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Abstract

This paper theoretically analyzes the Early Warning System (EWS) of the IMF based on the principal-agent model. We search for trade-off of the optimal contract of the IMF under the interim intervention and the noise of the signal. The main findings are as follows. First, when the net loss coming from noise under good fundamental is higher than the net gain by interim intervention under bad fundamental, the debtor country exerts less effort as the noise effect becomes larger. Secondly, when the net loss in good fundamental is smaller than the net gain in the bad fundamental, accurate signal may give rise to the moral hazard problem. Thirdly, when the marginal utility by the intervention of the IMF is higher on bad fundamentals than on good fundamentals, the higher ability of the IMF to mitigate the crisis will elicit a less policy effort from the country. On the other hand, when the economy has higher marginal utility in case of good fundamentals, deeper intervention of the IMF offers an incentive of a greater policy effort to the country. Fourthly, mandating the IMF to care about the country welfare as well as safeguarding its resources, does not necessarily mean the debtor country will exerts less efforts.

keywords: the IMF, EWS, principal-agent model, optimal contract

1 Introduction

As more developing countries liberalize their capital control regulations, and as more investors invest huge money abroad, the possiblity of financial crisis could get higher. Then vulnerable countries are always at the risk of currency crisis in exchange with chance of welcoming beneficial capital flows. The IMF is expected to take necessary action to prevent crisis by forecasting and advising developing country authorities.[1] The EWS

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[1]For the survey and further discussion of the EWS, refer to Berg, Boresztein, and Pattilo (2004).

seems to be a good tool for this challenging work. The IMF is expected to help developing countries build needed and reliable economic statistical database. It is a foundation of every EWS studies for crisis prevention. Prevention of possible crisis concerns with both the effort of the program country and the IMF.

This paper focuses on two roles of the IMF to produce stability of debtor country's fundamentals and the financial market: the International Lender of Last Resort (ILOLR), and countries' surveillance with the application of EWS. While the ILOLR is the way of providing short-term liquidity to crisis countries and subject to appropriate conditions, "surveillance" is an effective monitoring that would limit the extent of debtor moral hazard, and redress problem through policy consultation. The EWS is attempted to predict currency crisis, to warn the debtor country in advance, and therefore to prevent the severe crisis. However, if the action of IMF in the interim period may lead to another exposure to international liquidity cycles, and cause an unnecessary crises by international creditors.

Recent literature focus on the implication of asymmetric and private information for the behavior of debtor countries and speculators. Botmand and Diks (2005) analyze the speculative attacks based on the global games, developed by Morris and Shin (2000). Chami, Sharma, and Shim (2004) find the role of the coinsurance arrangement among debtor countries to safeguard themselves against the currecy attacks based on the principal-agent theory. These theories only divide the timing into the parts: before the crisis and after the crisis.

In this paper, we develop a simple principal-agent model with three timing: before the crisis, the interim period, and the final period. This paper focuses on the interim intervention of the IMF under the EWS approach. We explore the incentive effects of the IMF financing and analyze the trade-off when the anticipation of the IMF is suffering from the noise. There is a benefit when the IMF warns earlier when the fundamental is in the bad situation. Especially, we analyze two cases: the case when the IMF warns in advance although the fundamental is good and the case when the IMF does not warn although the fundamental is bad. We also analyze the optimal level of the contract as LOLR.

The main results are as follows. First, when the net loss of inaccurate signal under good fundamental is higher than the net gain by the proper intervention under bad fundamental, the debtor country exerts less effort as the noise effect becomes larger. A signal which frequently gives false alarms will definitely make the world economy confused or have countries skeptical about the warning system and as a result they become less willing to take necessary action. Therefore the IMF should minimize the noise so that the country becomes more willing to take large policy actions. Secondly, when the net loss in good fundamental is smaller than the net gain in the bad fundamental, accurate signal may give rise to the moral hazard problem. Intentional concealing of the information may have positive effects to solve this problem. Thirdly, when the marginal utility from the intervention of the IMF is higher on bad fundamentals than on good fundamentals, the higher ability of the IMF to mitigate the crisis will elicit a less policy effort from the country. On the other hand, when the economy has higher marginal utility in case of good fundamentals, deeper intervention of the IMF offers an incentive of a greater policy effort to the country: although the noise let the economy face the shock, higher intervention mitigates the shock, so the country is induced a larger policy response. Fourthly, mandating the IMF to care about the country welfare as well as safeguarding its resources, does not necessarily mean the debtor country will exert less efforts.

