

# Intervention Policy in a Dynamic Environment: Coordination and Learning\*

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## Abstract

We model a dynamic economy with strategic complementarity among investors and endogenous government interventions that mitigate coordination failures. We establish equilibrium existence and uniqueness, and show that one intervention can affect another through altering public information structure. A stronger initial intervention helps subsequent interventions through increasing likelihood of positive news, but also leads to negative conditional updates. Our results suggest that optimal policy should emphasize initial interventions when coordination outcomes tend to correlate. Neglecting informational externalities of initial interventions results in over- or under-interventions depending on intervention costs. Moreover, saving smaller funds before saving the big ones under certain circumstances costs less and generates greater informational benefits. Our paper is informative of multiple intervention programs such as those during the 2008 financial crisis.

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# 1 Introduction

Coordination failures are prevalent and socially costly. Thus, effective interventions may ameliorate such damaging outcomes. For example, financial systems, especially short-term credit markets, are vulnerable to liquidity shocks and runs by investors. The 2008 financial crisis witnessed a series of runs on both financial and non-financial institutions. In response, governments and central banks around the globe employed an array of policy actions over time. Given the novelty, the scale, and the intertwined nature of such interventions, it is natural to study how costly endogenous interventions relate to each other.

More broadly, how should a government formulate intervention policy in a dynamic economy with strategic complementarity? How does intervention in one institution or market affect subsequent interventions in other institutions or markets? This paper tackles these questions by modeling the government as a large player in sequential global games, and focusing on information transmission from one intervention to another. We find that many interventions not only improve welfare contemporaneously, but also dynamically affect coordination among agents in future interventions. Consequently, when intervention costs are comparable across coordination games, optimal policy often features an emphasis on the initial intervention. Decision-makers for one intervention may not internalize the informational externality of the intervention outcome on other interventions, thus may over- or under-intervene depending on the intervention costs. Moreover, an optimal policy may entail saving smaller funds first before saving larger funds to generate an information structure with less cost but greater benefits. The insights apply to situations with multiple interventions in which agents' actions exhibit strategic complementarity. Examples include interventions in currency attacks, stock market crises, bank runs, real estate programs, cross-sector industrialization, and technology subsidy programs.

We introduce the model in the context of runs on Market Market Mutual Funds (MMMMFs) in September 2008 and subsequently on commercial papers, both triggered by investors' interpretation of Lehman's failure as a revelation of the credit risk and systemic illiquidity of commercial paper.<sup>1</sup> The initial successful intervention with unlimited insurance to all

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<sup>1</sup>The run on commercial papers is primarily in financial commercial papers as opposed to ABCPs, according to Kacperczyk and Schnabl (2010).

MMMF depositors and the Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facilities (AMLF) arguably affected how investors reacted to later interventions in the commercial paper market such as the Commercial Paper Funding Facility (CPFF) program.<sup>2</sup> Another context that motivates the study is the federal governments multiple attempts at stabilizing the housing market in a wide range of regions through the Neighborhood Stabilization Programs (NSPs) of 2008-2010.<sup>3</sup> These interventions provided funding for local housing authorities to purchase, renovate, and sell foreclosed properties in an effort to moderate the sizeable declines in home prices driven by the massive wave of foreclosures during the credit crisis.<sup>4</sup> Because the intervention outcomes were revealed gradually over time, and housing markets across neighborhoods share common component, people update their priors on the underlying health of housing markets from initial intervention outcomes, and behave differently in the local program.

Specifically, in a two-period economy, a group of atomistic investors in each period choose whether to run or remain invested in a fund.<sup>5</sup> Running guarantees a higher payoff if the fund fails, whereas staying pays more if the fund survives. The fund survives if and only if the total measure of investors who choose to stay is above a fundamental threshold  $\theta_t$  – interpreted as an unhedgeable system-wide illiquidity shock or as a measure of the persistent quality of the underlying investment, and is ex-ante positively correlated across the two periods. Following the global games framework,  $\theta$  in each period is unobservable and each investor receives a noisy signal. Prior literature has established that in static settings, there exists a unique equilibrium in which the fund survives as long as the true  $\theta$  is below a threshold  $\theta^*$ , and each investor stays if and only if his private signal is below a certain threshold  $x^*$ .

We then incorporate policy responses in a crisis and the formation of expectations by

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<sup>2</sup>See Schmidt, Timmermann, and Wermers (2016) for more details on the run on MMMFs. As discussed in Bernanke (2015) page 283, the government was keenly aware that AIG’s failure might affect market participants’ beliefs and lead to runs in other markets, just like Lehman’s commercial paper had triggered the run on money market funds.

<sup>3</sup>See Westrupp (2017) for a summary of the NSP and its impact on mitigating foreclosure externalities.

<sup>4</sup>One may view regional foreclosures as broadly analogous to “runs” due to the negative externality of a particular foreclosure on the values of neighboring properties. For example, Campbell, Giglio, and Pathak (2011) document a negative spillover effect of 1% per new foreclosure within a 0.10 mile radius. Guiso, Sapienza, and Zingales (2013) document the prevalence of strategic defaults during this period.

<sup>5</sup>Running on the fund in the first period corresponds to the run on MMMFs, and that in the second period corresponds to the run in financial commercial papers’ market.

modeling interventions in our baseline setup as direct liquidity injections to funds experiencing runs.<sup>6</sup> The equilibrium  $\theta^*$  increases strictly with the size of government's intervention  $m$ : a greater liquidity injection makes the fund more likely to survive. Therefore, in a static economy, a benevolent government trades off this contemporaneous benefit and intervention costs.

In a dynamic setting, government intervention in the first period alters the informational environment in the second period. Indeed, agents' prior beliefs on  $\theta_2$  are truncated, since whether or not a run occurs during the first period is public information. When the fund has survived in the first period, agents learn that  $\theta_1 < \theta_1^*$ , and with positive probability that their belief on  $\theta_2$  shifts downwards, making coordination easier. The opposite holds if the fund has failed in the first period. To the extent this public signal is useful, initial success increases the likelihood of subsequent success and initial failure increases the likelihood of subsequent failure, endogenously giving rise to the greater tendency for coordination outcomes across different periods to be correlated (*endogenous correlation effect*). Initial intervention is then more important as it increases the probability of survival in both periods.

However, initial intervention also has an informational cost, and thus its magnitude must be tempered. When a large intervention leads to a fund's survival, investors may infer that the outcome is due to the intervention itself and not on strong fundamentals. Conversely, if the fund fails despite a large initial intervention, investors become even more pessimistic about the market's fundamentals. This *conditional inference effect* on beliefs harms investors' welfare and drives the government to intervene less for more favorable conditional updates. Therefore, the optimal policy has to consider the initial intervention's informational effect and trade off the two competing forces: intervening more to increase the likelihood of good news (truncating  $\theta$  from above), and intervening less initially to encourage more favorable conditional updates (lower  $\theta^*$ ).

We establish results on the existence and uniqueness of equilibrium and study the impli-

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<sup>6</sup>Many crisis interventions are indeed direct liquidity injections. For example, Duygan-Bump, Parkinson, Rosengren, Suarez, and Willen (2013) discuss how AMLF and CPFF were essentially liquidity injections that alleviated funds' pressure to meet redemptions without suffering fire sales. Other examples include the Economic Stimulus Act of 2008 that reduced firms' tax obligations directly, or TARP which intended to improve the liquidity of hard-to-value assets through secondary market mechanisms. We discuss how our setup nests other forms of intervention in Section 5.6.

cations for the optimal policy of a benevolent government. When the intervention costs are comparable that the endogenous intervention amounts are similar even absent public learning, the endogenous correlation effect dominates. Optimal policy then generally emphasizes initial intervention – the scale of intervention in the first period always exceeds that in the second period – to kill two birds with one stone (improving fund survivals in both periods).

This result also implies that a decision maker who neglects the informational externality of one intervention on another would under-intervene initially. However, when the intervention costs across the two periods differ drastically, so much so that survival in the first period does not guarantee survival in the second period (when second period cost is too high relative to the first and private signals are relevant for the marginal investor), nor does failure lead to failure (when second period cost is so low that one can intervene more despite the negative update from first period’s failure), the conditional inference effect can dominate. The more the government considers the informational externality, the more it shades intervention. This intuition also applies to countries and regions sharing common fundamentals where one country’s investors learn from another country’s intervention outcome. In that sense, a global social planner such as the European Union may have a role in mitigating inefficient interventions in member countries or states.

Finally, when the government endogenously decides the order of interventions in funds of different sizes, the larger fund is “too big to save first”, because it costs less to intervene in the smaller fund first to induce the same updating on the fundamentals, and the larger fund benefits more from the reduced uncertainty. This complements studies on institutions deemed “too big to fail” in that though bigger funds could be systemically important, they are generally not the best targets in an initial intervention.

This paper contributes to our understanding of how interventions shape the information environment during a crisis, hence is useful for studying and assessing policies that aim to avoid inefficient equilibria. In particular, we highlight the role of government intervention on information structure: not only does it affect the probability of good news versus bad news, but it also affects the informativeness of news.<sup>7</sup> It thus complements existing

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<sup>7</sup>Bernanke and Geithner spoke of the financial crisis as a bank run and emphasized the need to combat a financial crisis with the “use of overwhelming force to quell panics” (p. 397 in Geithner (2014)), a tactic of “shock and awe” that often connotes managing market expectations by the government. This means not

work on government interventions in markets with strategic complementarity.<sup>8</sup> For example, Acharya and Thakor (2014) consider how liquidation decisions by informed creditors of one bank signal systematic shocks to other creditors and create contagions, and how selective bailout could be efficient when the regulator observes the systematic shock. Huang (2016) studies how the interaction between policy maker’s reputation building and speculators’ learning of the policy-maker’s type determines speculative attacks and regime changes. Regarding the design of intervention policy, Bebchuk and Goldstein (2011) examine the effectiveness of various forms (rather than the extent) of exogenous government policies in avoiding self-fulfilling credit market freezes, Sakovics and Steiner (2012) analyze who matters in coordination failures and how to set intervention targets, and Choi (2014) shows the importance of bolstering the strong in order to prevent contagion. Like these studies that focus on one particular aspect of intervention, we demonstrate how information structure design should play an important role in formulating intervention policies, and should be considered together with previously discussed factors. Different from them all, this paper concerns the dynamic interaction of multiple endogenous interventions under general cost functions.

This paper is also related to global games and equilibrium selection (Carlsson and Van Damme, 1993; Morris and Shin, 1998), especially in dynamic settings (Frankel and Pauzner, 2000; Angeletos, Hellwig, and Pavan, 2007), with the government as a large player (Corsetti, Dasgupta, Morris, and Shin, 2004; Angeletos, Hellwig, and Pavan, 2006). Our paper adds to earlier studies by explicitly modeling the government as a large player that endogenously selects coordination equilibrium through both static and dynamic channels, in order to provide theoretical insights on how endogenous interventions relate to one another. Different from Angeletos, Hellwig, and Pavan (2006) that demonstrate that endogenous intervention signals government type and leads to equilibrium multiplicity, our paper explores how endogenous intervention shapes information structure rather than signaling govern-

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only do the financial networks matter for intervention policies, information structure also plays a crucial role in coordination. Although it is challenging to isolate the informational aspect from systemic connectedness, it was an important element of both the Lehman Brothers episode and the Eurozone bank bailouts in 2010 and 2011.

<sup>8</sup>Strategic complementarity in financial markets is well-recognized in prior literature such as Diamond and Dybvig (1983), and more recently by empirical studies including Chen, Goldstein, and Jiang (2010) and Hertzberg, Liberti, and Paravisini (2011).

ment’s private information. This paper is most closely related to Angeletos, Hellwig, and Pavan (2007) that extend global games to a dynamic setup where agents take actions over multiple periods and can learn about the fundamental over time. The authors point out that multiplicity resurfaces from the interaction between endogenous learning based on regime survivals and exogenous learning induced by private news arrivals.<sup>9</sup> We introduce endogenous interventions, which leads to endogenous equilibrium multiplicity and selection, and show that the policy and public learning feedback each other and have profound implications on the optimal policy design and coordination outcomes. We also demonstrate that either shutting down the interaction of public learning and private learning, or reducing the private signal precision would restore uniqueness even in a dynamic setting.

Finally, this paper adds to the emerging literature on finance applications of information design and Bayesian persuasion (e.g. Myerson (2013); Gentzkow and Kamenica (2011); Bergemann and Morris (2017)). In particular, it is related to Goldstein and Huang (2016) that model policy-makers costlessly and endogenously design information in a coordination game. The authors focus on a one-shot intervention where the government pre-commits to a regime change policy in order to increase the probability of the survival of the status-quo. The information transmission relies on the truncation of beliefs as in Angeletos, Hellwig, and Pavan (2007), but is endogenous, and there is no learning across multiple coordination games. Lenkey and Song (2016) is another paper that analyzes the tradeoffs in information design to study how a redemption fee affects runs on financial institutions when investors are asymmetrically informed about fundamentals. Our paper adds to both Goldstein and Huang (2016) and Lenkey and Song (2016) by introducing costly information design and underscoring the role of intervention costs in determining optimal information structure and policy (as well as characterizing the tradeoffs in information design more analytically). Most distinctly, the endogenous correlation effect is novel and to our best knowledge, we are the first to derive implications of information design on how multiple endogenous interventions relate to one another.

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<sup>9</sup>The Bayesian learning from public signals without endogenous government actions has also been discussed in several other papers. For example, Manz (2010) studies information contagion; Ahnert and Bertsch (2015) study information choice and contagion after wake-up-calls; Taketa (2004), studies contagion via a common investor base; Li and Ma (2016) study contagion and fire sales after a bank run. We thank an anonymous referee for suggesting this literature.

The rest of the paper is organized as follows: Section 2 lays out the basic framework and establishes a static benchmark. Section 3 characterizes the equilibrium in dynamic settings. Section 4 solves for the optimal policy and presents its implications. Section 5 discusses the results and extends the model. Section 6 concludes.

## 2 Model

This section introduces the model with a representative intervention form: government directly infusing liquidity to funds subject to runs in each period.<sup>10</sup> We start by analyzing a static model as our benchmark in Section 2.1 and move to the dynamic setting in Section 2.2.

### 2.1 Static Benchmark

#### Model setup

A fund has a continuum of investors indexed by  $i$  and normalized to unit measure. Each has one unit capital invested in the fund, and simultaneously choose between two actions: stay ( $a_i = 1$ ) or withdraw ( $a_i = 0$ ). For the remaining analysis, we interpret withdrawals as “runs” on the fund, and staying can be interpreted as rolling over short-term debts. The net payoff from running on the fund and investing the proceeds in an alternative vehicle (such as treasury bill) is always equal to  $r$ , whereas the payoff to each investor from staying is  $R$  if the fund survives the run ( $s = S$ ), and is 0 if the fund fails ( $s = F$ ). Let  $R > r > 0$ , then an investor finds it optimal to stay if and only if she expects the probability of survival exceeds the cost of illiquidity defined as  $c \equiv \frac{r}{R}$ . Table 1 (left panel) shows the net payoff of each action under different states and actions. In the right panel of Table 1, we normalize the payoff matrix by subtracting  $r$  and scaling by  $\frac{1}{R}$ . For notational convenience, we use the normalized net payoffs for the remainder of the paper.

Agents’ decisions are complements: the fund is more likely to survive as more agents

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<sup>10</sup>Section 5.6 discusses how this setup applies to other intervention forms.

Table 1: Net Payoffs and Normalized Net Payoffs

	Stay	Run		Stay	Run
Survive	$R$	$r$	Survive	$1 - c$	$0$
Fail	$0$	$r$	Fail	$-c$	$0$

choose to stay. Specifically, the fund survives if and only if

$$A + m \geq \theta \tag{1}$$

where  $A$  represents total measure of agents who choose to stay,  $m \in [0, \bar{m}]$  is the size of the government’s liquidity injection to the fund and is bounded above by a constant  $\bar{m} > 0$ , and  $\theta \in \mathbb{R}$  summarizes the underlying fundamental.<sup>11</sup> In the context of the run on MMMFs in 2008,  $A$  would represent the volume of net redemption of fund shares,  $m$  represents the magnitude of government intervention, such as insurance offerings and liquidity facilities.  $\theta$  represents the fundamental degree of illiquidity of the underlying fund assets. For the fund to survive, the remaining liquidity  $A + m$  must dominate the liquidity shock  $\theta$ . The government cares about social welfare comprised of investors’ total payoff less the intervention cost  $k(m)$ , which is weakly increasing and convex.  $k(m)$  captures the legal political capital expended, tax distortion, or moral hazard associated with the intervention policy.<sup>12</sup>

Apparently, coordination is needed when both  $\theta$  and  $m$  are commonly known by all agents. Indeed, if  $\theta - m \in (0, 1)$ , two equilibria coexist. In one equilibrium, all investors stay and in the other one, all investors run. Global games resolve this issue of equilibrium multiplicity through introducing incomplete information. We apply the same technique to assume that agents each observe a noisy private signal of  $\theta$ . In particular, agent  $i$  observes,

$$x_i = \theta + \varepsilon_i \tag{2}$$

where the noise  $\varepsilon_i \sim Unif[-\delta, \delta]$  is i.i.d. across investors. For simplicity, we assume that the

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<sup>11</sup>Similar to Goldstein and Huang (2016), we assume the government publicly commits to the intervention. We note that  $\theta$  can be interpreted as the government’s credibility as well. See Bernanke (2015) pages 218-219.

<sup>12</sup>Intervention costs and political constraints are real, at least at the onset of the crisis (Swagel (2015)). In Section 5.4, we model fund managers’ actions and microfound the cost using moral hazard induced by interventions.

prior distribution of  $\theta$  is uniform on  $[-B, B]$  where  $B \gg \max\{\delta, \bar{m}\}$ .<sup>13</sup> We also assume the government does not know the realization of the fundamental  $\theta$  and does not have private signal about it.<sup>14</sup>

The timing in this single-period game is as follows: the government announces  $m$ , then each investor  $i$  receives a private signal  $x_i$ , and plays the stage game choosing whether to stay, before their payoffs are realized. We restrict the equilibrium set to symmetric Perfect Bayesian Equilibria (PBE) in monotone strategies: all agents' strategies are symmetric and monotonic *w.r.t.*  $x$  and  $m$ .<sup>15</sup> Specifically, agent  $i$ 's strategy  $a_i(x_i, m)$  is non-increasing in  $x_i$  and non-decreasing in  $m$ . We first examine the equilibrium of investors' stage game in each period given the government's action.

### Investors' Stage Game Given Intervention

Since  $B \gg \max\{\delta, \bar{m}\}$ , it is *w.l.o.g.* to further restrict the equilibrium set to threshold equilibria denoted by  $(\theta^*, x^*)$ . The fund survives if and only if  $\theta \leq \theta^*$  and each investor stays if and only if his signal  $x \leq x^*$ . Lemma 1 below summarizes the equilibrium outcome in the static game.

