policy conflict may occur. The intuition is the same as behind the headline 'Tight Money-Tight Credit' finding of Carrillo et al. (2017). The only difference from $\varepsilon > 0$ is that a real-world prudential authority may have a lower κ, i.e. it may be less averse to loosening macroprudential measures than to tightening them. Proposition 5 however shows that this does not necessarily reduce the likelihood of a policy conflict and inferior outcomes - unless κ is sufficiently small.

H.4.2. *Positive/Negative Demand Shocks.* These cases of $\varepsilon^D \neq 0 = \varepsilon$ are represented in Table 1 by the left and right cells of the middle row, and have generally been the focus of most of the macroeconomic literature prior to the 2008 crisis. In this case the roles of the policies are reversed relative to our benchmark setting, and so is the social optimum. It is now (S, N), i.e. society prefers the central bank to use its comparative advantage and stabilize the demand shock using monetary policy, whereas macroprudential policy does not respond. As such, ρ no longer expresses aversion to leaning against the wind in the financial markets. Furthermore, the interpretation of the types of policymakers is the opposite. Only central banks with $\rho = 0$ are fully-benevolent, whereas those with $\rho > 0$ are partially-benevolent. On the other hand, the macroprudential authority is fully-benevolent for any $\kappa \geq 0$.

In principle, there could still be a strategic conflict between M&Ms analogous to our benchmark analysis. The outcomes of both policies would again depend on the values of their secondary objectives relative to their primary objectives, as well as all the other parameters. The five scenarios of Figure 1 could still occur. Within the Game of

Chicken scenario, the policy with a sufficiently greater degree of leadership (low revision probability) would dominate and ensure its preferred regime.

In high-income countries, a Policy Deadlock and other inferior outcomes are however unlikely in regards to demand shocks. Central banks historically do not have a problem responding to demand shocks, and have a solid track record of keeping price inflation on target (which implies an output target equal to the natural rate). It is the case also because they are formally accountable for achieving their numerical inflation target. This implies that ρ is likely to be low in the case of demand shocks. In contrast, the macroprudential authority is likely to be even more averse to responding to demand shocks than to financial shocks, which implies a high value of κ in this case. Therefore, under demand shocks Macroprudential Dominance or Symbiosis are highly likely, and so is the socially optimal outcome (S, N).[48]

H.4.3. *Financial and Demand Shocks in the Same Direction.* Focus on the two cells of Table 1 featuring shocks with the same sign, i.e. $\varepsilon^D > 0 < \varepsilon$ and $\varepsilon^D < 0 > \varepsilon$ (the latter occurring e.g. during 2007-2009). In this case both policies have an incentive to respond to their own shock in pursuit of their primary objective. Nevertheless, both may again hope for the other policy to respond to a greater extent and thus help them to minimize their own instrument variability. This implies that while a Policy Deadlock and Regime Switching are less likely under such combination of shocks than under our benchmark shocks, they should not be fully excluded from consideration of policy conflict. Our earlier insights apply here as well, namely that the more pre-committed policy (Stochastic leader) may be able to induce the opponent to stabilize 'more than a fair share' of the combined shocks.

H.4.4. *Financial and Demand Shocks in the Opposite Direction.* Consider the two cells of Table 1 featuring shocks with opposites signs, i.e. $\varepsilon^D > 0 > \varepsilon$ and $\varepsilon^D < 0 < \varepsilon$ (the latter e.g. during 2011-2016). They feature a tradeoffs-driven conflict, because the optimal action of one policy in pursuit of its primary objective goes directly against the optimal actions of the other policy - one is tightening and one loosening conditions. Nevertheless, a tradeoffs-driven conflict implies a strategic policy conflict; potentially a more intense one because the constraints of the economy stand in the way of effective policy coordination. The conflict in this case has a different manifestation to the baseline analysis (for low levels of $\frac{\rho}{\varphi}$ and $\frac{\kappa}{\lambda}$). Rather than trying to induce the opponent into action (S) by inaction (N), each policymaker tries to offset the opponent's action by a *more aggressive* action. Such tug-of-war (S, S) outcome, interpretable as Tight Money-Tight Credit, is counter-productive and only leads to an overall increase in volatility of financial and macro variables. This is summarized as Remark 6 in the main text.

H.5. **Longer-term Perspective and Policymakers' Discounting.** A longer-term macro specification must ensure that leverage and output go back towards their natural levels, i.e. a 'correction' must take place if a temporary bubble occurs. Such correction

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[48]The (effective) zero lower bound on interest rates obviously plays a role here. If it is binding, the central bank cannot use conventional monetary policy measures and hence the use of macroprudential (or fiscal) instruments may become appropriate.

implies greater variability of all the main variables, the size of which is increasing with the size of the short-term imbalance - i.e. it is greater after (N, N) than after (S, N).

Nevertheless, if the macroprudential authority is impatient, it largely discounts these longer-term effects, so the results of our benchmark analysis would be unchanged. The only difference may be that a patient (long-term oriented) central bank would be more open to leaning against the wind (for a given ρ) in order to avoid major corrections and crises resulting from a Policy Deadlock. In the presence of an impatient macroprudential authority, the central bank's patience may therefore decrease (increase) the likelihood of the Monetary (Macroprudential) Dominance scenario, and turn out to be a strategic disadvantage for the central bank and society. This is summarized in Remark 7, whereby the case of Sweden seems to be a case in point.

In the opposite situation of a patient prudential authority the longer-term perspective would make macroprudential policy more open to stabilizing credit shocks - with the view of minimizing future (post-correction) financial and economic variability. Such P would therefore favour the society's first-best (N, S) over the third-best (S, N) for a greater range of κ. This would have the quantitative effect of making the Policy Deadlock and Macroprudential Dominance scenarios less likely, and the Symbiosis of M&Ms more likely. It can therefore be concluded that institutional measures that lengthen the optimizing horizon of the macroprudential policymaker improve the chances of implicit coordination - increasing expected social welfare. This seems highly desirable given the growing magnitude of costly financial cycles over the past four decades.

Appendix I. Monetary Policy Reforms Towards Transparency

In search for the explanation of the high inflation of the 1970s, one stream of the literature initiated by Rogoff (1985) had suggested that monetary policy should be delegated to an independent and conservative central bank in order to eliminate the inflation bias and improve monetary policy credibility. The pioneering Reserve Bank of New Zealand Act of 1989 combined the needed instrument independence with a high degree of transparency and accountability - essentially constituting a contract with the Governor of the central bank (see Walsh, 1995). Transparency related to several policy areas, but the key was legislating a numerical inflation target for which the Governor was personally accountable. Obviously, to leave room for short-run stabilization policy, the inflation target in most countries has been specified as a medium-term objective that only needs to be achieved on average over the business cycle, not at every point in time. There exists substantial evidence that explicit inflation targets have indeed improved monetary policy credibility and did not lead to greater volatility of output (see Libich, 2011).