The rest of paper is organized as follows. Section 2 presents a model to explain how the IMF influences on the macro-policy of debtor countries using a framework of a principal-agent model. Section 3 examines the effectiveness of the IMF's lending based on the characteristics of the IMF. Section 4 concludes.

2 Theoretical Approach

In this section, based on the principal-agent model, we examine the incentive effects of the IMF's intervention and trade-offs under some noise of signals. We try to access how public intervention could affect the scale of capital flows and welfare of the country.

2.1 Benchmark case 1: expost intervention

The pricipal is the IMF and the agent is the debtor country. We assume that the country has a Von-Neumann-Morgenstern utility function:

$$U(y,e) = u(y) - v(e), \tag{1}$$

where u is a continuously differentiable concave function with $u' > 0$ and $u'' < 0$. y is the net output while e is effort level of the debtor country. Policy efforts result in cost, $v(e)$, where v is a convex function: $v' > 0$, $v'' > 0$. The output is given by

$$y = \lambda L - rL, \tag{2}$$

where L is the international capital flows invested in the domestic country. λL is a production function and λ is productivity of the debtor country. [2] r is the return rate to pay back to the international investors.

We assume that the country is subject to the crisis probability θ and the exogenous shock leads to a loss of output. The expected utility of the debtor country is

$$E(U) = (1-\theta(e))u(L_G - rL) + \theta(e)u\left[\left(1 - \frac{\alpha_3}{\sigma_F}\right)L_B - \beta rL\right] - v(e), \tag{3}$$

where $L_G \equiv \lambda_G L$ is output under good fundamental while $L_B \equiv \lambda_B L$ is output under bad fundamental. We assume $\lambda_G > \lambda_B$: productivity is higher in the good fundamental. α_3 is the the damage level that lowers the output of the debtor country in the final period and σ_F is the parameter that reflects the efficacy of the IMF to reduce the output losses in the final period. β is discount factor of internatinoal investors and reflects the loss by drawing capital back in the interim period. The first term in the right hand side is the expected return of the debtor country with good fundamental and the second term is the expected return when the economy is facing the crisis. We also assume that the policy effort (e) can reduce the cost: $\theta' < 0$, $\theta'' > 0$.

The IMF has a fixed amount of resources, x, as an endowment so that it can intervene and make contingent loans to the crisis-facing debtor country. And it is assumed that the IMF also concerns the debtor country's utility. Thus, the utility function becomes:

$$U_{IMF}(x-\sigma, y) = \tilde{u}(x) + \gamma u(y), \tag{4}$$

[2] It is possible to assume a increasing-return-to-scale production function, such as L^λ and $\lambda > 1$. Then the volumn of the capital inflow is dependent on the productivity of the debtor country.

where $\tilde{u}(x)$ means the IMF's utility positively depends on the size of its own resources. Here, $\sigma \in \{0, \sigma_I, \sigma_F\}$ is defined as the cost of the IMF to diminish the bad effect of the crisis. $u(y)$ is the debtor country's utility function and $\gamma(\in [0,1])$ is the relative weight of the IMF's direct concern for the welfare of the debtor country.