#### Lemma 1

*In the static game, there exists a unique symmetric PBE in monotone strategies  $(\theta^*, x^*)$ ,*

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<sup>13</sup>We assume  $B$  is sufficiently large relative to  $\bar{m}$  so that the government cannot guarantee a successful intervention. This is a realistic feature also present in Dávila and Goldstein (2015). Uninformative prior corresponds to  $B \rightarrow \infty$ . We use uniform distributions for greater analytical tractability, see also Goldstein and Pauzner (2005) and Bouvard, Chaigneau, and Motta (2015). Section 5 discusses Normally distributed signals and the role of bounded support on equilibrium multiplicity.

<sup>14</sup>Essentially we are assuming that institutional investors are typically more informed about the fundamental state of the market, which is consistent with Diamond and Kashyap (2015) (financial institutions know more about the fundamental illiquidity), Bond and Goldstein (2015) (government relies on market prices to learn fundamentals), Sakovics and Steiner (2012) (governments' inferior knowledge on utilizing or allocating resources leads to tax and subsidy distortions), and Bernanke (2015) (government uncertain about how the market reacts to intervention).

<sup>15</sup>In fact, Van Zandt and Vives (2007) show that with regularity conditions ensuring the games are monotone supermodular, we do not need to limit ourselves to monotone strategies. While that holds at least in many static games (Morris and Shin (1998); Vives (2014); Bebchuk and Goldstein (2011)) including our static game, it is not the main focus and we simply concentrate on the natural case of monotone strategies, especially in our dynamic setup.

where

$$\begin{cases} \theta^* &= 1 + m - c \\ x^* &= 1 + m - c + \delta(1 - 2c). \end{cases} \quad (3)$$

Each investor's strategy follows  $a_i = \mathbb{1}\{x_i \leq x^*\}$ . The fund's outcome  $s = S$  if  $\theta \leq \theta^*$  and  $s = F$  otherwise.

According to Lemma 1, the fund survives if and only if  $\theta \leq \theta^*$ . Each agent stays if and only if his private signal  $x_i \leq x^*$ . Note that  $\theta^*$  increases in  $m$  and so is  $x^*$ . In other words, the fund is more likely to survive and investors are more inclined to stay if the size of government intervention increases. This is the static effect of government intervention on coordination. In the next section, we show that government intervention has dynamic coordination effects.

## Welfare and Optimal Intervention

Let  $V_i$  be investor  $i$ 's net payoff and  $W = E \left[ \int_0^1 V_i di \right]$ . Then investors' welfare is

$$W = \frac{1}{2B} \left[ \underbrace{\int_{-B}^{\theta^*} (1-c) d\theta}_{\text{fundamental}} - \underbrace{\int_{x^*-\delta}^{\theta^*} (1-c) \left( 1 - \frac{x^* - (\theta - \delta)}{2\delta} \right) d\theta}_{\text{overrun}} - \underbrace{\int_{\theta^*}^{x^*+\delta} c \frac{x^* - (\theta - \delta)}{2\delta} d\theta}_{\text{underrun}} \right]$$

Let us interpret the above payoff function.  $\frac{1}{2B}$  is the probability density of the uniform distribution. The terms inside the square bracket split into three terms. The first term, *fundamental*, equals to the net payoff if all agents stay when the fund survives. The second term, *overrun*, represents the net payoff loss due to the fact that some agents choose to run when the fund survives. The last term, *underrun*, is the net loss from agents who choose to stay when the fund fails.

Simple calculation suggests that total welfare is

$$W - k(m) = \frac{(1-c)[1 + B - c(1 + \delta) + m]}{2B} - k(m)$$

The marginal benefit of  $m$  on  $W$  is a constant,  $\frac{(1-c)}{2B}$ . This result comes from the fact that an increase in  $m$  also raises  $\theta^*$  linearly, making the fund more likely to survive.  $\frac{(1-c)}{2B}$  is the net payoff from stay  $1 - c$ , scaled by the probability density  $\frac{1}{2B}$ . Therefore, intervention improves coordination. Because the intervention cost lies in a compact set, there always exists an optimal intervention:

$$m^* = \sup \left\{ m \in [0, \bar{m}] : \lim_{\epsilon \rightarrow 0} \frac{k(m + \epsilon) - k(m)}{\epsilon} \leq \frac{1 - c}{2B} \right\}$$

For example, if  $k(m) = \frac{1}{2}zm^2$ , then  $m^* = \min \left\{ \frac{1-c}{2zB}, 1 \right\}$ .

## 2.2 Dynamic Economy

We now extend the static model to a two-period dynamic economy. In each period, there is a unit measure of agents who choose whether or not to stay or run. The government intervenes in each period with  $m_1$  and  $m_2$ . Agents in period 2 observe whether or not there was a run in period one. To focus on Bayesian learning from public intervention outcomes, we assume that the mass of agents in each period are non-overlapping, in that they do not observe the private signals in other periods. The government's cost of intervention now is  $K(m_1, m_2)$ , which is weakly increasing and convex in both arguments, and satisfies  $K(0, 0) = 0$ , where  $\{m_1, m_2\} \in I$ , and  $I \subset R^2$  indicates a convex set of feasible interventions. For ease of exposition, we assume for the remaining of the paper that the cost is defined on  $\mathcal{C}[0, \bar{m}_1] \times \mathcal{C}[0, \bar{m}_2]$ , where  $\bar{m}_1$  and  $\bar{m}_2$  are finite constants.

Importantly, the two periods are linked: (a) the fundamentals  $\{\theta_t\}_{t=1,2}$  are identical across two periods. We omit the subscript of  $\theta$  now and relax the assumption in Section 5.3 by only requiring positively correlated fundamentals; (b) agents in period 2 also observe the public outcome of whether investment has succeeded in the first period, indicated by  $s_1 = S$  or  $s_1 = F$ ; (c) there could potentially be interaction between the costs of intervention across the two periods.

The government chooses interventions to maximize investors' welfare subtracting the intervention cost  $K(m_1, m_2)$ . In each period, agents simultaneously choose between stay with the fund ( $a_t = 1$ ) or run ( $a_t = 0$ ). The period-by-period normalized payoff structure is

identical to the static game: running ( $a_t = 0$ ) always guarantees 0 payoff whereas staying ( $a_t = 1$ ) pays off  $1 - c$  in survival and  $-c$  in failure. Agents' decisions within the same period are complements: investment in period  $t$  succeeds if and only if

$$A_t + m_t \geq \theta, \tag{4}$$

where  $A_t$  is the total measure of investors who choose to invest,  $m_t$  denotes the size of liquidity injected by the government. Again,  $\theta$  represents the fundamental. Similar to the interpretation of the static game, the runs could represent runs on MMMF and financial commercial papers respectively, with  $\theta$  representing the market-wide illiquidity or credit issues for commercial papers that affects both periods.

The timing within each period goes as follows. First, government announces  $m_t$ . Second, each investor  $i$  in period  $t$  receives a private signal  $x_{it} = \theta + \varepsilon_{it}$  about the fundamental where  $\varepsilon_{it} \sim Unif[-\delta, \delta]$ . Lastly, investors choose whether to stay and their payoffs realize. The setup is dynamic in the sense that period 1's outcome is revealed before investors take actions in period 2.

In the baseline, we study a problem in which the government maximizes welfare by solving

$$\max_{m_1, m_2} E \left[ \int_0^1 V_{1i} di + \int_0^1 V_{2i} di \right] - K(m_1, m_2). \tag{5}$$

Given  $\mathcal{I}$  is compact, an optimal policy exists in general, which exhibits interesting features. We solve this problem in two steps. The next section takes government interventions as given, and derive the stage game equilibrium of coordination. Section 4 then examines a benevolent government's optimal policy design. the posterior distribution of theta is impacted by the fact that the MMMF market did not fail, perhaps due to the earlier intervention

### 3 Coordination Equilibrium

Our equilibrium concept is symmetric Perfect Bayesian equilibria (PBE) in monotone strategies. We first examine the stage game of investors' coordination in each period, taking the intervention as given. Specifically, all agents' strategies are symmetric and monotonic

w.r.t.  $x_t$  and  $m_t$ : agent  $i$ 's strategy in period  $t$ ,  $a_{it}(x_{it})$ , is non-increasing in  $x_{it}$  and non-decreasing in  $m_t$ ,  $t = 1, 2$ .

### 3.1 Equilibrium and Social Welfare in Period 1

The analysis in period 1 is identical to the static game. We relabel the unique threshold equilibrium with time subscripts  $(\theta_1^*, x_1^*) = (1 + m_1 - c, 1 + m_1 - c + \delta(1 - 2c))$ . The fate of the fund is  $s_1 = S$  if  $\theta \leq \theta_1^*$  and  $s_1 = F$  otherwise. Agents adopt a threshold strategy  $a_{i1} = \mathbb{1}\{x_{i1} \leq x_1^*\}$ .

The social welfare in period 1 is also identical to the static economy,

$$W_1 - K(m_1, 0) = \frac{(1 - c)[1 + B - c(1 + \delta) + m_1]}{2B} - K(m_1, 0).$$

### 3.2 Equilibrium in Period 2

In period 2, the outcome of period 1 intervention (henceforth referred to as public news) is publicly known. As a result, beliefs on  $\theta$  are truncated either from above or from below.

Unless specified otherwise, we assume for the remainder of the paper  $2\delta > 1$  and  $\frac{1}{2\delta+1} < c < \frac{2\delta}{1+2\delta}$ . These assumptions correspond to the fact that during crisis uncertainty is high and cost of illiquidity is in an intermediate range where agents do not overwhelmingly prefer staying or running. These assumptions ensure a unique threshold equilibrium in period 2 for both  $s_1 = S$  and  $s_1 = F$ , and for all values that  $m_1$  and  $m_2$  take on.<sup>16</sup>

#### 3.2.1 Survival News

If the fund in period 1 has survived ( $s_1 = S$ ), the prior belief on  $\theta$  is bounded above at  $\theta_1^*$ :  $\theta \sim Unif[-B, \theta_1^*]$ . In this case, it is possible that investors stay regardless of their signals. In fact, this is the equilibrium if and only if  $m_2 > m_1 - c$ . In this equilibrium, the (hypothetical) threshold  $x_2^*$  satisfies  $x_2^* \geq \theta_1^* + \delta$ , which is always above all agents' realized signals. We call such equilibrium *Equilibrium with Dynamic Coordination* because the government's intervention in the first period has a dominant effect on improving coordination

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<sup>16</sup>We discuss equilibrium multiplicity and the case of  $\delta \rightarrow 0$  in Section 5.1.

among investors in the second period:

**Lemma 2** (Stage Game Equilibrium with Dynamic Coordination)

If  $s_1 = S$ ,  $(\theta_2^*, x_2^*) = (\infty, \infty)$  consists an equilibrium if and only if  $m_2 > m_1 - c$ .<sup>17</sup>

Next, we turn to threshold equilibria with  $\theta_2^* < \theta_1^*$  so that the fate of the fund in period 2 still has uncertainty. Likewise, any threshold equilibrium  $(\theta_2^*, x_2^*)$  necessarily satisfies two conditions. First, when  $\theta = \theta_2^*$ ,  $A_2 + m_2 = \Pr(x_2 < x_2^* | \theta = \theta_2^*) + m_2 = \theta_2^*$ . Second, the marginal agent who receives the signal  $x_2^*$  is just indifferent between stay and run,  $\Pr(\theta \leq \theta_2^* | x_2 = x_2^*, \theta \in [-B, \theta_1^*]) = c$ .

We analyze the equilibrium in two cases, depending on whether the marginal investor finds the public news “useful”. Ignoring the public news, the marginal investor’s posterior belief on  $\theta$  is simply  $\Pr(\theta | x_2 = x_2^*) \sim \text{Unif}[x_2^* - \delta, x_2^* + \delta]$ . If  $x_2^* + \delta < \theta_1^*$ , then  $\Pr(\theta \leq \theta_2^* | x_2 = x_2^*, \theta \in [-B, \theta_1^*]) = \Pr(\theta \leq \theta_2^* | x_2 = x_2^*)$  and he finds the public news useless. We call such equilibrium *Equilibrium without Dynamic Coordination* because intervention in the first period has no effect on coordination in the second period.

**Lemma 3** (Stage Game Equilibrium without Dynamic Coordination)

If  $s_1 = S$  and  $m_2 < m_1 - 2\delta(1 - c)$ , there exists an equilibrium with thresholds  $(\theta_2^*, x_2^*)$  where

$$\begin{cases} \theta_2^* = 1 + m_2 - c \\ x_2^* = 1 + m_2 - c + \delta(1 - 2c) \end{cases} \quad (6)$$

Notice that when public news is useless, the dynamic game is simply a repeated version of the static game. However, if  $x_2^* + \delta > \theta_1^*$ ,  $\Pr(\theta \leq \theta_2^* | x_2 = x_2^*, \theta \in [-B, \theta_1^*]) \neq \Pr(\theta \leq \theta_2^* | x_2 = x_2^*)$ , and the marginal investor finds the public news useful. We call this equilibrium *Equilibrium with Partial Dynamic Coordination* as government intervention in the first period has partially improved the coordination among investors in the second period. Equilibrium without dynamic coordination is an artifact of bounded noise in the private signals. For unbounded noise, there is always partial dynamic coordination.

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<sup>17</sup>Now that  $\theta \leq \theta_1^*$  is common knowledge, any equilibrium with  $(\theta_2^* > \theta_1^*, x_2^* > \theta_1^* + \delta)$  is equivalent to one with  $(\theta_2^*, x_2^*) = (\infty, \infty)$ .

**Lemma 4** (Stage Game Equilibrium with Partial Dynamic Coordination)

If  $s_1 = S$  and  $m_1 - 2\delta(1 - c) < m_2 < m_1 - c$ , there exists an equilibrium with thresholds

$$\begin{cases} \theta_2^* = 1 + m_2 - c + \frac{c[m_2 - m_1 + 2\delta(1 - c)]}{2\delta - c(1 + 2\delta)} \\ x_2^* = 1 + m_2 - c + \delta(1 - 2c) + \frac{c(1 + 2\delta)[m_2 - m_1 + 2\delta(1 - c)]}{2\delta - c(1 + 2\delta)}. \end{cases} \quad (7)$$

Combining Lemma 2, 3 and 4, Proposition 1 describes the equilibrium outcome given any  $(m_1, m_2)$  and  $s_1 = S$ .

**Proposition 1** (Equilibrium in period 2 when  $s_1 = S$ ) 1. If  $m_2 < m_1 - 2\delta(1 - c)$ , the unique equilibrium is the Stage Game Equilibrium without Dynamic Coordination.

2. If  $m_1 - 2\delta(1 - c) < m_2 < m_1 - c$ , the unique equilibrium is the Stage Game Equilibrium with Partial Dynamic Coordination.

3. If  $m_1 - c < m_2$ , the unique equilibrium is the Stage Game Equilibrium with Dynamic Coordination.

### 3.2.2 Failure News

If the fund in period 1 has failed ( $s_1 = F$ ), the prior belief on  $\theta$  is bounded below at  $\theta_1^*$ :  $\theta \sim Unif[\theta_1^*, B]$ . Proposition 2 below summarizes the equilibrium outcome in this case. The detailed derivation can be found in Appendix B. The only difference is that, in the Stage Game Equilibrium with Dynamic Coordination, investors choose to run regardless of their signals.

**Proposition 2** (Equilibrium in period 2 when  $s_1 = F$ ) 1. If  $m_2 < m_1 + 1 - c$ , the unique equilibrium is the Stage Game Equilibrium with Dynamic Coordination.

2. If  $m_1 + 1 - c < m_2 < m_1 + 2c\delta$ , the unique equilibrium is the Stage Game Equilibrium with Partial Dynamic Coordination.

3. If  $m_1 + 2c\delta < m_2$ , the unique equilibrium is the Stage Game Equilibrium without Dynamic Coordination.

### 3.2.3 Investors' Welfare and Dynamic Coordination

Let  $W_{2S} = E \left[ \int_0^1 V_{2i} di | s_1 = S \right]$  be the total expected payoff in period 2 conditional on  $s_1 = S$ . Also, let  $W_{2F} = E \left[ \int_0^1 V_{2i} di | s_1 = F \right]$  be the total expected payoff in period 2 when  $s_1 = F$ . Applying results from Proposition 1 and 2, we are able to obtain  $W_{2S}$  and  $W_{2F}$  for different values of  $m_1$  and  $m_2$ . Corollary 1 below shows the results.

**Corollary 1** (Investors' Welfare in Period 2) *1. Conditional on  $s_1 = S$*

(a) If  $m_2 < m_1 - 2\delta(1-c)$ ,  $W_{2S}^{nc} = \frac{(1-c)[1+B-c(1+\delta)+m_2]}{B+\theta_1^*}$ .

(b) If  $m_1 - 2\delta(1-c) < m_2 < m_1 - c$ ,  
 $W_{2S}^{pc} = \frac{1-c}{\theta_1^*+B} \left[ \theta_1^* + B + \frac{\delta c(c-m_1+m_2)^2 + 2\delta(c-m_1+m_2)[2\delta-c(1+2\delta)]}{[2\delta-c(1+2\delta)]^2} \right]$ .

(c)  $m_2 > m_1 - c$ ,  $W_{2S}^c = (1-c)$ .

*2. Conditional on  $s_1 = F$*

(a) If  $m_2 < m_1 + 1 - c$ ,  $W_{2F}^c = 0$ .

(b) If  $m_1 + 1 - c < m_2 < m_1 + 2c\delta$ ,  $W_{2F}^{pc} = \frac{1-c}{B-\theta_1^*} \frac{c\delta(-1+c-m_1+m_2)^2}{(-1+c+2c\delta)^2}$ .

(c) If  $m_2 > m_1 + 2c\delta$ ,  $W_{2F}^{nc} = \frac{1-c}{B-\theta_1^*} (m_2 - m_1 - c\delta)$ .

The superscripts of  $W_{2S}$  and  $W_{2F}$  refer to equilibrium types. *nc*, *pc* and *c* respectively stand for equilibrium without dynamic coordination, with partial coordination, and with coordination.

The left panel of Figure 1 plots  $W_{2S}$  against  $m_2$ , including the welfare function in all three different types of equilibria. Given  $m_1$ ,  $W_{2S}$  is continuous, increasing in  $m_2$ , and convex in the region that involves partial dynamic coordination. Unlike in the first period, the marginal effect of  $m_2$  on  $W_{2S}$  is no longer a constant. Initially,  $W_{2S}$  increases linearly in  $m_2$ , in which case the intervention in the first period has no dynamic coordination effect. When  $m_1 - 2\delta + 2c\delta < m_2 < m_1 - c$ , the marginal effect of  $m_2$  is increasing, due to the dynamic coordination effect of period 1 intervention. When  $m_2 > m_1 - c$ , the dynamic coordination effect is maximized and all agents' decisions are well coordinated towards an equilibrium without any run. In that case, further increasing  $m_2$  has no effect.

Similarly, the right panel of Figure 1 plots  $W_{2F}$  against  $m_2$ , including the welfare function in all three different types of equilibria. Given  $m_1$ ,  $W_{2F}$  is continuous, increasing in  $m_2$ , and convex when the equilibrium involves partial dynamic coordination. The effect of  $m_2$  on  $W_{2F}$  is not a constant either. When  $m_2 < m_1 + 1 - c$ , the failed intervention in period 1 makes all agents very pessimistic. A slight increase in  $m_2$  does not change people's belief and therefore, the marginal effect of  $m_2$  on  $W_{2F}$  is zero. When  $m_1 + 1 - c < m_2 < m_1 + 2c\delta$ , the marginal effect of  $m_2$  on  $W_{2F}$  is positive and increasing. Finally, when  $m_2 > m_1 + 2c\delta$ , the dynamic effect is zero and  $W_{2F}$  increases linearly in  $m_2$ .

Clearly,  $m_1$  affects both  $W_{2S}$  and  $W_{2F}$  by altering  $\theta_1^*$  and thus the resulting informational structure. Since  $W_{2S}$  and  $W_{2F}$  are piecewise in  $m_1$  and thus not everywhere differentiable, we define left-hand derivative of  $W_{2S}$  and  $W_{2F}$  w.r.t.  $m_1$  as the *conditional inference effect*, as Figure 2 illustrates.

**Proposition 3 (Conditional Inference Effect)**

*Investors' welfare  $W_{2S}$  and  $W_{2F}$  decrease in  $m_1$  conditional on  $s_1$  and  $m_2$ .*

This effect is consistent with the fact that government often face uncertainties on intervention outcome, and is aware of the informational detriments of using large interventions.<sup>18</sup> However, the overall effect of  $m_1$  on the unconditional  $E[W_2]$  is non-monotone because besides the conditional inference effect, the probability of  $s_1 = S$  also increases linearly with  $m_1$ . Thus to the extent that intervention outcomes are correlated across the two period, increasing  $m_1$  kills two birds with one stone. Figure 3 shows this non-monotonic property by plotting  $E[W_2] = \Pr(s_1 = S)W_{2S} + (1 - \Pr(s_1 = S))W_{2F}$  against  $m_1$ , taking  $m_2$  as given. Obviously, the overall effect attains its highest level at  $m_1 = m_2 + c$ , and starts to decline afterward.<sup>19</sup> We note that the declines happen in regions where the stage game equilibrium has dynamic coordination only in one state of the world, in which case conditional inference effect dominates. These are also regions where  $m_1$  and  $m_2$  are far apart (for example, due to asymmetric intervention costs discussed in the next section).

<sup>18</sup>See, for example, Bernanke (2015) page 282 on the intervention in AIG, "A critical question was whether the proposed \$85 billion line of credit would in fact save the company. For us, the ultimate disaster would be to lend such an enormous amount and then see the company collapse. "

<sup>19</sup>The decline is intuitive: conditional on  $s_1$ , a larger  $m_1$  leads to a more negative update on  $\theta_1^*$  because investors attribute fund's survival more to the large intervention. However, they become really pessimistic about the fundamental when the fund fails.

That said, the intervention outcomes are perfectly correlated if  $c - 1 < m_1 - m_2 < c$ , which is a region with stage game equilibrium with dynamic coordination no matter the fund survives or not in the first period. As we show in the next section, if the intervention costs are similar across the two periods, the interventions also tend to be close to one another even without public learning. This makes the public signal  $s$  dominant over the private signal  $x_{i2}$ , leading to a greater tendency for highly correlated coordination outcomes, which we refer to as the *endogenous correlation effect*.

**Proposition 4 (Endogenous Correlation Effect)**

*Investors' welfare  $E[W_2]$  increases in  $m_1$  when  $c - 1 < m_1 - m_2 < c$ .*

To get the general intuition for this effect, it is useful to compare equilibrium thresholds across different types of stage game equilibria. When  $s_1 = S$  and  $m_2 \in (m_1 - 2\delta(1 - c), m_1 - c)$ , both  $x_2^*$  and  $\theta_2^*$  in the Equilibrium with Partial Dynamic Coordination (Lemma 4) exceed their counterparts in the Equilibrium without Dynamic Coordination (Lemma 3), but are less than those in the Stage Game Equilibrium with Dynamic Coordination (Lemma 2). When the marginal agent finds the public news useful and realizes that the expected threshold level suggested by his signal alone is too stringent, he behaves more aggressively by choosing a higher threshold and running less. As a result,  $\theta_2^*$  is also higher and the fund is more likely to survive. Similarly, when  $s_1 = F$ , both  $x_2^*$  and  $\theta_2^*$  are the lowest (most stringent) in the Stage Game Equilibrium with Dynamic Coordination, followed by the Stage Game Equilibria with partial and no dynamic coordination. If we take coordination outcomes without dynamic learning as the benchmark, the dynamic coordination effect of initial intervention is that initial survival increases the likelihood of subsequent survival, and initial failure increases the likelihood of subsequent failure, which drives Proposition 4. Again, anecdotes during the recent financial crisis support that the policy makers weigh heavily this impact of one intervention on subsequent coordination outcomes.<sup>20</sup>

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<sup>20</sup>For example, Geithner (2014) page 215 recounts how requiring haircuts in FDIC's involvement in Washington Mutual (WaMu) makes the intervention weaker, and the policy makers were concerned that it might lead to higher probability of failure, "more bank failures and much bigger FDIC losses down the road", and that "more failures would eventually require more aggressive government interventions". Bernanke (2015) also mentions on page 277 that "financial panics are a collective loss of the confidence essential for keeping the system functioning", and the FDIC's sale of WaMu would likely trigger downgrades and worsen market beliefs.

## 4 Dynamic Intervention and Optimal Policy

Given the costs and constraints of intervention, how should the government allocate resources across two periods, and how does the information structure channel affect the scale and sequence of interventions? This section discusses three key implications on the optimal policy: emphasis on initial intervention, under- and over-intervention by myopic governments, and the “too big to save first” phenomenon.

Although we derive these implications for general cost functions, we occasionally consider the case in which the government faces solely a hard budget constraint,  $m_1 + m_2 = M$ , to illustrate the main tradeoffs in explicit closed-forms. This section also focuses on the case of *committed intervention*, which corresponds to choosing  $m_2$  before  $s_1$  is realized. Section 5.5 examines the case of *contingent intervention*, which corresponds to choosing  $m_2$  after  $s_1$  is realized. The former describes situations in which the government has to roll out policy programs before knowing the outcome of previous interventions.

### 4.1 Emphasis on Initial Intervention

First suppose the government has a total budget  $M$  that can be costless used across the two periods. In other words,  $K(m_1, m_2) = \frac{\mathbb{I}_{\{m_1+m_2>M\}}}{1-\mathbb{I}_{\{m_1+m_2>M\}}}$ . A benevolent government solves the following problem,

$$\max_{m_1, m_2} E \left[ \int_0^1 V_{1i} di + \int_0^1 V_{2i} di \right] \tag{8}$$

$$s.t. m_1 + m_2 = M. \tag{9}$$

We have shown earlier the information channel that arises from dynamic learning: while  $W_1$  increases linearly with  $m_1$ ,  $W_2$  is non-monotonic in  $m_1$  and increases with  $m_2$  in a non-linear manner. Since the government also faces a hard budget constraint  $m_1 + m_2 = M$ , an

increase in  $m_1$  necessarily crowds out  $m_2$  through the budget channel.<sup>21</sup> When the government optimally allocates resources in two periods, it needs to consider both.

Figure 4 plots a typical social welfare  $W$  as  $m_1$  varies. The pattern delivered by the figure holds for all parameters. (a)  $W$  is always flat for either small or large  $m_1$ . (b)  $W$  always attains its maximum at  $m_1 = \frac{M+c}{2}$ . Therefore, whenever  $M$  is large, the government should invest  $m_1^* = \frac{M+c}{2}$ . Lemma 6 in the Appendix summarizes the aggregate social welfare and the net benefit of initial intervention.

Therefore, the optimal intervention plan also depends on  $M$ , the total resources available to the government. When  $M$  is small ( $M < \frac{M+c}{2}$ ), it is optimal to set  $m_1 = M$ . In contrast, when  $M$  gets larger, increasing  $m_1$  may actually decrease the total payoff and the optimal  $m_1 = \frac{M+c}{2}$ .

Proposition 5 below characterizes the optimal intervention under different  $M$ s.

**Proposition 5** (Optimal Intervention)

*The optimal intervention under budget constraint  $M$  is  $\min(\frac{c+M}{2}, M)$ . Optimal intervention always emphasizes initial intervention:  $m_1^* > m_2^*$ .*

At the optimal intervention level, the fund in period 2 survives if and only if the fund in period 1 survives. The endogenous correlation effect completely dominates. The intuition for  $m_1^* > m_2^*$  is then apparant. To see this, suppose the government equally splits the budget and invests  $\frac{M}{2}$  in each period. Two periods' intervention outcomes are completely correlated. Knowing this, government always has incentives to kill two birds with one stone – increasing  $m_1$  to increases the survival probability in period-1 (and period-2) fund.<sup>22</sup>

One may question whether the results are driven by the fact that imposing the budget constraint takes away the flexibility of  $m_2$  after  $m_1$  is chosen. By specifying a very general  $K(m_1, m_2)$ , we show that emphasizing initial intervention is a very robust phenomenon. For committed interventions, the government separately chooses  $m_1$  and  $m_2$  all before  $s_1$  is realized. This corresponds to situations where governments have to setup funding facilities or provide subsidies even before the outcomes of earlier interventions are known yet.

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<sup>21</sup>See Geithner (2014) pages 264-266 for an example of intervention cost and budget consideration.

<sup>22</sup>The ratio  $\frac{m_2^*}{m_1^*}$  is weakly increasing in  $M$  and weakly decreasing in  $c$ , thus the tilt towards initial intervention is most significant when the government has a small budget or the illiquidity cost is high.

**Proposition 6** (Emphasis on Early Intervention)

*If intervention cost satisfies  $K(m_1, m_2) > K\left(\frac{1}{2}[m_1 + m_2], \frac{1}{2}[m_1 + m_2 - 2c]\right)$ , optimal policy strictly emphasizes initial intervention, i.e.,  $m_1^* > m_2^*$ .*

The condition in the proposition is satisfied by many plausible cost functions, such as one that is separable and symmetric in  $m_1$  and  $m_2$ , or one that emphasizes consistency in the sense that  $K(m_1, m_2)$  only depends on  $m_1 + m_2$  and  $|m_1 - m_2|$  and is increasing in  $|m_1 - m_2|$ . It is worth pointing out that this proposition is not about comparing the absolute sizes of the interventions. Given that we have normalized the total capital in the economy to one in both periods, we are really talking about a notion of intervention relative to the market size. Therefore, the conclusion could apply more broadly, especially when the coordination games are scale-invariant, i.e., the normalized intervention, cost, and participation scale proportionally with the market size.<sup>23</sup>

## 4.2 Information Externality and Myopic Intervention

This section examines the situations where the decision-maker for the initial intervention does not fully take into consideration the informational impact on subsequent interventions. This happens in the real world when the incumbent government is not expecting to be re-elected and does not fully consider the impact of current intervention on coordination games and interventions under the future government.<sup>24</sup> This could also happen when one EU country's intervention does not fully consider the informational externality on neighboring countries with correlated fundamentals but not necessarily comparable intervention costs.

We characterize how the information externality on the second period in our model affects  $m_1^*$ . In general, a myopic government—one who ignores this negative impact—may fail to formulate a welfare-maximizing policy. Understanding such myopic interventions

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<sup>23</sup>Indeed, the eligible ABCPs for AMLF constitutes less than half of the commercial paper markets, thus the scale of AMLF (\$150 billion in the first 10 days relative to the magnitude of the run-\$172 billion plummet from the \$3.45-trillion MMF sector) is higher than CPFF (\$144 billion usage in the first week, relative to a reduction of commercial paper outstanding, larger both in percentage (15%) and in level (330 billion)) that targets almost the entire commercial paper markets. AMLF and its success also seem to have helped later interventions. For example, CPFF was also effective and even generated \$5 billion in net income for the government.

<sup>24</sup>Evidence for government myopia abounds. See for example, Lee (1988).

can facilitate formulating forward-looking policies and coordinated efforts among multiple governments.

To highlight the information externality from the initial intervention, we shut down the budget channel in our general intervention cost function by setting  $K_{12}(m_1, m_2) = 0$  for the remainder of the paper.<sup>25</sup> In general, the government chooses  $\{m_1, m_2\}$  to maximize welfare. For a given  $m_1$ , define the objective as

$$Y(m_1; \chi) = W_1 - K(m_1, 0) + \chi \max_{m_2} \left[ \frac{B + m_1 + 1 - c}{2B} [W_{2S} - (K(m_1, m_2) - K(m_1, 0))] \right. \\ \left. + \frac{B - m_1 - 1 + c}{2B} [W_{2F} - (K(m_1, m_2) - K(m_1, 0))] \right] \quad (10)$$

Here,  $\chi \in [0, 1]$  measures how much the government cares about the fate of the fund in the second period. In particular,  $\chi = 0$  corresponds to the static benchmark, and  $\chi = 1$  corresponds to the case in which the second fund's fate is equally important. Often,  $\chi < 1$  because of short-termism of the government. Alternatively, in the context of global economy in which countries' fundamentals are highly correlated,  $\chi$  captures the extent that one country considers the externality it imposes on other countries.

We are interested in  $\frac{\partial m_1^*}{\partial \chi}$ , the effect of government myopia on the initial intervention, which generally depends on cost parameters. By Theorem 2.1 in Athey, Milgrom, and Roberts (1998),  $m_1^* \equiv \operatorname{argmax}_{m_1} Y(m_1, \chi)$  is non-increasing in  $\chi$  iff  $Y$  has decreasing differences in  $\chi$  and  $m_1$ , and is non-decreasing in  $\chi$  iff  $Y$  has increasing differences in  $\chi$  and  $m_1$ .

**Proposition 7** (Myopic Intervention)

*A myopic government may under- or over- intervene initially. In particular,*

1.  $\frac{\partial m_1^*}{\partial \chi} \geq 0$ , iff either  $m_1^* \geq c$  and  $m_2^* = m_1^* - c$  always or  $m_1^* \leq c$  and  $m_2^* = 0$  always.
2.  $\frac{\partial m_1^*}{\partial \chi} \leq 0$ , iff either  $m_2^* > m_1^* + 1 - c$  always or  $m_1^* > c$  and  $m_2^* < m_1^* - c$  always.

Note that this result emphasizes  $m_1$  relative to the case where the intervention externality is absent. A myopic government under-intervenes initially when intervention outcomes are

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<sup>25</sup>The case of hard budget constraint trivially predicts that the more the government considers the welfare in the second period, the less it would intervene in the first period.

perfectly correlated. This happens when the costs of intervention in the two periods are comparable. When they are both small ( $m_1^* \geq c$  and  $m_2^* = m_1^* - c$ ) or both large ( $m_1^* \leq c$  and  $m_2^* = 0$ ), the endogenous correlation effect dominates. Hence, increasing the first period's survival probability increases the survival for second period one for one. It is therefore more important to increase the probability of survival by increasing  $m_1$ , a fact that a myopic government neglects.

To link Proposition 7 to exogenous parameters, we provide in the next corollary some sufficient conditions that lead to under-intervention. These conditions are neither unique, nor restrictive. For simplicity in exposition, we assume for the remainder of the paper that  $K$  is twice-differentiable in a continuous feasible range of intervention  $\mathcal{I}$ . This specification includes cases of budget constraint and separable quadratic intervention costs. Let  $K_i$  denote the partial derivative w.r.t.  $m_i$ .

## Corollary 2

*Myopic government under-intervenes initially if one of the two following conditions holds:*

1.  $K_1(c, \cdot) > \frac{1-c}{B}$  and  $K_2(\cdot, 1-c) \geq \frac{1-c}{B} \frac{c\delta}{2c\delta+c-1}$ .
2. For some  $b > c$ , it holds  $K_1(b, \cdot) > \frac{1-c}{B}$ ,  $K_1(c, \cdot) < \frac{1-c}{B} \frac{\delta-c(1+2\delta)}{2\delta-c(1+2\delta)}$ ,  $K_2(\cdot, b-c) \leq \frac{1-c}{2B}$ , and  $K_2(\cdot, 1) \geq \frac{(1-c)c\delta}{B(2c\delta+c-1)}$ .

Interestingly, failure to consider dynamic coordination could also result in excessive intervention through the information structure it creates. For example, this happens when the cost for first intervention is sufficiently small such that the initial intervention is large scale, yet the second intervention is sufficiently costly that survival does not always lead to survival. At the same time, a high  $m_1$  reduces the quality of good news, reducing the marginal benefit of  $m_2$ . When the costs of intervention in the two periods are rather disproportionate, outcomes are less correlated, and the conditional inference effect dominates.<sup>26</sup> For a myopic government, shading  $m_1$  makes it easier to intervene in the second period no matter the

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<sup>26</sup>The countries could differ in dimensions such as fiscal budget, financial depth, fundamentals, or liquidity. The heterogeneity not only affects interventions during the crisis, but also the safety of assets, as discussed in He, Krishnamurthy, and Milbradt (2016).

fund survives or fails in the first period. Again, the next corollary gives some illustrating sufficient conditions under which over-intervention occurs.

### Corollary 3

*A myopic government over-intervenes initially if one of the following conditions holds:*

1. For some  $b \geq 0$ , it holds  $K_1(c, \cdot) > \frac{1-c}{B}$  and  $K_2(\cdot, b + 2c\delta) < \frac{1-c}{2B} \frac{\delta}{1+2\delta}$ .
2.  $K_1(b, \cdot) > \frac{1-c}{B}$ ,  $K_1(c, \cdot) < \frac{1-c}{B} \frac{\delta - c(1+2\delta)}{2\delta - c(1+2\delta)}$ ,  $K_2(\cdot, 0) > \frac{1-c}{2B} \frac{2\delta}{2\delta - c(1+2\delta)}$ .

We illustrate the results in Figures 6 and 7. We also note that when the conditions for increasing or decreasing differences do not hold globally, optimal initial intervention can be non-monotonic in  $\chi$ . For example, in Figure 8,  $m_1^*$  increases with  $\chi$  initially and finally decreases.

The above proposition calls for coordinated interventions across governments. For example, since economic fundamentals across EU countries are highly correlated, one member's isolated intervention imposes informational externality on other members. In the case of AMLF and CPFF, it is likely that because the capacity to intervene using CPFF is comparable to that in AMLF, the later intervention was able to fully capture the benefit from investors' learning of earlier intervention. According to the above proposition, this provides additional justification for the overwhelming scale of AMLF.

### 4.3 “Too Big to Save First”

In this section, we consider how the government intervenes in two funds of different sizes, given the dynamic coordination effect. In particular, we examine the case the government decides both the size and the sequence of interventions.