2.2 Case 2: Interim Intervention with Perfect Signal

In case 2, we assume that the IMF can observe the fundamental of the debtor country beforehand. There are also two situations: high output with good fundamental and interim interim intervention to bad-fundamental economy. In this case, the IMF can set a proper intervention level so that it can guide the debtor country to keep the fundamental good. The expected utility of the debtor country becomes:

$$E(U) = (1-\theta(e))u(L_G - rL) + \theta(e)u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta rL\right] - v(e), \tag{5}$$

where σ_I is the parameter that reflects the efficacy of the IMF to reduce the output losses in the interim period and α_2 is the crisis level in the interim period. The first term is the expected return of the debtor country with good fundamental. The second term is the expected return when the IMF intervene and mitigate the crisis of the bad-fundamental country.

Case 2 is assumed to be always better than benchmark 1 case. In the next section we consider when there exists noise of the prediction of the IMF. We examine how the economy and the IMF suffers from noise and how noise distort the economy.

2.3 Case 3: Interim Intervention with Noise

We assume that the timing of the principal-agent process is as follows.

1. The role of the IMF and the abilitiy to lessen the crisis (σ) is precomminted. The probability of wrong message sending (ε) is common knowledge.

2. International capitals (L) flow in as far as the expected return from domestic investment is higher than that on world markets. We assume that there is an elastic supply of international investors wiiling to enter the domestic market.

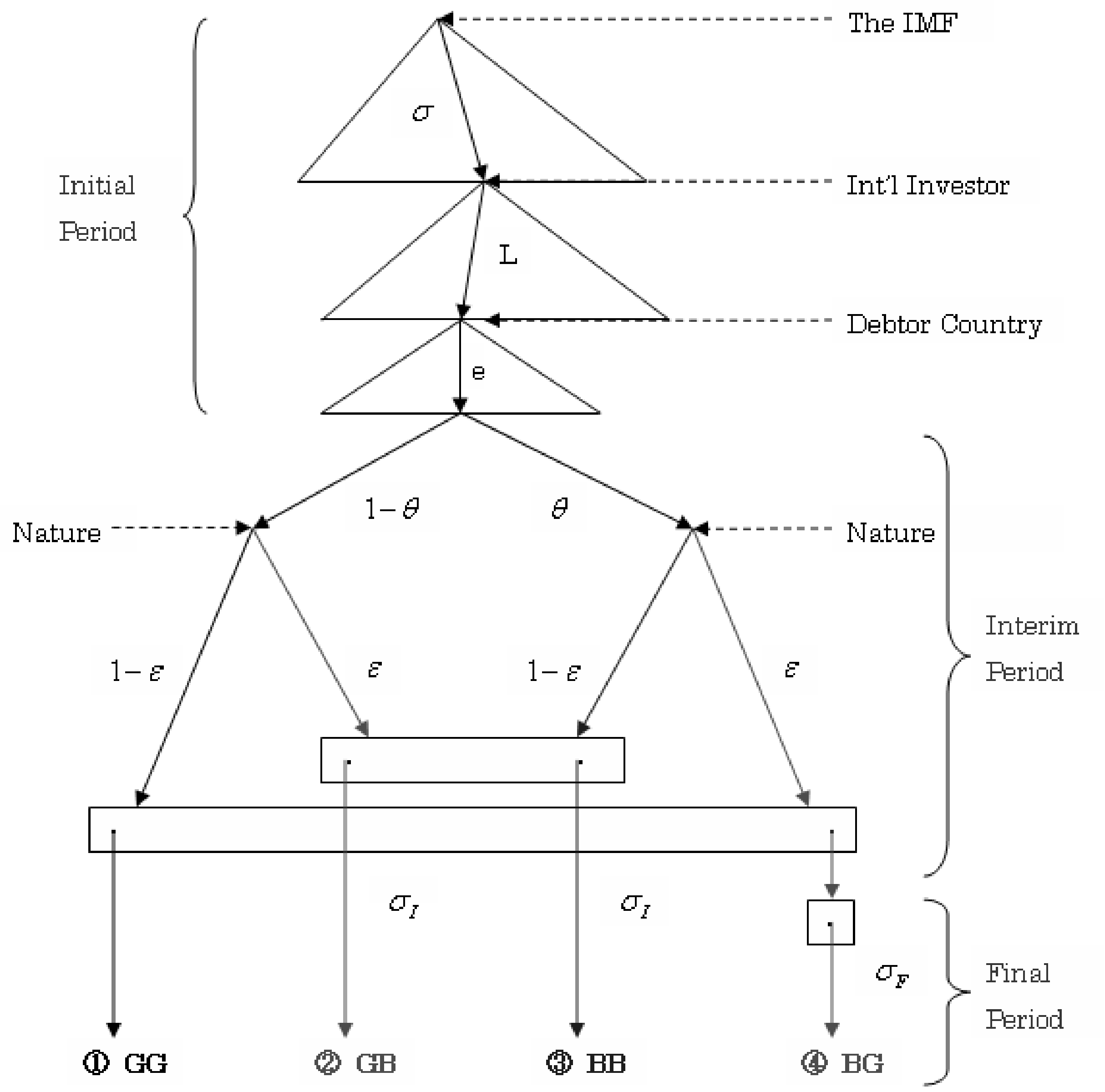
3. After receiving L, the debtor country chooses the level of effort (e) to foster the higher net expected output and not to fall into the crisis.