Without loss of generality, we normalize the size of fund 1 to 1, and the size of fund 2 to  $\lambda > 1$ . Here, size simply refers to the total measure of investors. We continue to assume that fund 1 survives if and only if

$$A_1 + m_1 \geq \theta,$$

where  $A_1$ ,  $m_1$  and  $\theta$  have the same interpretations as before. Besides, fund 2 survives if and

only if

$$\lambda A_2 + m_2 \geq \theta \lambda,$$

where  $A_2 = \frac{\int_0^\lambda 1_{\{a_{2i}=1\}} ds}{\lambda} \in [0, 1]$  is the fraction of investors who choose to stay and thus  $\lambda A_2$  is the liquidity from remaining investors. Fund 2 survives if and only if the total liquidity is greater than  $\theta \lambda$ . The threshold is also augmented by  $\lambda$  so that we are not distorting the funds' survival probability absent interventions.<sup>27</sup> The government's choice variables are extended: it chooses not only the intervention plan  $\{m_1, m_2\}$ , but also which fund to intervene first:

$$\max_{\iota, m_1, m_2} E \left[ \int_0^1 V_{1i} di + \int_0^\lambda V_{2i} di \right] - K(m_1, m_2)$$

If  $\iota = 1$ , the government intervenes fund 1 first.  $E \left[ \int_0^1 V_{1i} di \right] = \frac{1-c}{2B} [1 + B - c(1 + \delta) + m_1]$ , and  $E \left[ \int_0^\lambda V_{2i} di \right]$  depends on whether  $s_1 = S$  or  $s_1 = F$ . If  $\iota = 2$ , however, the outcome  $s_2$  arrives first,  $E \left[ \int_0^\lambda V_{2i} di \right] = \lambda \cdot \frac{1-c}{2B} [1 + B - c(1 + \delta) + m_2]$ , and  $E \left[ \int_0^1 V_{1i} di \right]$  depends on whether  $s_2 = S$  or  $s_2 = F$ .

Proposition 8 first illustrates the tradeoffs in the case in which the government has a budget constraint.

**Proposition 8** (Too Big to Save First)

*A benevolent government who faces a budget constraint always intervenes to induce perfectly correlated outcomes across interventions. Besides, it intervenes in the smaller fund first:  $\iota^* = 1$ .*

Appendix A.7 contains the proof, which has two steps. First, we show that given  $\iota$ , the optimal intervention plan always satisfies  $\frac{m_2^*}{\lambda} = m_1^* - c$ , and thus leads to correlated outcomes. Note that if  $\lambda = 1$ , the result is identical to that in Section 4.1 where  $m_2^* = m_1^* - c$ . Next, we compare different choices of  $\iota \in \{1, 2\}$  and show the optimal intervention sequence features

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<sup>27</sup> $\theta$  in the baseline specification captures the systemic illiquidity for a market or fund of unit size, therefore we scale it up when the fund size scales up. This is a natural specification because if we keep  $\theta$  unscaled while changing the size of the fund, we are implicitly making larger fund more likely to survive, which clouds the informational effect that we hope to focus on. To see this, let us examine the static example. The survival threshold for larger fund becomes  $\lambda(1 - c) + m$ , so with the same intervention the larger fund survives with greater probability.

$\iota^* = 1$ . Two factors contribute to this result. First, the larger fund benefits more from the resolution of uncertainty due to the revelation of the initial intervention’s outcome. Second, it is less costly to intervene into the smaller fund to create the same information structure.

The above result carries through with general intervention cost functions with  $K\left(m_1, \frac{m_2}{\lambda}\right) > K\left(\frac{1}{2}\left[m_1 + \frac{m_2}{\lambda}\right], \frac{1}{2}\left[m_1 + \frac{m_2}{\lambda} - 2c\right]\right)$ , a slight modification from the condition in Proposition 6.

Our result thus relates to the concept of “too big to fail”. Rather than emphasizing financial networks and connectedness, we are adding an information-structure perspective to the debate on systemic fragility. Some institutions could be too big to fail, but the best way to save them may entail saving the smaller ones first to better boost market confidence.<sup>28</sup>

## 5 Discussions and Extensions

In the analysis so far we have left out complicating factors such as institution network. So the aforementioned policy implications should not be interpreted as direct policy prescriptions. Nevertheless, they provide key insights for policy-making. As Goldstein and Huang (2016) point out, an important angle of coordination games is the transmission of information from the policy-maker. For example, intervention during the MMMF crisis altered public information not only for that particular event but also for the ensuing commercial paper crisis. That is, any information revealed about Lehman-related liquidity from the MMMF intervention would be relevant to market participants for the commercial paper intervention. In the case of housing stabilization policies, such information transmission reverberates across markets and across time. While it would be difficult to quantitatively assess the relative importance of the dynamic information transmission mechanism, it is clear that such dynamic effects do indeed exist and should be carefully noted by policy makers.<sup>29</sup>

Given the importance of our channel, we now relate it to prior literature to highlight how

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<sup>28</sup>Our results do not contradict ‘too big to fail’ in that we are not discussing which institutions to save, but which institutions to save first. One way to think about this is that among the too-big-to-fail institutions, if the government can commit to which institutions intervention outcome to be revealed first, it is informationally efficient to reveal the intervention outcome of the smaller fund first.

<sup>29</sup>Other examples in the literature such as currency attack models (e.g. Morris and Shin (1998)) and bank runs (e.g. Goldstein and Pauzner (2005)) would also have information transmission both across markets/banks and across time.

this paper augments our understanding of equilibrium multiplicity and selection, as well as information design. Then we enrich the setup to allow imperfectly correlated fundamentals, managers' endogenous actions, moral hazard, alternative distributional assumptions, and various forms of intervention (including contingent interventions), e.t.c, to add realism and show robustness of our findings.

## 5.1 Learning, Endogenous Multiplicity, and Bounded Support

We first relate our paper to Angeletos, Hellwig, and Pavan (2007) (AHP). Foremost, endogenous intervention affects the public information structure, and thus public learning. The presence of public learning also feeds back to the governments decision on the optimal policy. This link is new to AHP and has profound implications on the optimal policy and coordination outcomes as demonstrated in Section 4. In the discussion below, we explain why our baseline model yields unique equilibrium and how equilibrium multiplicity is restored via a mechanism isomorphic to the one in AHP. We then highlight how equilibrium multiplicity could be endogenized by intervention policy, before discussing how the key results are robust to distributional assumptions and the role of bounded support in the interaction of private and public information.

AHP show that multiple equilibria emerge under the same conditions that guarantee uniqueness in static global games. The results rely on endogenous learning from regime survivals and exogenous learning from private news that arrives over time. We show that two elements are necessary for this multiplicity result. First, private information interacts with endogenous learning from earlier coordination outcomes. Second, the private information is either very precise or gets very precise as agents continuously receive private signals about the fundamental. Without the first element, the game is equivalent to one in which agents receive only one summary private signal in each period.<sup>30</sup> Our baseline model demonstrates that without the second element, we have an unique equilibrium. Below, we show that multiple equilibria may exist when private signals are very precise. That is, when  $\delta$  gets very small.<sup>31</sup>

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<sup>30</sup>The variance of the signal is  $Var\left(\frac{\sigma^2}{n}\right)$  with  $n$  signals in period- $n$ .

<sup>31</sup>Likewise, AHP show that there always exists an equilibrium in which no attack occurs after the first

To see this, note that the set of parameters we have examined corresponds to imprecise signals ( $2\delta > 1$  and  $\frac{1}{1+2\delta} < c < \frac{2\delta}{1+2\delta}$ ). Moreover, the signal does not get more precise because agents are non-overlapping. If we relax the parameter assumptions, or allow agents' signals to become more precise over time, multiplicity follows. Proposition 9 complements Propositions 1 and 2.<sup>32</sup>

**Proposition 9** (Equilibria with general  $\delta$  and  $c$ )

1. If  $s_1 = S$  and  $\frac{2\delta}{2\delta+1} < c < 1$ ,
  - (a) If  $m_2 < m_1 - c$ , the unique equilibrium is the Stage Game Equilibrium without Dynamic Coordination.
  - (b) If  $m_1 - c < m_2 < m_1 - 2\delta(1 - c)$ , all three types of equilibria exist. However, in the Stage Game Equilibrium with Partial Dynamic Coordination, the threshold  $\theta_2^*$  decreases with  $m_2$ ,
  - (c) If  $m_1 - 2\delta(1 - c) < m_2$ , the unique equilibrium is the Stage Game Equilibrium with Dynamic Coordination.
2. If  $s_1 = F$  and  $0 < c < \frac{1}{2\delta+1}$ 
  - (a) If  $m_2 < m_1 + 2c\delta$ , the unique equilibrium is the Stage Game Equilibrium with Dynamic Coordination.
  - (b) If  $m_1 + 2c\delta < m_2 < m_1 + 1 - c$ , all three types of equilibria exist. However, in the Stage Game Equilibrium with Partial Dynamic Coordination, the threshold  $\theta_2^*$  decreases with  $m_2$ .
  - (c) If  $m_2 > m_1 + 1 - c$ , the unique equilibrium is the Stage Game Equilibrium without Dynamic Coordination.

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period, and this would be the unique equilibrium if agents did not receive any private information after the first period. One can easily write a two-period version of AHP and show this is the only equilibrium if the private signal is sufficiently imprecise.

<sup>32</sup>Technically, multiple equilibria resurface because we can apply the argument of iterated deletion of dominated regions only from one end of  $\theta$  space. Despite this, with slight modifications on the intervention cost functions, the main intuitions for the results from earlier sections still apply as long as we are consistent with equilibrium selection.

Our baseline model also differs from AHP in that the private signal is bounded.<sup>33</sup> Government's action therefore plays a role in equilibrium multiplicity and selection because it endogenizes how public learning interacts with private signals that is exogenous in AHP. In particular, when the government's intervention induces equilibria with full or no dynamic coordination, either private signal or public learning completely dominates, a situation left out when focusing on Normal distributions. Consequently, the equilibrium is unique even if the signal is infinitely precise. In this regard, the government's endogenous intervention can determine the equilibrium multiplicity through determining how public learning and private information interact, and selectively eliminating certain equilibria.

Next, we discuss the case when private signals follow Normal distribution which are unbounded, i.e.,  $\varepsilon_i \sim N(0, \delta)$ . We still assume that investors are non-overlapping to keep matters comparable with our baseline model.<sup>34</sup> We characterize the equilibrium in each period and emphasize that government intervention in period 1 still has a dynamic informational effect on period 2.

Lemma 5 below summarizes equilibrium outcomes in two periods. Detailed analysis can be found in Appendix C.

**Lemma 5**

*Equilibrium when signals follow Normal distribution*

1. Given  $m_1$ , there exists unique equilibrium thresholds in period 1:

$$\begin{aligned}\theta_1^* &= 1 + m_1 - c \\ x_1^* &= 1 + m_1 - c - \delta\Phi^{-1}(c).\end{aligned}$$

2. Given  $(m_1, m_2)$  and  $s_1 = S$ ,

(a) When  $m_2 > m_1 - c$ ,  $(\theta_2^* = \theta_1^*, x_2^* = \infty)$  consists a threshold equilibrium.

(b) Equilibrium strategies  $(\theta_2^*, x_2^*)$  which satisfy  $\theta_2^* < \theta_1^*$  and  $x_2^* < \infty$  may or may not exist. If they exist, they can be non-unique.

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<sup>33</sup>Uniform  $[-\delta, \delta]$  in our model but unbounded support in their model ( $N(z, \frac{1}{\alpha})$ ).

<sup>34</sup>The case when investors perfectly overlap can be identically analyzed as one in which  $\varepsilon_i \sim N(0, \frac{\delta}{2})$ . All results in this section are unchanged.

Table 2 presents the local comparative statics when there exists a unique equilibrium strategy. When  $m_1$  increases from 0.7 to 0.9, both  $\theta_2^*$  and  $x_2^*$  decrease, validating the dynamic coordination effect.

Table 2:  $\theta_2^*$  as a function of  $m_1$  ( $s_1 = S$ )

$m_1$	0.7	0.75	0.8	0.85	0.9
$\theta_2^*$	0.7602	0.6981	0.6693	0.6511	0.6384
$x_2^*$	0.9667	0.8222	0.7565	0.7152	0.6866

Other parameters are  $c = 0.5, \delta = 0.5, m_2 = 0.1$ .

## 5.2 Intervention Costs and Interactions

In this section, we relate our paper to Goldstein and Huang (2016) [GH] which studies costless information design in a stand-alone coordination game. The policymaker in their paper trades off committing to a policy that abandons the regime too often (fund failure due to policy) versus maintaining the regime too much that the information revealed to speculators conditional on regime survival is not positive enough to avoid triggering attacks (fund failure due to speculator run). We analyze similar tradeoffs in a setting with multiple potentially costly interventions.

We first compare the tradeoff between endogenous correlation effect and conditional inference effect to the tradeoff in GH, and show their setup can be reinterpreted under our framework with the regime-change policy as a costless initial intervention, and the agents' coordination game as our subsequent intervention game. In this regard, we add to GH by explicitly identifying the information design tradeoff suggested therein and characterizing it under general cost functions. While GH studies the effect of one intervention, we study how interventions endogenous relate to each other. Moreover, we characterize the situations when either the endogenous correlation or the conditional inference effect dominates, and discuss the implications for policy.

Our paper resembles GH in that the initial intervention essentially designs information for the subsequent intervention. The key differences are: (1) their information design is costless whereas that in our setup is costly in general; (2) their information design impacts

only one coordination game where as in our setup it impacts multiple coordination games (one through the contemporaneous coordination, and one through dynamic informational channel); (3) the game ends if the regime fails through the regime change policy whereas the subsequent coordination game is always played; (4) we study multiple interventions and discuss how heterogeneity (such as fund size) affects optimal policy.

We add to GH by first showing the tradeoffs in information design in a general setting with multiple interventions that are potentially costly. In their setup, abandoning too often results in failures, which is related to the fact that we want good news. We generalize this to multiple interventions and identify a novel endogenous correlation effect of intervention outcomes. Success in one intervention makes a subsequent one more likely. However, in their setup maintaining the regime too often is costly as there is less informational benefit when the regime is maintained. This is equivalent to our conditional inference effect which says we want good news to be really good news with which the agents positively update significantly.

In GH, because information design is costless, the policymaker optimally commits to abandoning the regime with a high enough frequency so that a regime maintenance results in no attack. Similarly in our setting, without information design cost and contemporaneous coordination, the government chooses an informational structure such that survival leads to survival and failure leads to failure, because that's the best information one can provide to the investors (which tells them whether the fund would survive or not).

That said, information design is generally costly in our setting because it is achieved through costly initial intervention. This implies that the optimal design may not always involve perfectly correlated survival outcomes. Moreover, relative intervention costs in both coordination games matter, and has implications when thinking about endogenous intervention policy across countries or across episodes of runs, where intervention costs could differ drastically. In particular, survival (policy not to abandon) leads to survival (no subsequent attack) holds only when the intervention costs across the two periods are comparable. If one intervention's cost is so low, but the subsequent intervention's cost is extremely high due to, for example, moral hazard, the initial success as public news is not quite relevant for the subsequent coordination because the high cost prohibits correlated outcomes, but its failure would make investors really negatively update.

Our setup allows us to derive the thresholds of run and survival, the agents' payoffs, and the optimal policy in closed-form, if we focus on the information design benefit, or use some tractable cost functions. By doing so, we provide a comprehensive analysis in closed-form and an alternative illustration of the tradeoffs also discussed in GH. Our setup also allows us to discuss issues that cannot be analyzed in a single coordination game. For example, we highlight how intervention has both contemporaneous coordination effect and dynamic information design impact. We also discuss how heterogeneity (such as fund size) in coordination games affect the optimal policy (Proposition 8).

### 5.3 Correlated Fundamentals and Multi-Period Interventions

So far we have assumed  $\theta_1 = \theta_2$ , what if the fundamentals across the two periods are positively correlated but non-identical? One way of introducing imperfectly-correlated fundamentals is to simply make  $\theta_2$  a noisy version of  $\theta_1$ . However, this formulation is generally not analytically tractable. Therefore we use a specific binary noise structure to show that our results extend to the case of imperfectly-correlated fundamentals.

Suppose at the beginning of period 2, everyone learns whether the fundamental in period 2 is identical to that in period 1, or just an independent one. In other words, it becomes public whether period 2 is an extension of period 1's coordination game, or an independent one. Specifically, we assume that with probability  $q$ ,  $\theta_2 = \theta_1$ , and with probability  $1 - q$ ,  $\theta_2$  is a random draw from  $[-B, B]$  independent of  $\theta_1$ . Our baseline model corresponds to  $q = 1$ . In the case that  $q = 0$ , the intervention problem is symmetric which yields our benchmark policy  $m_1^* = m_2^*$ . With  $q \in (0, 1)$ , the intuition for all the implications continues to apply and the previous results are only affected qualitatively.

To see how  $m_1^*$  is affected by the correlation, we note

$$\begin{aligned}
m_1^* &= \operatorname{argmax}_{m_1} \left\{ W_1 - K(m_1, 0) + q \max_{m_2} \mathbb{E}[W_2 - (K(m_1, m_2) - K(m_1, 0)) | \theta_2 = \theta_1] \right. \\
&\quad \left. + (1 - q) \max_{m_2} \mathbb{E}[W_2 - (K(m_1, m_2) - K(m_1, 0)) | \theta_2 \perp \theta_1] \right\} \\
&= \operatorname{argmax}_{m_1} \left\{ W_1 - K(m_1, 0) + q \max_{m_2} \mathbb{E}[W_2 - (K(m_1, m_2) - K(m_1, 0)) | \theta_2 = \theta_1] \right\},
\end{aligned} \tag{11}$$

where we have used  $K_{12} = 0$ . Direct inspection tells us the government's objective is exactly  $Y(m_1; q)$  defined in Equation 10. Similar to Proposition 7, the correlation positively increase  $m_1^*$  when the cost functions are comparable (Corollary 2); the correlation reduces  $m_1^*$  if the cost functions are asymmetric (Corollary 3); otherwise, the effect could be non-monotone, as illustrated in Figures 6 to 8 (replacing  $\chi$  by  $q$ ). Thus how the correlation in the fundamental affects endogenous government intervention also depends on the intervention costs.

The economic mechanism and intuition in the baseline model can also be generalized to a multi-period setup. While such an exercise is beyond the scope of this paper and does not add to the insights we bring, we briefly describe the implication of emphasizing early interventions under such settings. For simplicity, suppose that the economy lasts for  $n$  periods with the same fundamental  $\theta$ . In each period, there is a continuum of investors of measure 1 who choose whether to stay or run. The government, equipped with total resources  $M$ , aims to maximize the aggregate welfare across  $n$  periods. If  $n = 2$ , the setup returns to the main section.

Suppose the proposed intervention plan equally divides the total resources across  $n$  periods,  $m_1 = m_2 = \dots = m_n = \frac{M}{n}$ , then it is clear that the intervention outcomes in all periods are perfectly correlated:  $s_1 = s_2 = \dots = s_n$ . As a result, the government has incentive to increase  $m_1$ , which consequently raises the possibility of  $\Pr(s_1 = 1)$ , as well as  $\Pr(s_i = 1)$  for  $i = 2, \dots, n$ . Given optimal intervention  $m_1^* > \frac{M}{n}$ , the government now allocates the remaining resources  $M - m_1^*$  across  $n - 1$  periods. A similar argument tells us that  $m_2^* > \frac{M - m_1^*}{n - 1}$ . Along the line of the analysis, we could reach the result  $m_1^* > m_2^* > \dots > m_n^*$ . In other words, optimal intervention plan always emphasizes early intervention.

## 5.4 Moral Hazard

Moral hazard is a big concern in government bailouts. Indeed, fund managers may divert the capital injected by the government, or gamble by investing in projects with risk profiles different from the pre-specification. We now demonstrate that our general cost specification already encompasses many forms of moral hazard. In particular, we show that managerial stealing and risk shifting provide micro-foundations for the intervention cost. Moreover, by modeling moral hazard, we enrich the model with fund managers' utility function and

endogenous actions, making the analysis more realistic and relevant.

## Cash Diversion

First consider the case in which the fund manager is able to divert a fraction  $\eta \in [0, 1]$  for any amount of liquidity  $\mu$  injected by the government. Suppose the fund manager gets compensated  $a$  share of the surplus she generates for investors, and among the diverted capital, she can consume  $f(\eta)\mu \leq \eta\mu$ , where  $f : [0, 1] \mapsto [0, 1)$  satisfies  $f'(\cdot) > 0$  and  $f''(\cdot) \leq 0$ . The rest  $\mu[\eta - f(\eta)]$  is inefficiently lost (iceberg costs), consistent with the standard assumption in the literature that cash diversion is increasingly inefficient in the amount diverted.<sup>35</sup> Because the fund manager only cares about her own fund, she does not internalize the intervention externality. Thus to pin down the unique  $\eta$ , she equalizes the marginal benefit of keeping more injected liquidity in the fund,  $\frac{(1-c)\mu}{2B}$ , to the marginal benefit of stealing more  $f'(\eta)\mu$ .

Under this setup, the optimal intervention problem is isomorphic to the problem solved earlier, where intervention incurs a cost  $k(m)$  in the period. To see this, note that the government is aware of the diverting technology. Therefore, to effectively inject  $m$  to the fund, the government needs to spend  $\mu$  such that  $(1 - \eta)\mu = m$ . Equivalently, injecting  $m$  into the fund costs the government  $k(m) = k_o\left(\frac{m}{1-\eta}\right) - \frac{f(\eta)m}{1-\eta}$ , where  $k_o(\mu)$  is other social costs not associated with cash diversion. If  $k_o$  is increasing and convex in  $m$ , adding the moral hazard cost preserves these properties, consistent with our cost specification.

## Risk Shifting

Now consider the case in which the fund manager could secretly choose projects with survival threshold  $\theta + \Delta$  with a corresponding private payoff  $\alpha\Delta$  conditional on success after paying the promised payoffs to investors (or some asymmetric split of the additional payoff). The project is thus more illiquid and risky (failure probability is higher), but the fund manager has incentives to shift the risk because she captures the upside (limited liability means she does not incur additional loss upon failure). Let the fixed cost of risk shifting be

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<sup>35</sup>This specification captures the fact that the fraction of diversion matters for the efficiency loss. Alternatively, one could use  $f(\eta\mu)$ , where  $f : [0, \mu] \mapsto [0, \mu)$  satisfies  $f'(\cdot) > 0$  and  $f''(\cdot) \leq 0$ , which implies the diversion efficiency depends on the total amount. This does not affect our conclusion.

$c_o \geq 0$ , then given the liquidity injection  $m$ , the optimal risk shifting is

$$\Delta^* = \operatorname{argmax}_{\Delta} \left[ \alpha \Delta \frac{1-c+m-\Delta}{2B} - c_o \mathbb{I}_{\{\Delta > 0\}} \right] = \frac{1-c+m}{2} \mathbb{I}_{\left\{c_o < \frac{\alpha(1-c+m)^2}{8B}\right\}} \quad (12)$$

The greater the intervention, the greater the distortion in investment by the manager. Compared to the case where moral hazard is absent, the welfare is reduced by

$$\left[ c_o + \frac{\Delta^*(1-c)}{2B} - \frac{1-c+m-\Delta^*}{2B} \alpha \Delta^* \right] \mathbb{I}_{\left\{c_o < \frac{\alpha \Delta^*(1-c+m-\Delta^*)^2}{2B}\right\}}, \quad (13)$$

where the first term is the reduction in welfare due to a lower probability of fund survival, and the second term is the private benefit to the fund manager. For simplicity, we assume  $c_o > \frac{\alpha(1-c)^2}{8B}$  and  $\alpha$  is sufficiently small (for example,  $\alpha < \frac{1-c}{1-c+m}$ ) so that moral hazard is only induced by the intervention, then the moral hazard cost can be nested in  $k(m) = k_o(m) + \left[ c_o + \frac{-\alpha m^2 + 2m(1-c)(1-\alpha) + (2-\alpha)(1-c)^2}{8B} \right] \mathbb{I}_{\left\{c_o < \frac{\alpha(1-c+m)^2}{8B}\right\}}$ . Once again,  $k(m)$  is weakly increasing and convex in  $m$ .

Because the sum of increasing and convex functions is still increasing and convex, our general cost function accommodates multiple types of moral hazard. To put it differently, moral hazard considerations constitute and motivate the general cost function we use. For example, when the moral hazard of risk shifting and stealing are both present, their costs can still be represented by the general cost function in our model, and such moral hazard costs motivate the cost specification.

## 5.5 Contingent Interventions

In reality, governments can sometimes choose the size of later intervention after the outcome of the initial intervention is realized. We analyze this case in this section. The intuition and key tradeoff in earlier discussions still apply. Note that any  $m_{2F} \in (0, 1+m_1^*-c]$  cannot be optimal since if  $s_1 = F$ , the fund in the second still fails for sure despite for costly intervention. If  $m_{2F}^* = 0$ , the endogenous correlation effect is even reinforced. If  $m_{2F}^* > 1+m_1^*-c$ , however, it is possible to have failed initial intervention but successful subsequent intervention, and the endogenous correlation effect is weaker. The overall dynamic coordination

still boils down to a tradeoff between the endogenous correlation effect and the conditional inference effect.

**Proposition 10** (Emphasis on Initial Intervention (Contingent Case))

When  $K_2(0, 1 - c) > \frac{(1-c)^2}{B-1}$ , then contingent interventions strictly emphasizes initial intervention:  $m_1^* > m_{2S_1}^*$ .

This result extends Proposition 6 to contingent interventions. If the cost for the subsequent intervention (second period) is big enough, then initial intervention is emphasized. This is just one example of the sufficient conditions under which the endogenous correlation effect dominates the conditional inference effect. Note this result applies to situations in which the initial intervention is more costly than the subsequent intervention.

**Proposition 11** (Myopic Intervention (Contingent Case))

The government's initial intervention is weakly increasing in the extent it considers dynamic coordination, i.e.,  $\frac{\partial m_1^*}{\partial \chi} \geq 0$  if one of the two following conditions hold:

1.  $K(\cdot, 1 - c) - K(\cdot, 0) > \min\left\{\frac{(1-c)^2}{2c\delta-1+c}, \frac{c\delta(1-c)}{B-(1-c)}\right\}$  and  $K_1(c, \cdot) \geq \frac{1-c}{B}$ .
2.  $K(\cdot, 1 - c) - K(\cdot, 0) > \min\left\{\frac{(1-c)^2}{2c\delta-1+c}, \frac{c\delta(1-c)}{B-(1-c)}\right\}$  and  $1 - c - K(\cdot, 1 - c) + K(\cdot, 0) - (2 + B - c)K_2(\cdot, 1 - c) > 0$ .

The government's contingent intervention is weakly decreasing in the extent it considers dynamic coordination, i.e.,  $\frac{\partial m_1^*}{\partial \chi} \leq 0$ , when  $K_2(\cdot, 0) > \frac{1-c}{B+c-2} \frac{2\delta}{2\delta-c(1+2\delta)}$  and  $K_1(c, \cdot) < \frac{1-c}{B} \frac{\delta-c(1+2\delta)}{2\delta-c(1+2\delta)}$ .

These sufficient conditions for under- and over-interventions simply correspond to corollaries 2 and 3. With contingent interventions, myopic government still under-or over- intervenes initially. The optimal initial intervention is weakly increasing in the extent it considers dynamic coordination, i.e.,  $\frac{\partial m_1^*}{\partial \chi} \geq 0$ , iff either  $m_1^* \geq c$  and  $m_{2S}^* = m_1^* - c$  and  $m_{2F}^* = 0$ , or  $m_1^* \leq c$  and  $m_{2S}^* = m_{2F}^* = 0$  always. It is weakly decreasing iff  $m_1^* > c$  and  $m_{2S}^* < m_1^* - c$  and  $m_{2F}^* = 0$  always. Because when  $m_{2F}^* = 0$ , the endogenous correlation effect is the same as in the committed intervention case, and the same intuition carries through.

Next, regarding the sequence of interventions in funds of different sizes, saving the smaller fund first is still cheaper to create the same learning on the fundamental, and the larger fund

still benefits more from the uncertainty reduction. A policy that induces perfectly correlated outcomes and saves the larger fund first cannot be optimal. In other words, the larger fund is still “too big to save first.”

**Proposition 12** (Too Big to Save First (Contingent Case))

*If interventions always lead to perfectly correlated outcomes ( $s_1 = s_2$ ), it is socially efficient to save the small fund first.*

Finally, we compare the optimal initial intervention in committed and contingent interventions. This again depends on the intervention costs. To see how the nature of intervention affects  $m_1^*$ , we write

$$\begin{aligned}
m_1^* = \operatorname{argmax}_{m_1} & \left\{ W_1 - K(m_1, 0) + (1 - \zeta) \max_{m_2} \mathbb{E}[W_2 - (K(m_1, m_2) - K(m_1, 0))] \right. \\
& + \zeta \left[ \max_{m_{2S}} \frac{B + m_1 + 1 - c}{2B} [W_{2S} - (K(m_1, m_{2S}) - K(m_1, 0))] \right. \\
& \left. \left. + \max_{m_{2F}} \frac{B - m_1 - 1 + c}{2B} [W_{2F} - (K(m_1, m_{2S}) - K(m_1, 0))] \right] \right\} \quad (14)
\end{aligned}$$

where  $\zeta$  is the indicator for contingent intervention. Similar to Proposition 7,  $m_1^*$  is increasing in  $\eta$  if the above expression has increasing differences in  $m_1$  and  $\eta$ . This depends on the cost functions and endogenous interventions. For example, consider a local deviation from the optimal committed intervention policy. If cost functions are such that endogenous correlation effect dominates (e.g., symmetric cost function), initial failure leads to subsequent failure and the option to contingent intervention on  $s_1$  means we can save on the state of failure, and use that to the conditional inference cost in the state of success when we increase initial intervention. Therefore the optimal contingent policy uses a larger  $m_1$  to increase success probability without incurring additional information cost due to the conditional inference effect.

## 5.6 Various Forms of Interventions

In the model, we have interpreted intervention as liquidity injection. We argue below that our model nests a broader array of interventions that are commonly used (Bebchuk and Goldstein, 2011; Diamond and Rajan, 2011).

**Direct lending and investing in borrower funds** This is exactly the interpretation in our model. During the financial crisis of 2008-2009, the US government directly participated in the commercial paper market through direct purchasing. Our general cost function to a large extent captures investment returns to the government and some inefficiencies discussed in Bebchuk and Goldstein (2011).

**Direct capital infusion to investors** Governments around the globe have injected capital to both retail and institutional investors. For instance, the U.S. Troubled Asset Relief Program (TARP) provided about US\$250 billion to banks, and the UK injected about US\$90 billion to its major banks. Tax breaks and related measures represent capital infusion to retail investors directly. To map these policies into our model, suppose the government injects a fraction  $\alpha$  of investors' existing capital. This changes the capital of each investor from 1 unit to  $1 + \alpha$  without altering the investor's optimization problem. Consequently, the one period survival threshold becomes  $\theta^* = (1 - c)(1 + \alpha)$ . We can relabel  $m = (1 - c)\alpha$  and the model solutions are equivalent. Thus, the intervention again increases the probability of survival.

**Government guarantees** During the financial crisis, governments used guarantees that are similar to FDIC to limit the potential losses of the lenders. Specifically in our model, suppose that the government guarantees a proportion  $\xi$  of a lender's or investors losses, then the lender who stays (rolls over) receives the return  $R$  when the fund survives, and  $-(1 - \xi)c$  if it fails. Since our investors are risk neutral, the survival threshold now is  $\theta^* = \frac{1-c}{1-c\xi}$ . Again, we can relabel  $m = \frac{c(1-c)\xi}{1-c\xi}$  and this is equivalent to an intervention that increases the probability of success.

**Interest Rate Reduction** During the financial crisis, the Fed Reserve Board cut the fed funds rate from 4.25% in Jan 2008 to 1% in Oct 2008. Many other countries took similar measures in the face of a global contraction in lending. In the model, this is equivalent to reducing  $r$ , the payoff for not investing. Under risk-neutrality, it is equivalent to increasing the survival probability through changing  $c$ , which is exactly the role of  $m$  in our model.

## 6 Conclusion

How should a benevolent government intervene in a dynamic environment in which agents have strategic complementarity? Through the lens of sequential global games in which governments are large players who mitigate coordination failures, we establish general results on the existence and uniqueness of equilibria, and show that government interventions can affect coordination both contemporaneously and dynamically. A stronger initial intervention helps subsequent interventions through increasing likelihood of positive news, but also leads to negative conditional updates. Our results suggest that optimal intervention often emphasizes initial action, validating the conventional wisdom. However, depending on costs across interventions, an initial intervention could have either a positive or negative informational externality on subsequent coordination. Finally, some funds are “too big to save first” because they benefit more from resolution of uncertainty about the fundamentals, and intervening in smaller funds first costs less to generate this informational structure. Our paper thus has policy relevance to various intervention programs, such as the bailouts of money market mutual funds and of financial commercial papers market during the 2008 financial crisis.

The dynamic learning mechanism and thus the information-structure effect also apply to broader contexts, such as interventions in currency attacks, credit market freezes, cross-sector industrialization, regulatory union, and green energy development. Our discussion therefore opens several avenues for future research. For example, how the government simultaneously designs information structure and signals their private knowledge about economic fundamentals? Moreover, this paper only considers common forms of interventions. Understanding the optimal contingent intervention not only is of theoretical interest, but also provides new insights and guidance to policymakers.

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# Appendix

## A Derivations and Proofs

### A.1 Proof of Lemma 1

Suppose there is a threshold  $x^* \in \mathbb{R}$  such that each agent invests if and only if  $x \leq x^*$ . The measure of agents who invest is thus,

$$A(\theta) = \Pr(x \leq x^* | \theta) = \begin{cases} 0 & \text{if } \theta > x^* + \delta \\ \frac{x^* - (\theta - \delta)}{2\delta} & \text{if } x^* - \delta \leq \theta \leq x^* + \delta \\ 1 & \text{if } \theta < x^* - \delta. \end{cases} \quad (15)$$

It follows that the investment succeeds if and only if  $\theta \leq \theta^*$  where  $\theta^*$  solves

$$A(\theta^*) + m = \theta^*. \quad (16)$$

By standard Bayesian updating, the posterior distribution about  $\theta$  conditional on the private signal is also uniform distribution with bandwidth  $2\delta$ . Therefore, the posterior probability of investment success is

$$\Pr(s = S | x) = \Pr(\theta \leq \theta^* | x) = \begin{cases} 0 & \text{if } x > \theta^* + \delta \\ \frac{\theta^* - (x - \delta)}{2\delta} & \text{if } \theta^* - \delta \leq x \leq \theta^* + \delta \\ 1 & \text{if } x < \theta^* - \delta. \end{cases} \quad (17)$$

For the marginal investor who is indifferent between investing or not, his signal  $x^*$  satisfies

$$\Pr(s = S | x^*) = c \quad (18)$$

Jointly solve equations (16) and (18), we obtain the two thresholds

$$\begin{cases} \theta^* = 1 + m - c \\ x^* = 1 - c + \delta - 2c\delta + m. \end{cases} \quad (19)$$

### A.2 Proof of Lemma 2

*Proof.* “if”  $\Leftarrow$

If  $m_2 > m_1 - c$ , and if all agents know that other agents will adopt a threshold strategy  $x_2^* = \infty$ , then

$$A_2 + m_2 = 1 + m_2 > 1 + m_1 - c = \theta_1^* > \theta. \quad (20)$$

Therefore, the investment succeeds with probability 1. Therefore, it is individually rational for each agent to set  $x_2^* = \infty$ .

“only if”  $\Rightarrow$

We prove by contradiction. Suppose that an equilibrium in which all agents adopt a threshold  $x_2^* = 1 + m_1 - c + \delta$  when  $(m_1 - c) - m_2 = \Delta > 0$ . Therefore, any agent with a signal  $x_2 < \theta_1^* + \delta$  will invest. In other words,

$$\Pr(\theta < 1 + m_2 | x_2, \theta < \theta_1^*) \geq c$$

holds for any  $x_2$ .

Consider an agent who observes  $\hat{x}_2 = m_1 + 1 - c + \delta - \frac{\Delta}{2}$ . Such an agent exists when  $\theta \in (m_1 + 1 - c + \delta - \frac{\Delta}{2}, m_1 + 1 - c + \delta)$ . Apparently,

$$\Pr(\theta < 1 + m_2 | x_2 = \hat{x}_2, \theta < \theta_1^*) \geq c = 0 < c$$

which violates the assumption that all agents invest irrespective of their signals. □

### A.3 Proof of Lemma 3, 4, Proposition 1, 2, and 9

Here we solve the equilibrium in period 2 under both  $s_1 = S$  and  $s_1 = F$ , and under all parameter values. The solutions directly prove the lemmas and propositions.

Our solutions take two steps. First, we assume a solution pair  $(\theta_2^*, x_2^*)$  exists and derive the equilibrium values. Second, we check the conditions that these solutions must satisfy and thus derive the parameter ranges such that they indeed constitute a solution.

#### Case 1: Period 1 fund survives: $s_1 = S$

1. If  $\theta_1^* - 2\delta < \theta_2^* < \theta_1^*$ , then in equilibrium

$$\theta_2^* - m_2 = A(\theta_2^*) = \begin{cases} 1 & \text{if } x_2^* - \theta_2^* > \delta \\ \frac{x_2^* - (\theta_2^* - \delta)}{2\delta} & \text{if } -\delta \leq x_2^* - \theta_2^* < \delta \\ 0 & \text{if } x_2^* - \theta_2^* < -\delta \end{cases}$$

and

$$c = \begin{cases} 1 & \text{if } x_2^* < \theta_2^* - \delta < \theta_2^* < \theta_1^* \\ \frac{\theta_2^* - (x_2^* - \delta)}{2\delta} & \text{if } \theta_2^* - \delta < x_2^* < \theta_1^* - \delta \\ \frac{\theta_2^* - (x_2^* - \delta)}{\theta_1^* - (x_2^* - \delta)} & \text{if } \theta_1^* - \delta < x_2^* < \theta_2^* + \delta \\ 0 & \text{if } \theta_2^* + \delta < x_2^*. \end{cases}$$

Jointly solve the above equations, the solutions are.