4. Nature roles the dice ($\theta(e)$) and the market reaction is done. The probability function $\theta(e)$ is a decreasing convex function of e. Thus with ε, four types of output are realized.

5. The EWS of the IMF expects the output realization, L_H or L_L, with the probability of ε.

6. If the country faces the crisis and calls for the help (σ) from the IMF, the IMF manages crisis.

Figure 1: Game Tree



2.4 EWS

The IMF has a role in the interim date. It has access to an imperfect signal considering the state of the debtor country's finances at the interim period. The IMF has a signal to indicate whether the country is making enough efforts and has sufficient resources to pay the debt in full. Based on this information, the IMF pronounces its view of the current state of fundamentals and chooses whether or not to intervene. The joint distribution over the signals and the real state of fundamentals is given in Table 1.

Table 1: IMF as a whistle blower (EWS)

Fundamental / IMF signal	Good	Bad
Good	$(1-\theta)(1-\varepsilon)$	$(1-\theta)\varepsilon$
Bad	$\theta\varepsilon$	$\theta(1-\varepsilon)$

note: 1) rows explain the conditions of fundamentals and columns explain the messages from the IMF
2) θ is the probability that the country enters a crisis.
3) ε is the degree of noise in the IMF's signal.

The IMF's signal is imperfect in two ways. First, the signal space is binary, {Good, Bad}, so it only tells whether the fundamentals are good or bad. Thus with this simple signal system, it may be hard to tell how bad the fundamental is. Secondly, the binary signal suffers from noise. Even when the signal is incorrect, the market reacts.

- **[Fundamentals, IMF signal] = [Bad, Bad] (Relevant Intervention with Signal):** In this case, the anticipation is correct and economy falls into the bad state. The IMF takes measure so that the economy recovers soon under the IMF's discipline. The IMF attenuates the effect of the parameter α_2 by a factor σ_I, which stands for the efficiency of intervention in the interim period, and the crisis is overcomed.
- **[Fundamentals, IMF signal] = [Good, Bad] (Irrelevent Intervention with Noise):** In the interim period, the debtor country realizes good outcome and has enough resource, but the IMF mistakenly pronounces wrong signal. Therefore, due to the coordination game among the international investors, the wrong signal let the economy decrease as much as α_1 and the IMF enters to mitigate the self-fulling shock. he output is less than that of correct signal. Therefore, in this model the intervention efficiency of the IMF in the interim period is gets lower as the noise becomes bigger.
- **[Fundamentals, IMF signal] = [Bad, Good] (Non-Intervention with Noise):** When the IMF mistakenly fails to detect the situation of the country fundametal, the intervention of the IMF is also delayed. Therefore, the damage (α_3) becomes biggest and the country is exposed to the full impact of crisis in the final period. Compared to two former cases, the intervention of the IMF is undertaken later after the debtor country is fully facing the crisis. Therefore, although the IMF fails to pronounce early it lessens the crisis as much as σ_F in the final period. It is assumed that intervention in the interim period with accurate is more efficient than that in the final period.