- (a)  $\theta_2^* = 1 + m_2 - c$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c)$ . The solution exists if  $m_1 - 2\delta < m_2 < m_1 - 2\delta(1 - c)$ .
- (b)  $\theta_2^* = 1 + m_2 - c + \frac{c[m_2 - m_1 + 2\delta(1 - c)]}{2\delta - c(1 + 2\delta)}$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c) + \frac{c(1 + 2\delta)[m_2 - m_1 + 2\delta(1 - c)]}{2\delta - c(1 + 2\delta)}$ . The solution exists in two cases: 1)  $m_1 - 2\delta(1 - c) < m_2 < m_1 - c$  if  $0 < c < \frac{2\delta}{1 + 2\delta}$ ; 2)

$$m_1 - c < m_2 < m_1 - 2\delta(1 - c) \text{ if } \frac{2\delta}{1+2\delta} < c < 1$$

2. If  $\theta_2^* < \theta_1^* - 2\delta$ , then in equilibrium

$$\theta_2^* - m_2 = A(\theta_2^*) = \begin{cases} 1 & \text{if } x_2^* - \theta_2^* > \delta \\ \frac{x_2^* - (\theta_2^* - \delta)}{2\delta} & \text{if } -\delta \leq x_2^* - \theta_2^* < \delta \\ 0 & \text{if } x_2^* - \theta_2^* < -\delta \end{cases}$$

and

$$c = \begin{cases} 1 & \text{if } x_2^* < \theta_2^* - \delta \\ \frac{\theta_2^* - (x_2^* - \delta)}{2\delta} & \text{if } \theta_2^* - \delta < x_2^* < \theta_2^* + \delta \\ 0 & \text{if } \theta_2^* + \delta < x_2^*. \end{cases}$$

Jointly solve the above equations, the solutions are.

(a)  $\theta_2^* = 1 + m_2 - c$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c)$ . The solution exists if  $m_2 < m_1 - 2\delta$ .

Combine the above results, we prove Lemma 3, 4, Proposition 1, and half of Proposition 9. The next case finishes the rest of the proof.

#### Case 2: Period 1 fund fails: $s_1 = F$

The analysis is identical. We will just list the results as below.

(a)  $\theta_2^* = 1 + m_2 - c - \frac{(1-c)(m_1+2c\delta-m_2)}{c(1+2\delta)-1}$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c) - \frac{(1-c)(1+2\delta)(m_1+2c\delta-m_2)}{c(1+2\delta)-1}$ .. The solution exists in two cases: 1)  $m_1 + 2c\delta < m_2 < m_1 + (1 - c)$  if  $0 < c < \frac{1}{1+2\delta}$ ; 2)  $m_1 + (1 - c) < m_2 < m_1 + 2c\delta$  if  $\frac{1}{1+2\delta} < c < 1$ .

(b)  $\theta_2^* = 1 + m_2 - c$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c)$ . The solution exists if  $m_1 + 2c\delta < m_2 < m_1 + 2\delta$ .

(c)  $\theta_2^* = 1 + m_2 - c$  and  $x_2^* = 1 + m_2 - c + \delta(1 - 2c)$ . The solution exists if  $m_2 > m_1 + 2\delta$ .

Combining this result, Proposition 2 and the other parts of 9 naturally follow.

## A.4 Proof of Proposition 5

Plugging in the government's budget constraint, we are able to obtain the aggregate social welfare as a function of  $m_1$ . As a by-product, we are also able to calculate the net benefit of initial intervention. Lemma 6 summarizes the results.

#### Lemma 6

Aggregate Social Welfare  $W$  and Net benefit of initial intervention  $\left. \frac{\partial W}{\partial m_1} \right|_{m_1+m_2=M}$

1. If  $m_1 > \frac{M+2\delta(1-c)}{2}$ ,

$$\begin{aligned} W &= W_1 + \Pr(s_1 = S) W_{2S}^{nc} + \Pr(s_1 = F) W_{2F}^c \\ &= \frac{1-c}{2B} [2 + 2B - 2c(1+\delta) + M] \\ \frac{\partial W}{\partial m_1} &= 0. \end{aligned}$$

*This case only exists for  $M > 2\delta(1-c)$ .*

2. If  $\frac{M+c}{2} < m_1 < \frac{M+2\delta(1-c)}{2}$ ,

$$\begin{aligned} W &= W_1 + \Pr(s_1 = S) W_{2S}^{pc} + \Pr(s_1 = F) W_{2F}^c \\ &= \frac{1-c}{2B} [2 + 2B - c(2+\delta) + 2m_1 \\ &\quad + \frac{\delta c(c+M-2m_1)^2 - 2\delta[c-2(1-c)\delta](c+M-2m_1)}{[c-2(1-c)\delta]^2}] \\ \frac{\partial W}{\partial m_1} &= \frac{(1-c)[2c(1+2\delta)[c-2(1-c)\delta] - 4c\delta(c+M-2m_1)]}{2B[c-2(1-c)\delta]^2} < 0. \end{aligned}$$

*This case only exists for  $M > c$ .*

3. If  $\frac{M-(1-c)}{2} < m_1 < \frac{M+c}{2}$ ,

$$\begin{aligned} W &= W_1 + \Pr(s_1 = S) W_{2S}^c + \Pr(s_1 = F) W_{2F}^c \\ &= \frac{1-c}{2B} [2 + 2B - c(2+\delta) + 2m_1] \\ \frac{\partial W}{\partial m_1} &= \frac{1-c}{B} > 0. \end{aligned}$$

*This case always exists.*

4. If  $\frac{M-2c\delta}{2} < m_1 < \frac{M-(1-c)}{2}$ ,

$$\begin{aligned} W &= W_1 + \Pr(s_1 = S) W_{2S}^c + \Pr(s_1 = F) W_{2F}^{pc} \\ &= \frac{1-c}{2B} \left[ 2 + 2B - c(2+\delta) + 2m_1 + \frac{c\delta(-1+c+M-2m_1)^2}{(-1+c+2c\delta)^2} \right] \\ \frac{\partial W}{\partial m_1} &= \frac{1-c}{2B} \left[ 2 - \frac{4c\delta(c-2m_1+M-1)}{(2c\delta+c-1)^2} \right]. \end{aligned}$$

*This case only exists for  $M > 1-c$ . We note that the derivative changes sign from negative to positive exactly once in this region.*

5. If  $m_1 < \frac{M-2c\delta}{2}$ ,

$$\begin{aligned} W &= W_1 + \Pr(s_1 = S) W_{2S}^c + \Pr(s_1 = F) W_{2F}^{nc} \\ &= \frac{1-c}{2B} [2 + 2B - 2c(1+\delta) + M] \\ \frac{\partial W}{\partial m_1} &= 0. \end{aligned}$$

This case only exists for  $M > 2c\delta$ .

Given that the welfare function is continuous, the maximum welfare in case 3 is higher than case 1 and 5, and how welfare varies with respect to  $m_1$  in region 2 and 4, the result in the proposition follows.

## A.5 Proof of Proposition 6

*Proof.* Suppose the optimal  $m_1 < m_2$ , we show this leads to a contradiction. Notice welfare  $W_1 + E[W_2] - K(m_1, m_2)$  is

$$L = -K(m_1, m_2) + \frac{1-c}{2B} \begin{cases} 2(m_1 + 1 - c + B) - c\delta & \text{if } m_2 < m_1 + (1-c) \\ 2(m_1 + 1 - c + B) - c\delta + \frac{c\delta(-1+c-m_1+m_2)^2}{(-1+c+2c\delta)^2} & \text{if } m_1 + (1-c) < m_2 < m_1 + 2c\delta \\ m_1 + m_2 + 2(1-c+B-c\delta) & \text{if } m_2 > m_1 + 2c\delta. \end{cases} \quad (21)$$

We want to show that the above is not optimal because it is strictly dominated by the welfare at  $(m'_1, m'_2) = (\frac{1}{2}[m_1 + m_2], \frac{1}{2}[m_1 + m_2 - 2c])$ , which equals

$$L' = \frac{1-c}{2B} [m_1 + m_2 + 2(1-c+B) - c\delta] - K\left(\frac{1}{2}(m_1 + m_2), \frac{1}{2}[m_1 + m_2 - 2c]\right) \quad (22)$$

The case when  $m_2 < m_1 + (1-c)$  and when  $m_2 > m_1 + 2c\delta$  are straightforward. It remains to show that  $W' > W$  when  $m_1 + (1-c) < m_2 < m_1 + 2c\delta$ . Note that

$$\begin{aligned} \text{sgn}(L' - L) &= \text{sgn}\left[(m_2 - m_1) - \frac{c\delta(-1+c-m_1+m_2)^2}{(-1+c+2c\delta)^2}\right] \\ &= \text{sgn}\left\{-c\delta\left[(-1+c)^2 + (m_2 - m_1)^2 + 2(-1+c)(m_2 - m_1)\right] + (m_2 - m_1)(-1+c+2c\delta)^2\right\} \\ &= \text{sgn}\left\{-c\delta(m_2 - m_1)^2 + \left[2c\delta(1-c) + (-1+c+2c\delta)^2\right](m_2 - m_1) - c\delta(-1+c)^2\right\}. \end{aligned}$$

It suffices to show  $\text{sgn}\left\{-c\delta(m_2 - m_1)^2 + \left[2c\delta(1-c) + (-1+c+2c\delta)^2\right](m_2 - m_1) - c\delta(-1+c)^2\right\} > 0$  at both  $m_2 = m_1 + 2c\delta$  and  $m_2 = m_1 + (1-c)$ , which is straightforward algebra.

Notice that when the cost is separable and symmetric,

$$\begin{aligned} &K(m_1, m_2) - K\left(\frac{1}{2}[m_1 + m_2], \frac{1}{2}[m_1 + m_2 - 2c]\right) \\ &= \left[K(m_2) - K\left(\frac{1}{2}[m_1 + m_2]\right)\right] - \left[K\left(\frac{1}{2}[m_1 + m_2 - 2c]\right) - K(m_1)\right] > 0 \end{aligned} \quad (23)$$

due to  $K$  being weakly convex and increasing. The above also holds when  $\frac{1}{2}[m_1 + m_2 - 2c]$  is replaced by  $\frac{1}{2}(m_1 + m_2)$  and  $K$  only depends on  $m_1 + m_2$  and  $|m_1 - m_2|$  and is increasing in  $|m_1 - m_2|$ . Therefore initial intervention is strictly emphasized under those conditions.  $\square$

## A.6 Proof of Proposition 7 and Corollaries 2 and 3

*Proof.* The following identity holds

$$\begin{aligned}
\frac{\partial}{\partial \chi} Y(m_1; \chi) &= \max_{m_2} [\mathbb{E}[W_2(m_1, m_2) - (K(m_1, m_2) - K(m_1, 0))]] \\
&= [\mathbb{I}_{\{m_2^* > m_1 + 1 - c\}} + \mathbb{I}_{\{m_1 > c\}} \mathbb{I}_{\{0 < m_2^* < m_1 - c\}}] (\mathbb{E}[W_2(m_1, m_2^*)] - (K(m_1, m_2^*) - K(m_1, 0))) \\
&\quad + \mathbb{I}_{\{m_1 \geq c\}} \mathbb{I}_{\{m_2^* = m_1 - c\}} (\mathbb{E}[W_2(m_1, m_1 - c)] - (K(m_1, m_1 - c) - K(m_1, 0))) \\
&\quad + \mathbb{I}_{\{m_1 \leq c\}} \mathbb{I}_{\{m_2^* = 0\}} \mathbb{E}[W_2(m_1, 0)]
\end{aligned} \tag{24}$$

Note that fixing  $m_1$ , increasing  $m_2$  does not increase welfare  $\mathbb{E}[W_2]$  in  $[m_1 - c, m_1 + 1 - c]$ , thus the four indicator products sum to one. This is seen in Figure 5, with the four indicators corresponding to  $m_2 > m_1 + 1 - c$ ,  $m_2 < m_1 - c$ ,  $m_2 = m_1 - c$ , and  $m_1 - c < m_2 \leq m_1 + 1 - c$  respectively. The first term is non-increasing in  $m_1$  while the last two terms are non-decreasing. In general, the overall expression is non-monotone in  $m_1$  because its value could jump up or down when the indicators change values. However, if parameters are such that one indicator function is always one, then the expression is monotone in  $m_1$  and we could draw robust comparative statics. If one of the first two indicators is always 1 as we vary  $m_1$ , then  $Y$  has decreasing differences in  $m_1$  and  $\chi$ ; if one of the last two indicators is always 1,  $Y$  has increasing differences. The conclusions then follow from Theorem 2.1 in Athey, Milgrom, and Roberts (1998).

Corollaries 2 and 3 provide some examples of sufficient conditions that lead to underintervention or overintervention globally when the government is myopic. We prove them below, but note that there are other sufficient conditions, especially ones on cost parameters defined through levels rather than derivatives:

If  $K_1(c, \cdot) > \frac{1-c}{B}$ , we have  $m_1^* < c$  because the maximum marginal benefit of  $m_1$  on investors' welfare is  $\frac{1-c}{B}$ ,  $K_1(c, \cdot) \geq \frac{1-c}{B}$  implies  $m_1^* \leq c$ . Therefore  $m_2^* > m_1 - c$  for sure and  $W_{2S} = (1 - c)$ . Given  $K_2(\cdot, c(1 + 2\delta)) < \frac{1-c}{2B} \frac{\delta}{1+2\delta}$ , we have  $K(\cdot, c(1 + 2\delta)) < \frac{c(1-c)\delta}{2B}$ , then  $\frac{B - m_1 - 1 + c}{2B} W_{2F} > K(m_1, m_1 + 2\delta c) - K(m_1, 0)$ . Thus the increase in  $W_{2F}$  exceeds the intervention cost at  $m_2 = m_1 + 2\delta c$ ,  $m_2^* > m_1 + 1 - c$ . When this happens we know  $\frac{\partial Y}{\partial \chi}$  equals the first term with the first indicator product being one, and is non-increasing in  $m_1$ . Thus  $Y$  has decreasing differences in  $m_1$  and  $\chi$ .

Alternatively, if  $K_1(b, \cdot) > \frac{1-c}{B}$ , we have  $m_1^* < b$  for  $b$  potentially bigger than  $c$ . If the cost in the second intervention is sufficiently small such that  $m_2^* > b + 2c\delta > 2c\delta + m_1^*$ , we also have the first indicator product being 1 and  $Y$  has decreasing differences in  $m_1$  and  $\chi$ . One sufficient condition is  $[W_2(m_1^*, m_1^* + 2c\delta) - W_2(m_1^*, m_1^* - c)] / c(1 + 2\delta) > K_2(b + 2c\delta)$ , i.e.,  $K_2(b + 2c\delta) < \frac{(1-c)\delta}{2B(1+2\delta)}$ .

Next for the last indicator to be one always,  $K_1(c, \cdot) > \frac{1-c}{B}$ . In addition,  $K_2(\cdot, 1 - c) \geq \frac{1-c}{B} \frac{c\delta}{2c\delta + c - 1}$  is a sufficient condition for  $m_2^* = 0$  because this implies the cost exceeds the benefit at both  $m_2 = 1 - c + m_1$  and  $m_2 = m_1 + 2c\delta$ , and the convexity of  $K$  in  $m_2$  excludes  $m_2^* > 1 - c + m_1$ . Then  $\frac{\partial Y}{\partial \chi}$  equals the last term and is non-decreasing in  $m_1$ . We could alternatively use  $K(\cdot, 1 - c) \geq \frac{c(1-c)\delta}{2B}$  as a sufficient condition on cost, rather than on the derivative. The same goes for other sufficient conditions that we provide in this proposition.

Next, if  $K_1(b, \cdot) > \frac{1-c}{B}$  and  $K_1(c, \cdot) < \frac{1-c}{B} \frac{\delta-c(1+2\delta)}{2\delta-c(1+2\delta)} \leq \frac{\partial Y}{\partial m_1}$  for some  $b > c$ , we have  $b > m_1^* > c$ . On the one hand, if in addition the minimum marginal benefit in region  $m_2 \leq m_1^* - c$  is bigger than the maximum marginal cost, i.e.,  $\min \left\{ \frac{1-c}{2B}, \frac{1-c}{2B} \frac{2\delta(1-c)}{2\delta-c(1+2\delta)} \right\} \geq \frac{1-c}{2B} \geq K_2(\cdot, b-c) > K_2(\cdot, m_1-c)$ , we have  $\mathbb{E}[W_2] - (K(m_1, m_2) - K(m_1, 0))$  increasing in the entire region of  $[0, m_1-c]$ . Moreover, if  $K_2(m_1^*, m_1^*+1-c) > K_2(\cdot, 1) \geq \frac{(1-c)c\delta}{B(2c\delta+c-1)}$ , the lower bound on marginal cost is weakly bigger than the maximum marginal benefit (RHS) in the region  $m_2 \geq 1-c+m_1^*$ , therefore  $m_2^* = m_1^* - c$  and the third indicator product is always one.  $Y$  has increasing differences in  $m_1$  and  $\chi$ .

On the other hand,  $K_2(\cdot, 0) > \frac{1-c}{2B} \frac{2\delta}{2\delta-c(1+2\delta)}$  implies  $\frac{1-c}{2B} \frac{2\delta}{2\delta-c(1+2\delta)} < K_2(m_1, m_1-c)$ , which means the maximum marginal benefit in the region  $m_2 \leq m_1^* - c$  taken at equality is less than the marginal cost. Thus  $m_2^* < m_1^* - c$  and the second indicator product is always one.  $Y$  has decreasing differences in  $m_1$  and  $\chi$ .

These sufficient conditions are stated in the corollaries. We note that instead of directly computing the derivatives for the first term in  $\frac{\partial Y}{\partial \chi}$ , when  $m_2^*$  is interior we can apply envelop theorem to compute the partial derivative in  $m_1$  of  $\mathbb{E}[W_2(m_1, m_2)] - (K(m_1, m_2) - K(m_1, 0))$ . Because  $K_{12} = 0$ , we know the partial derivative must be negative in the corresponding regions from figure 3.  $\square$

## A.7 Proof of Proposition 8

*Proof.* Define  $n_1 = m_1$  and  $n_2 = \frac{m_2}{\lambda}$ . The two inequalities on funds' survival translate into

$$\begin{aligned} A_1 + n_1 &\geq \theta \\ A_2 + n_2 &\geq \theta \end{aligned}$$

For the remaining analysis, we prove that a benevolent government who faces a hard budget constraint always prefers to first intervene into fund 1—the relatively smaller one.

We prove by backward induction. In the first step, we fix the choice of  $\iota$  to be 1 and study the optimal intervention plan  $(n_1, n_2)$  when  $\lambda$  varies. The budget constraint shows as  $n_1 + n_2\lambda = M$ . We will show that for both  $\lambda > 1$  and  $\lambda \in (0, 1)$ , the government will intervene up to  $n_2 = n_1 - c$ . The case that  $\lambda \in (0, 1)$  is simply isomorphic to  $\iota = 2$ . Thus, we establish the result that the government will always induce perfectly correlated intervention outcomes. In step 2, we compare different choices of  $\iota \in \{1, 2\}$  and show the optimal intervention order:  $\iota = 1$  if  $\lambda > 1$  and  $\iota = 2$  if  $\lambda \in (0, 1)$ . Thus, the smaller fund should always be bailed out first.