2.5 The Country's Objective Function

The expected utility of the debtor country becomes: [3]

$$
\begin{aligned}
E(U) &= (1-\theta)(1-\varepsilon)u(L_G - rL) + (1-\theta)\varepsilon u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta r L\right] \\
&\quad +\theta\varepsilon u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B - \beta r L\right] + \theta(1-\varepsilon)u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta r L\right] - v(e), \quad (6)
\end{aligned}
$$

where σ is the parameter that reflects the efficacy of the IMF to reduce the output losses. The first term is the expected return of the debtor country with good fundamental and accurate signal. The second term is the expected return with good fundamental and inaccurate signal. The third term is the expected return with bad fundamental and inaccurate signal. Finally the fourth term is the expected return with bad fundamental and accurate signal.

From here we consider when ε is not zero. Table 2 explains explains the final realization of output based on four types.

TABLE 2: IMF as a firefighter (ILOLR)

Fundamental / IMF signal	Output Realization	Probability
a) Good, Good	$L_G - rL$	$(1-\theta)(1-\varepsilon)$
b) Good, Bad	$(1-\frac{\alpha_1}{\sigma_I})L_G - \beta r L$	$(1-\theta)\varepsilon$
c) Bad, Good	$(1-\frac{\alpha_3}{\sigma_F})L_B - \beta r L$	$\theta\varepsilon$
d) Bad, Bad	$(1-\frac{\alpha_2}{\sigma_I})L_B - \beta r L$	$\theta(1-\varepsilon)$

note: The second column shows: a) The income level when fundamental is good and the signal is good. b) The income level when fundamental is good and the signal is bad. c) The income level when fundamental is band and the signal is good. d) The income level when fundamental is bad and the signal is bad.

Assuming the interior solution, e satisfies the following first-order condition:

$$
\begin{aligned}
\frac{\partial EU}{\partial e} &= \theta'(e)\left\{\varepsilon u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B - \beta r L\right] + (1-\varepsilon)u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta r L\right]\right. \\
&\quad \left. -(1-\varepsilon)u(L_G - rL) - \varepsilon u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta r L\right]\right\} - v'(e) = 0. \quad (7)
\end{aligned}
$$

This equation means the policy effort is chosen so that the marginal utility equals the marginal cost of the policy to overcome the policy. Since $e^* > 0, \theta'(e) < 0$ and $v'(e) > 0$, we have

$$
\begin{aligned}
&(1-\varepsilon)u(L_G - rL) + \varepsilon u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta r L\right] \\
&> \quad \varepsilon u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B - \beta r L\right] + (1-\varepsilon)u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta r L\right], \quad (8)
\end{aligned}
$$

[3] For simplicity, the following assumptions are made without loss of generality:
Assumption 1. $\alpha_3 > \alpha_2 > \alpha_1 > 0$.
The case with good fundamentals and bad signal is the worst case with the lowest outcome.
Assumption 2. $1 > \frac{\alpha_i}{\sigma}, i \in \{1, 2, 3\}$: the IMF has an ability enough to ameliorate the crisis.
Assumption 3. Output in the IMF program is higher than staying outside: it is s sufficient condition for the debtor country to seek for the help from the IMF

which means the expected return on good fundamentals is higer than that on bad fundamentals even though noise exists. From (7), we can obtain the effect of the variables $\{\varepsilon, \sigma_I, \sigma_F\}$ on the policy effort, e^*.

Definition 1 *'the net benefit from the IMF's help' is the positive gap between two results in bad fundamental, $u[(1-\frac{\alpha_2}{\sigma})L_B - \beta rL] - u[(1-\frac{\alpha_3}{\sigma})L_B - \beta rL]$, to ameliorate the crisis under bad fundamentals.*

Definition 2 *'the net loss of high effort by the noise' is the positive gap between two results in good fundamental, $u(L_G - rL) - u[(1-\frac{\alpha_1}{\sigma})L_G - \beta rL]$, when the country reach to the good fundamental.*

The net benefit is under the situation that the IMF can help the debtor country earlier in the bad fundamentals. It is the purpose of the EWS. However, the net loss is the case when the signal turns out to be wrong in the good fundamental. Therefore, the signal is another factor to determine the effort level of the debtor country.