### Lemma 7

*Suppose  $\iota = 1$ ,  $\forall \lambda > 0$ , the optimal intervention plan is:*

$$\begin{aligned} n_1^* &= \frac{M + c\lambda}{1 + \lambda} \\ n_2^* &= \frac{M - c}{1 + \lambda}. \end{aligned}$$

*Under  $(n_1^*, n_2^*)$ , intervention always leads to correlated outcomes:  $s_1 = s_2$ .*

*Proof.* With heterogeneous fund sizes, the aggregate social welfare naturally follows.

1. If  $n_1 > \frac{M+2\delta\lambda(1-c)}{1+\lambda}$ ,

$$\begin{aligned} W &= \frac{1-c}{2B} \{[1+B-c(1+\delta)](1+\lambda) + M\} \\ \frac{\partial W}{\partial n_1} &= 0. \end{aligned}$$

2. If  $\frac{M+c\lambda}{1+\lambda} < n_1 < \frac{M+2\delta\lambda(1-c)}{1+\lambda}$ ,

$$\begin{aligned} W &= \frac{1-c}{2B} [1+B-c(1+\delta) + n_1] \\ &\quad + \lambda \frac{1-c}{2B} \left[ 1 + n_1 - c + B + \frac{\delta c(c-n_1+n_2)^2 + 2\delta(c-n_1+n_2)[2\delta-c(1+2\delta)]}{[2\delta-c(1+2\delta)]^2} \right] \\ \frac{\partial W}{\partial n_1} &< 0. \end{aligned}$$

3. If  $\frac{M-(1-c)\lambda}{1+\lambda} < n_1 < \frac{M+c\lambda}{1+\lambda}$ ,

$$\begin{aligned} W &= \frac{1-c}{2B} [(1+B-c+n_1)(1+\lambda) - c\delta] \\ \frac{\partial W}{\partial n_1} &> 0. \end{aligned}$$

4. If  $\frac{M-2c\delta\lambda}{1+\lambda} < n_1 < \frac{M-(1-c)\lambda}{1+\lambda}$ ,

$$\begin{aligned} W &= \frac{1-c}{2B} [1+B-c(1+\delta) + n_1] + \lambda \frac{1-c}{2B} [1+B-c+n_1] \\ &\quad + \lambda \frac{1-c}{2B} \frac{c\delta(-1+c-n_1+n_2)^2}{(-1+c+2c\delta)^2} \\ \frac{\partial W}{\partial n_1} &\text{ changes from negative to positive exactly once.} \end{aligned}$$

5. If  $n_1 < \frac{M-2c\delta\lambda}{1+\lambda}$ ,

$$\begin{aligned} W &= \frac{1-c}{2B} \{[1+B-c(1+\delta)](1+\lambda) + M\} \\ \frac{\partial W}{\partial n_1} &= 0. \end{aligned}$$

It easily establishes that  $\frac{\partial W}{\partial n_1} = 0$  in case 1 and 5,  $\frac{\partial W}{\partial n_1} > 0$  in case 3, and  $\frac{\partial W}{\partial n_1} < 0$  in case 2. Similar to the proof of Proposition 5, the aggregate welfare in case 1 equals that in case 5, the maximal welfare is attained at the right boundary of case 3. That is, when  $n_1 = \frac{M+c\lambda}{1+\lambda}$   $\square$

Now that we have established the result on optimal intervention plan  $(n_1^*, n_2^*)$  conditional on  $\iota$ , we can compare the social welfare under different  $\iota$ .

If  $\iota = 1$ , the total social welfare directly follows optimal  $(n_1^*, n_2^*) = \left(\frac{M+c\lambda}{1+\lambda}, \frac{M-c}{1+\lambda}\right)$

$$W|_{\iota=1} = \frac{1-c}{2B} \left[ \left(1 + B - c + \frac{M - (1-c)\lambda}{1+\lambda}\right) (1+\lambda) - c\delta \right].$$

If  $\iota = 2$ , then  $(n_1^*, n_2^*) = \left(\frac{M+c}{1+\lambda}, \frac{M-c\lambda}{1+\lambda}\right)$  and the total social welfare is

$$W|_{\iota=2} = \frac{1-c}{2B} \left[ (1+B-c)(1+\lambda) - c\lambda\delta + (1+\lambda) \frac{M+c}{1+\lambda} \right].$$

Clearly,

$$W|_{\iota=1} - W|_{\iota=2} = \frac{1-c}{2B} c(1+\delta)(\lambda-1) > 0$$

□

## A.8 Proof of Proposition 10

*Proof.* If  $s_1 = S$ , increasing  $m_{2S}$  beyond  $m_1^* - c$  incurs additional cost without increasing  $\mathbb{E}[W_2]$ , as is clear in Figure 1. Thus,  $m_{2S}^* \leq m_1^* - c$ . When  $s_1 = F$ , the condition on the parameter means that the marginal cost of increasing  $m_{2F}$  at  $1-c$  exceeds the marginal benefit, which is bounded above by  $\frac{(1-c)^2}{B-1}$ . Thus  $m_{2F}^* < 1-c$ . Subsequently,  $m_{2F}^* = 0$  because increasing  $m_{2F}$  does not increase  $\mathbb{E}[W_2]$ , also clearly seen in Figure 1. □

## A.9 Proof of Proposition 11

In general, the government chooses  $\{m_1, m_{2S}, m_{2F}\}$  to maximize welfare. For a given  $m_1$ , define the objective as

$$\begin{aligned} Y(m_1; \chi) = & W_1 - K(m_1, 0) + \chi \left[ \frac{B + m_1 + 1 - c}{2B} \max_{m_{2S}} [W_{2S} - (K(m_1, m_{2S}) - K(m_1, 0))] \right. \\ & \left. + \frac{B - m_1 - 1 + c}{2B} \max_{m_{2F}} [W_{2F} - (K(m_1, m_{2F}) - K(m_1, 0))] \right] \end{aligned} \quad (25)$$

Here,  $\chi \in [0, 1]$  measures how much the government cares the fate of the second period's fund.

*Proof.* The proof is very similar to that in Proposition 7 and Corollaries 2 and 3, albeit algebraically more involved. We start with the first half of the proposition. Because the maximum marginal benefit of  $m_1$  on the investors' total welfare is  $\frac{1-c}{B}$ ,  $K_1(c, \cdot) \geq \frac{1-c}{B}$  implies  $m_1^* \leq c$ . Figure 1 implies when  $m_{2S} > m_1 - c$ ,

welfare is weakly decreasing in  $m_2$ , thus  $m_{2S}^* = 0$ .

$$\begin{aligned}
& \frac{\partial}{\partial m_1} \frac{\partial}{\partial \chi} Y(m_1; \chi) \\
= & \frac{d}{dm_1} \left[ \frac{B + m_1 + 1 - c}{2B} \max_{\{m_{2S}\}} [W_{2S} - (K(m_1, m_{2S}) - K(m_1, 0))] \right. \\
& \left. + \frac{B - m_1 - 1 + c}{2B} \max_{\{m_{2F}\}} [W_{2F} - (K(m_1, m_{2F}) - K(m_1, 0))] \right] \\
= & \frac{1-c}{2B} + \frac{\partial}{\partial m_1} \left[ \frac{B - m_1 - 1 + c}{2B} \max_{\{m_{2F}\}} [W_{2F} - (K(m_1, m_{2F}) - K(m_1, 0))] \mathbb{I}_{\{m_{2F} > m_1 + 1 - c\}} \right] \\
= & \frac{1-c}{2B} + \frac{1}{2B} [K(m_1, m_{2F}) - K(m_1, 0)] \mathbb{I}_{\{m_{2F}^* > m_1 + 1 - c\}} - \frac{1-c}{2B} \mathbb{I}_{\{m_{2F}^* > m_1 + 2c\delta\}} \\
& - \frac{1-c}{2B} \frac{2c\delta(-1+c-m_1+m_{2F}^*)}{(-1+c+2c\delta)^2} \mathbb{I}_{\{m_{2F}^* \in (m_1+1-c, m_1+2c\delta)\}} \\
\geq & 0
\end{aligned} \tag{26}$$

the second equality holds by Envelope Theorem and by the fact that if  $m_{2F} \leq m_1 + 1 - c$ , then taking  $m_{2F} = 0$  dominates as seen in Figure 1. When  $K(\cdot, 1-c) - K(\cdot, 0) > \frac{c\delta(1-c)}{B-(1-c)}$ ,  $W_{2F}(m_2 = m_1 + 2\delta c) < K(m_1, M_1 + 1 - c)$ , thus  $m_{2F}^* = 0$ ; when  $K(\cdot, 1-c) - K(\cdot, 0) > \frac{(1-c)^2}{2c\delta-1+c}$ , the last two terms on the RHS of the third equality is dominated by the first two term as  $m_{2F}^* = 0$ . In either case, we have the whole expression being non-negative.

From  $1 - c - K(\cdot, 1-c) + K(\cdot, 0) - (2+B-c)K_2(\cdot, 1-c) > 0$ , we have  $K_2(\cdot, 1-c) < \frac{1-c}{B+2-c} \frac{2\delta}{2\delta-(1+2\delta)c}$ , the marginal benefit for increasing  $m_{2S}$  in  $W_{2S}$  exceeds the cost as long as  $m_{2S} < m_1 - c$ , therefore  $m_{2S}^* = [m_1 - c]^+$ . When  $m_1 \leq c$ ,  $m_{2S}^* = 0$ , the local derivative is the same as above, thus is positive. When  $m_1 \geq c$ ,  $m_{2S}^* = m_1 - c$ ,  $m_{2F}^* = 0$ , the local derivative is

$$\begin{aligned}
& \frac{\partial}{\partial m_1} \frac{\partial}{\partial \chi} Y(m_1; \chi) \\
= & \frac{1-c}{2B} - \frac{1}{2B} [K(m_1, m_{2S}) - K(m_1, 0)] - \frac{m_1 + B + 1 - c}{2B} \frac{\partial}{\partial m_1} [K(m_1, m_1 - c) - K(m_1, 0)] \\
= & \frac{1-c}{2B} - \frac{1}{2B} [K(m_1, m_{2S}) - K(m_1, 0)] - \frac{m_1 + B + 1 - c}{2B} [K_2(m_1, m_1 - c) \\
& + K_1(m_1, m_1 - c) - K_1(m_1, 0)], \quad \text{note } K_1(m_1, m_1 - c) = K_1(m_1, 0) \\
= & \frac{1-c}{2B} - \frac{1}{2B} [K(m_1, m_{2S}) - K(m_1, 0)] - \frac{m_1 + B + 1 - c}{2B} [K_2(m_1, m_1 - c)] \\
\geq & \frac{1}{2B} [1 - c - K(m_1, 1-c) + K(m_1, 0) - (2+B-c)K_2(m_1, 1-c)] \geq 0
\end{aligned} \tag{27}$$

The last two inequalities come from the fact  $m_1 \leq 1$ , and the fact  $1 - c - K(\cdot, 1-c) + K(\cdot, 0) - (2+B-c)K_2(\cdot, 1-c) > 0$ . Therefore we have  $Y$  has increasing differences in  $(m_1, \chi)$ .

Now to prove the second half of the theorem, Note  $K_2(\cdot, 0) > \frac{1-c}{B+c-2} \frac{2\delta}{2\delta-c(1+2\delta)}$ , thus  $K(\cdot, 1-c) > \frac{1-c}{B+c-2} \frac{1-c}{1-c(1+\frac{1}{2\delta})} > \frac{1-c}{B-2+c}$ . And  $W_{2F}$  at  $m_2 = m_1 + 2c\delta$  is still less than  $K(m_1, m_1 + 1 - c) - K(m_1, 0)$ . Consequently  $m_{2F}^* = 0$ .  $K_2(\cdot, 0) > \frac{1-c}{B+c-2} \frac{2\delta}{2\delta-c(1+2\delta)}$  also implies  $\frac{1-c}{B+m_1+1-c} \frac{2\delta}{2\delta-c(1+2\delta)} < K_2(m_1, m_1 - c)$ ,

which means  $m_{2S}^* < m_1 - c$ .

$$\begin{aligned}
& \frac{\partial}{\partial m_1} \frac{\partial}{\partial \chi} Y(m_1; \chi) \\
= & \frac{d}{dm_1} \left[ \frac{B + m_1 + 1 - c}{2B} \max_{\{m_{2S}\}} [W_{2S} - (K(m_1, m_{2S}) - K(m_1, 0))] \right. \\
& \left. + \frac{B - m_1 - 1 + c}{2B} \max_{\{m_{2F}\}} [W_{2F} - (K(m_1, m_{2F}) - K(m_1, 0))] \right] \\
= & \frac{\partial}{\partial m_1} \left[ \frac{B - m_1 - 1 + c}{2B} \max_{\{m_{2F}\}} [W_{2S} - (K(m_1, m_{2S}) - K(m_1, 0))] \right] \\
= & \frac{\partial}{\partial m_1} W_{2S}(m_{2S}^*) + \frac{B - m_1 - 1 + c}{2B} \frac{\partial}{\partial m_1} [K(m_1, m_{2S}^*) - K(m_1, 0)] \\
& - \frac{1}{2B} (K(m_1, m_{2S}) - K(m_1, 0)) < 0
\end{aligned} \tag{28}$$

The first term is negative as  $m_{2S}^* < m_1 - c$ . The second term is non-positive as  $K$  is weakly increasing in second argument. Finally, the third term is zero as  $K$  has zero cross-partials.

Finally, the above argument would not work if  $m_1^* \leq c$ . But this can be ruled out in that the minimum  $\frac{\partial Y}{\partial m_1} = \frac{1-c}{2B} \left[ 1 - \frac{c(1+2\delta)}{2\delta - c(1+2\delta)} \right] = \frac{1-c}{B} \frac{\delta - c(1+2\delta)}{2\delta - c(1+2\delta)}$ . Notice we have used the fact that  $m_{2F}^* = 0$ . This is bigger than the marginal cost  $K_1(c, \cdot)$ , thus  $m_1^* > c$ , and we indeed have an interior  $m_{2S}^*$ .  $\square$

## A.10 Proof of Proposition 12

*Proof.* We prove the case under separable cost functions to focus on the information channel:  $K(m_1, m_2) = k(m_1) + k(m_2)$ . Again, let  $L$  ( $L'$ ) be the total welfare net the intervention cost if the smaller (larger) fund is saved first.

First, consider the case that  $m_1^* \leq c$  and  $m_1'^* \leq c$ . In this case,

$$\begin{aligned}
L &= \max_{m_1} \frac{1-c}{2B} [(1+B-c+m_1)(1+\lambda) - c\delta] - k(m_1) \\
L' &= \max_{m_1'} \frac{1-c}{2B} \left[ \left( 1 + B - c + \frac{m_1'}{\lambda} \right) (1 + \lambda) - c\lambda\delta \right] - k(m_1').
\end{aligned}$$

Since  $\lambda > 1$ , obviously  $L > L'$ .

Next, consider the case that both  $m_1^* > c$  and  $m_1'^* > c$ .

$$\begin{aligned}
L &= \max_{m_1} \frac{1-c}{2B} [(1+B-c+m_1)(1+\lambda) - c\delta] - k(m_1) - \frac{B+m_1+1-c}{2B} k((m_1-c)\lambda) \\
L' &= \max_{m_1'} \frac{1-c}{2B} \left[ (1+B-c+m_1')(1+\lambda) - c\lambda\delta \right] - k(\lambda m_1') - \frac{B+m_1'+1-c}{2B} k(m_1\lambda - c).
\end{aligned}$$

In this case, even if  $m_1^* = \frac{m_1'^*}{\lambda}$ ,  $L|_{m_1^* = \frac{m_1'^*}{\lambda}} - L'_{m_1' = m_1'^*}$  equals

$$L|_{m_1^* = \frac{m_1'^*}{\lambda}} - L'_{m_1' = m_1'^*} = c\delta(\lambda - 1) + \left[ k(m_1'^*) - k\left(\frac{m_1'^*}{\lambda}\right) \right] + \frac{B + \frac{m_1'^*}{\lambda} + 1 - c}{2B} \left[ k\left(\frac{m_1'^*}{\lambda} - c\right) - k\left(\left(\frac{m_1'^*}{\lambda} - c\right)\lambda\right) \right].$$

Since  $k(\cdot)$  is convex,

$$\begin{aligned} L|_{m_1^* = \frac{m_1'^*}{\lambda}} - L'_{m_1' = m_1'^*} &> \left[ k(m_1'^*) - k\left(\frac{m_1'^*}{\lambda}\right) \right] - \left[ k\left(\left(\frac{m_1'^*}{\lambda} - c\right)\lambda\right) - k\left(\frac{m_1'^*}{\lambda} - c\right) \right] \\ &> 0. \end{aligned}$$

□

## B Full Analysis of Section 3.2.2

Is there any equilibrium that agents choose to run irrespective of their signals? In other words, the threshold  $x_2^*$  that agents in period 2 adopt satisfy  $x_2^* \leq \theta_1^* - \delta$ . It turns out that such an equilibrium exists if and only if  $m_2 < m_1 + 1 - c$ . In this type of equilibrium, government intervention in the first period has a dominant effect on coordination among investors in the second period. Therefore, we name it after *Stage Game Equilibrium with Dynamic Coordination*.

Lemma 8 describes this type of equilibrium. Since it is common knowledge that  $\theta > \theta_1^*$ , any equilibrium with  $(\theta_2^* < \theta_1^*, x_2^* < \theta_1^* - \delta)$  is equivalent to  $(\theta_2^*, x_2^*) = (-\infty, -\infty)$ .

**Lemma 8** (Stage Game Equilibrium with Dynamic Coordination)

*If  $s_1 = F$ ,  $(\theta_2^*, x_2^*) = (-\infty, -\infty)$  consists an equilibrium if and only if  $m_2 < m_1 + 1 - c$ .*

Next, we turn to threshold equilibria with  $\theta_2^* > \theta_1^*$  so that the fate of the fund in period 2 still has uncertainty. Similar to the analysis when  $s_1 = S$ , we consider two types of equilibria, depending on whether the marginal investor find the public news useful.

**Lemma 9** (Stage Game Equilibrium without Dynamic Coordination)

*If  $s_1 = F$  and  $m_2 > m_1 + 2c\delta$ , there exists a equilibrium with thresholds*

$$\begin{cases} \theta_2^* = 1 + m_2 - c \\ x_2^* = 1 + m_2 - c + \delta(1 - 2c). \end{cases} \quad (29)$$

**Lemma 10** (Stage Game Equilibrium with Partial Dynamic Coordination)

*If  $s_1 = F$  and  $\min\{m_1 + 2c\delta, m_1 + 1 - c\} < m_2 < \max\{m_1 + 2c\delta, m_1 + 1 - c\}$ , there exists an equilibrium with thresholds*

$$\begin{cases} \theta_2^* = 1 + m_2 - c - \frac{(1-c)(m_1 + 2c\delta - m_2)}{c(1+2\delta) - 1} \\ x_2^* = 1 + m_2 - c + \delta(1 - 2c) - \frac{(1-c)(1+2\delta)(m_1 + 2c\delta - m_2)}{c(1+2\delta) - 1}. \end{cases} \quad (30)$$

Given any  $(m_1, m_2)$  and  $s_1 = F$ , Proposition 2 clearly follows Lemma 8, 9 and 10.