Using the implicit function theorem we can derive the effect of the signal and its noise on the policy effort, e.

Proposition 1 *When the net loss of high effort by the noise is higher than the net benefit from the IMF's help, the smaller the noise of the signal is, the larger the country does efforts: $\frac{\partial e^*}{\partial \varepsilon} < 0$; When the net benefit is bigger than the net loss of high effort, the larger the noise of the signal is, the larger the country does efforts : $\frac{\partial e^*}{\partial \varepsilon} > 0$.* [4]

The first case of Proposition 1 is when the net loss under good fundamental is higher than the net gain under bad fundamental. In such a case, the debtor country exerts less effort as the noise effect becomes larger. A possible case is the utility under bad fundamental and bad signal is not that different from that under bad fundamental and good signal. In this case the low effort level is not affected by the noise although the economy falls into the bad situation. But when the utility under good fundamental and bad signal deviates far from that under good fundamental and good fundamental, the high effort level is highly affected by the noise. When the noise is big, the debtor country does not want to endeavor efforts. However as noise becomes smaller, the country does not have to care about the failure of the IMF's signal so takes large policy actions. The second case of Proposition 1 is when the benefit by the IMF's interim intervention is larger under the bad fundamental. It means that the EWS can effectively minimize the crisis. However, Proposition 1 implies that the damage of crisis to the debtor country is minimized with little effort and, therefore, leads to the moral hazard problem. Ironically only when the noise becomes bigger, the debtor country does efforts.

Corollary 1 *When the net loss is higher than the net benefit from the IMF's help, the bigger the noise gets, the higher the probability of the crisis becomes: $\frac{\partial \theta}{\partial \varepsilon} > 0$.*

Corollary 2 *When the net benefit under the noise is bigger than the net loss, the bigger the noise gets, the lower the the probability of the crisis becomes: $\frac{\partial \theta}{\partial \varepsilon} < 0$.*

[4] For the proof, refer to the Appendix B.

Corollary 2 indicates a very interesting results. If the IMF can control the public information, it is optimal not to release all information to the market. The debtor country endeavors every effort not to fall into the worst situation. It is a possible solution to prevent the moral hazard problem.

Proposition 2 and 3 show the relationship between each volume of the interim and final helps by the IMF and the effort level by the debtor country.

Proposition 2 *The larger σ_F becomes, the smaller the policy effort becomes:* $\frac{\partial e^*}{\partial \sigma_F} > 0$.

Proposition 2 is very straightforward. If the IMF helps more in the worst case, the country exerts less effort. Proposition 3 compares two cases: good fundamental and wrong signals and bad fundamental and correct signal.

Proposition 3 *When the marginal utility of country from the intervention gets higher in the economy with bad fundamental and bad signal than that with good fundamental and incorrect signal,* $\frac{\partial e^*}{\partial \sigma_I} < 0$*; when the marginal utility with good fundamental and wrong signal is higher, the effort increases:* $\frac{\partial e^*}{\partial \sigma_I} > 0$.

Proposition 3 implies that the effort level is dependent on whether or not signal is correct. When the marginal utility under bad fundamentals with a correct signal is higer than that under good fundamental and incorrect signal, the smaller the mitigation effect (the more intervention of the IMF), the more the country exerts efforts.

Proposition 2 and 3 show when the marginal utility from the intervention of the IMF is higher on bad fundamentals than on good fundamentals, the higher ability of the IMF to mitigate the crisis will elicit a less policy effort e^* from the country. On the other hand, when the economy has higher marginal utility in case of good fundamentals, deeper intervention of the IMF offers an incentive of a greater policy effort e^* to the country: although the noise let the economy face the shock, higher σ mitigates the shock, so the country is induced a larger policy response.