## C Full Analysis of Normally Distributed Signals

The equilibrium outcome in period 1 is characterized by two thresholds  $(\theta_1^*, x_1^*)$  which satisfy

$$\begin{aligned} A_1(\theta_1^*) + m_1 &= \theta_1^* \\ \Pr(\theta < \theta_1^* | x_1 = x_1^*) &= c \end{aligned}$$

where  $A_1(\theta_1^*) = \Pr(x_1 < x_1^* | \theta = \theta_1^*)$  is the measure of investors who choose to roll over. Simple calculation shows that,

$$\begin{aligned} \theta_1^* &= 1 + m_1 - c \\ x_1^* &= 1 + m_1 - c - \delta \Phi^{-1}(c) \end{aligned}$$

The equilibrium in period 2 is again, state-independent. We discuss the outcomes when  $s_1 = S$  and leave the case  $s_1 = F$  to the Appendix. When the intervention in the first period has succeeded, equilibrium in the second period will be either a stage game equilibrium with full dynamic coordination (similar to Lemma 2), or one with partial dynamic coordination (similar to Lemma 4). The case without dynamic coordination vanishes as the support of the noise now spans between  $(\infty, \infty)$ . The first type of equilibrium is denoted as  $(\theta_2^*, x_2^*) = (\infty, \infty)$  and any equilibrium with  $(\theta_2^* > \theta_1^*, x_2^* = \infty)$  is equivalent. The necessary conditions that  $(\theta_2^*, x_2^*) = (\infty, \infty)$  consists an equilibrium are

$$\begin{aligned} \Pr(1 + m_2 > \theta | \theta < \theta_1^*) &= 1 \\ \Rightarrow m_2 &> m_1 - c. \end{aligned}$$

Likewise, the necessary conditions that an equilibrium with partial dynamic coordination exists is that the solution  $(\theta_2^*, x_2^*)$  to the equation system

$$\begin{aligned} A_2(\theta_2^*) + m_2 &= \theta_2^* \\ \Pr(\theta < \theta_2^* | x_2^*, \theta < \theta_1^*) &= c \end{aligned}$$

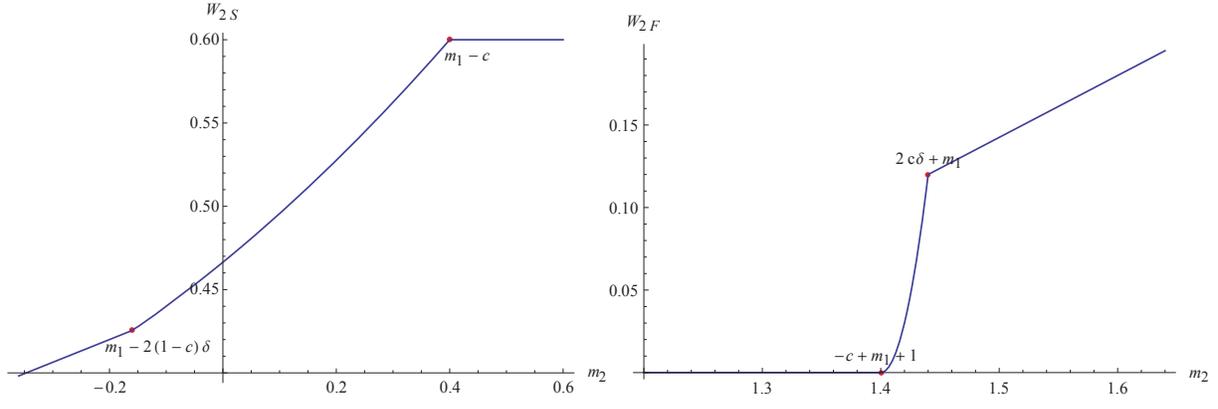
exists and satisfies  $\theta_2^* < \theta_1^*$ . Equivalently, we are looking for  $\theta_2^*$  that solves

$$1 - (\theta_2^* - m_2) = c \Phi \left( \frac{\theta_1^* - \theta_2^* - \delta \Phi^{-1}(\theta_2^* - m_2)}{\delta} \right) \quad (31)$$

We numerically solve equation (31).

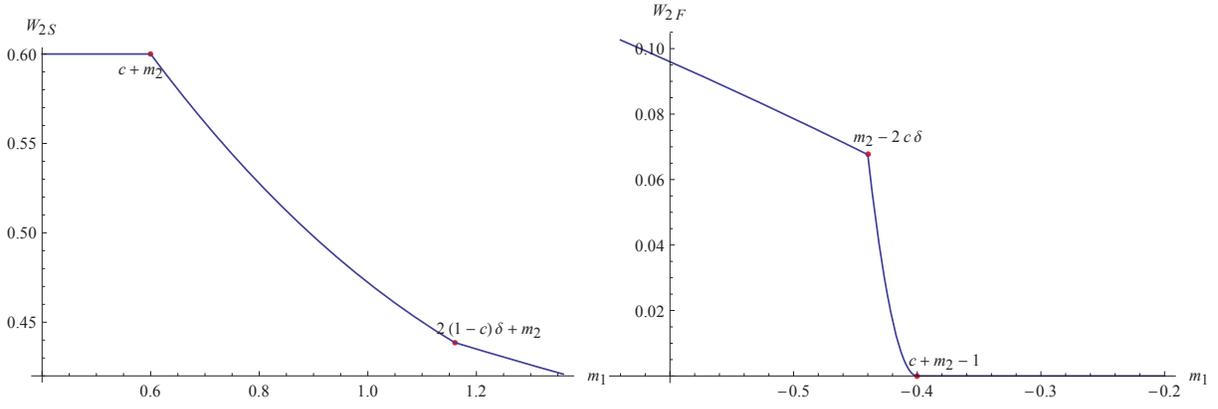
# Figures

Figure 1:  $W_{2S}$  and  $W_{2F}$  as A Function of  $m_2$



Parameters:  $\delta = 0.8$ ,  $c = 0.4$ ,  $B = 3$ ,  $m_1 = 0.8$ .

Figure 2:  $W_{2S}$  and  $W_{2F}$  as A Function of  $m_1$



Parameters:  $\delta = 0.8$ ,  $c = 0.4$ ,  $B = 3$ ,  $m_2 = 0.2$ .

Figure 3:  $E[W_2]$  as a function of  $m_1$

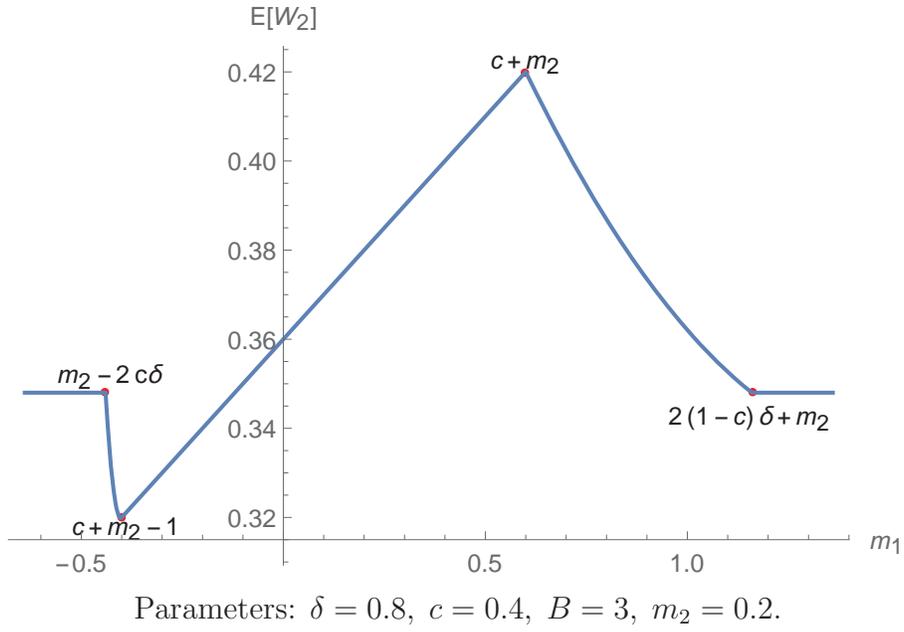


Figure 4:  $W_1 + W_2$  as A Function of  $m_1$  ( $m_1 + m_2 = M > 2c\delta$ )

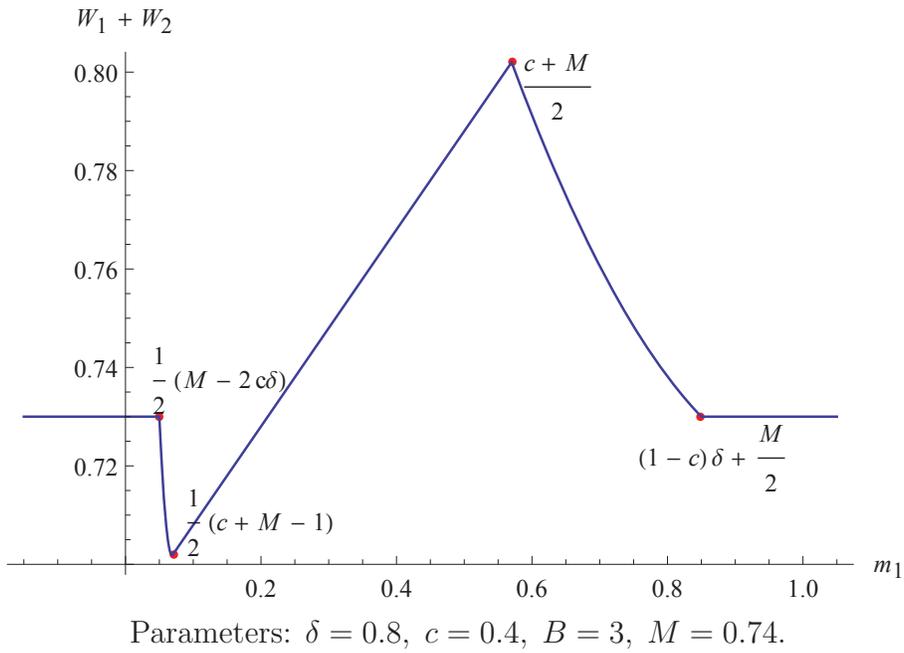


Figure 5:  $E[W_2]$  as A Function of  $m_2$

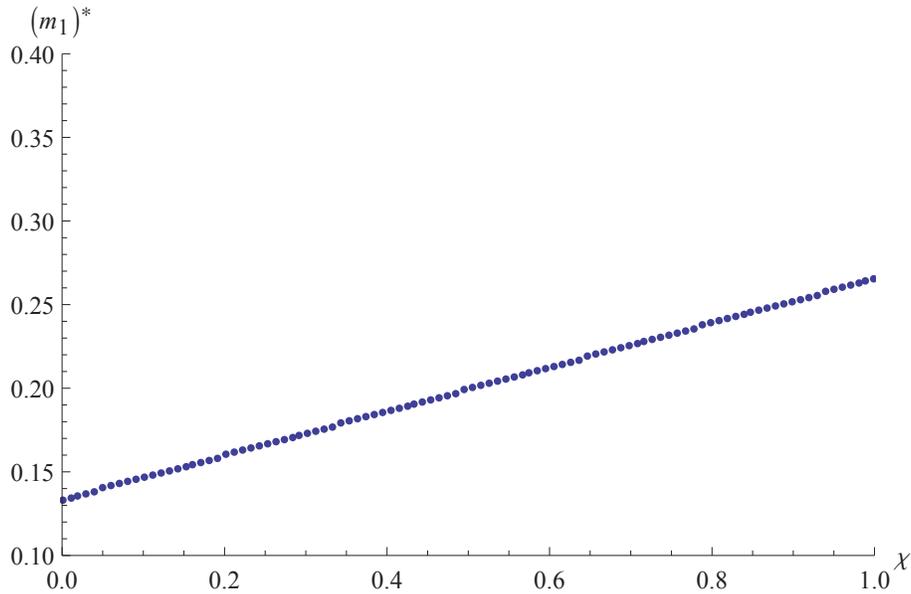
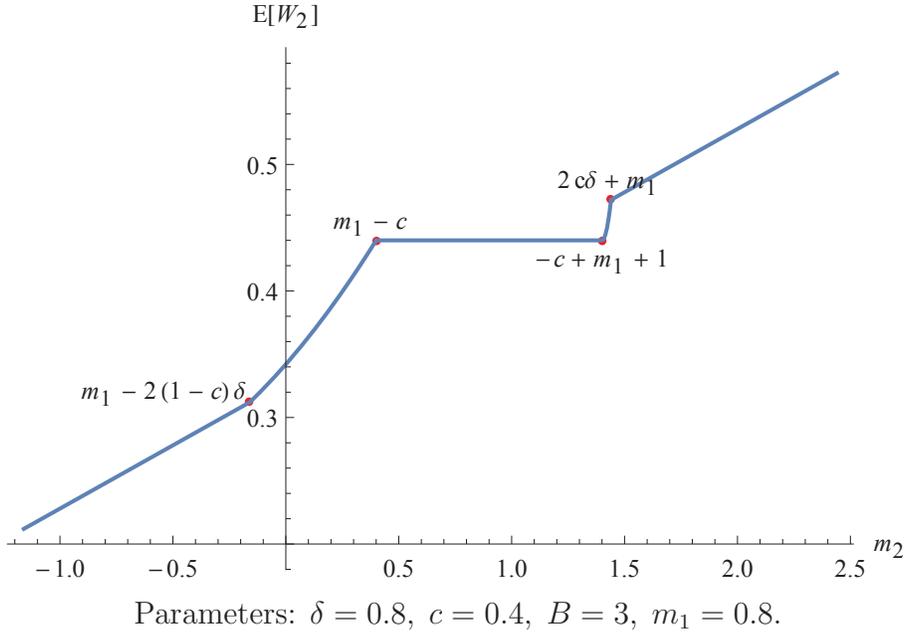


Figure 6: Endogenous initial intervention as a function of the extent the policy-maker considers the subsequent intervention

Parameters:  $\delta = 1.2, c = 0.6, B = 3, k_1 = 0.5, k_2 = 0.5, K(m_1, m_2) = \frac{1}{2}k_1m_1^2 + \frac{1}{2}k_2m_2^2$ .

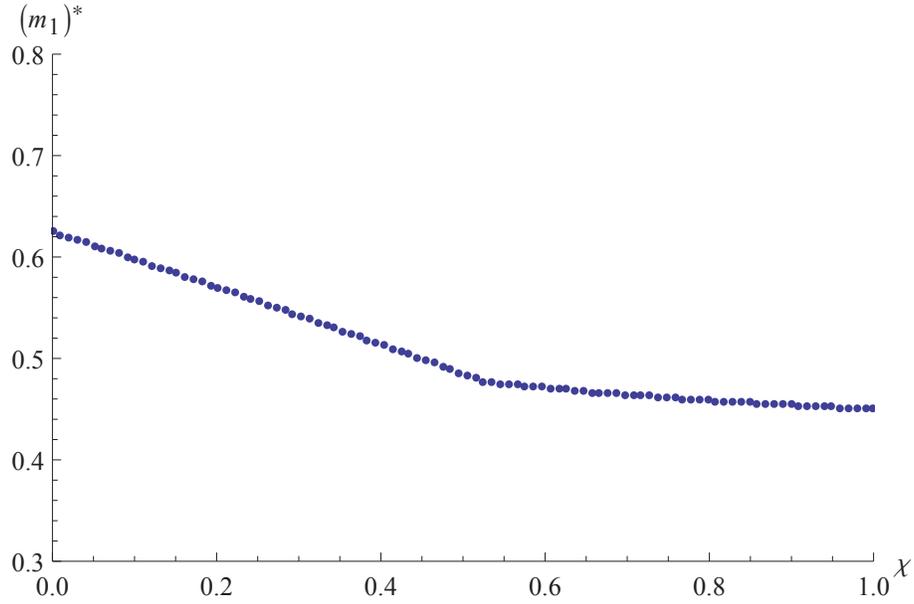


Figure 7: Endogenous initial intervention as a function of the extent the policy-maker considers the subsequent intervention

Parameters:  $\delta = 2$ ,  $c = 0.25$ ,  $B = 3$ ,  $k_1 = 0.2$ ,  $k_2 = 0.8$ ,  $K(m_1, m_2) = \frac{1}{2}k_1m_1^2 + \frac{1}{2}k_2m_2^2$ .

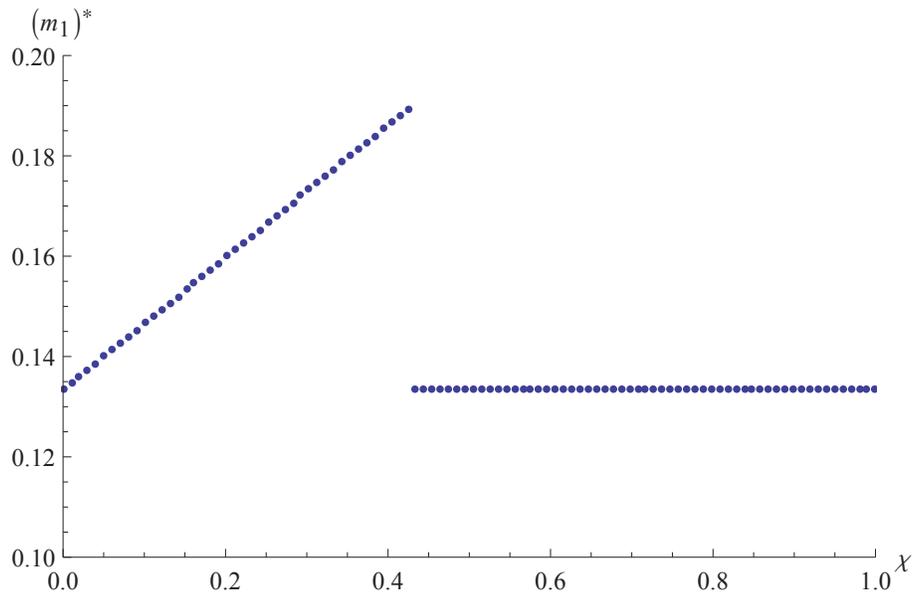


Figure 8: Endogenous initial intervention as a function of the extent the policy-maker considers the subsequent intervention

Parameters:  $\delta = 1.2$ ,  $c = 0.6$ ,  $B = 3$ ,  $k_1 = 0.5$ ,  $k_2 = 0.01$ ,  $K(m_1, m_2) = \frac{1}{2}k_1m_1^2 + \frac{1}{2}k_2m_2^2$ .