3 The Optimal Contract of the IMF

In this section, we find the optimal contract of the IMF. The expected utility function of the IMF is:

$$\begin{aligned} EU_{IMF} &= (1-\theta)(1-\varepsilon)[\tilde{u}(x,\varepsilon) + \gamma u(L_G - rL)] \\ &+ (1-\theta)\varepsilon\left\{\tilde{u}(x-\sigma_I,\varepsilon) + \gamma u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta r L\right]\right\} \\ &+ \theta\varepsilon\left\{\tilde{u}(x-\sigma_F,\varepsilon) + \gamma u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B - \beta r L\right]\right\} \\ &+ \theta(1-\varepsilon)\left\{\tilde{u}(x-\sigma_I,\varepsilon) + \gamma u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta r L\right]\right\} \\ &- \gamma v(e). \end{aligned} \tag{9}$$

The IMF's problem of choosing the optimal loan contract can be specified as follows :

$$\max_{\sigma_I,\sigma_F;\varepsilon} \quad EU_{IMF}(\sigma_I,\sigma_F,\varepsilon;e^*)$$

$$s.t. \quad e^* = \arg\max_e EU(\sigma_I,\sigma_F,\varepsilon) \tag{10}$$

$$EU(e^*;\sigma_I,\sigma_F,\varepsilon) \geq 0 \tag{11}$$

Equation (10) is incentive compatitibility constraint for the debtor country and equation (11) is participation constraint for the debtor country. By the assumption 3, the debtor country prefer to be a member of the IMF.

The principal-agent optimal contract can be solved by backward induction. First, we solve the expected utility maximization problem for the debtor country given $(\sigma_I,\sigma_F,\varepsilon)$. The solution (e^*) becomes the optimal value to satisfy the incentive compatibility constraint. Next, given the solution, the IMF offers the optimal contract or precommits its discipline (σ_I,σ_F).

3.1 IMF Objective : Balancing Country Welfare and Safeguarding of Resources

The first order conditions for the IMF's utility maximization with respect to the contract variables $\{\sigma_I,\sigma_F;\varepsilon\}$ are:

$$\begin{aligned} 0 = & - (1-\theta)\varepsilon\left\{\frac{\partial\tilde{u}(x-\sigma_I;\varepsilon)}{\partial\sigma_I} - \gamma\frac{\partial u[(1-\frac{\alpha_1}{\sigma_I})L_G-\beta rL]}{\partial\sigma_I}\right\} \\ & - \theta(1-\varepsilon)\left\{\frac{\partial\tilde{u}(x-\sigma_I;\varepsilon)}{\partial\sigma_I} - \gamma\frac{\partial u[(1-\frac{\alpha_2}{\sigma_I})L_B-\beta rL]}{\partial\sigma_I}\right\} \\ & - \frac{\partial\theta}{\partial e}\frac{\partial e}{\partial\sigma_I}[(1-\varepsilon)\tilde{u}(x,\varepsilon)-\varepsilon\tilde{u}(x-\sigma_F;\varepsilon)-(1-2\varepsilon)\tilde{u}(x-\sigma_I;\varepsilon)] \end{aligned} \tag{12}$$

$$\begin{aligned} 0 = & - \theta\varepsilon\left\{\frac{\partial\tilde{u}(x-\sigma_F;\varepsilon)}{\partial\sigma_F} - \gamma\frac{\partial u[(1-\frac{\alpha_3}{\sigma_F})L_G-\beta rL]}{\partial\sigma_F}\right\} \\ & - \frac{\partial\theta}{\partial e}\frac{\partial e}{\partial\sigma_F}[(1-\varepsilon)\tilde{u}(x;\varepsilon)-\varepsilon\tilde{u}(x-\sigma_F;\varepsilon)-(1-2\varepsilon)\tilde{u}(x-\sigma_I;\varepsilon)] \end{aligned} \tag{13}$$

Definition 3 *The expected utility of the debtor country when the IMF only considers safeguarding of resources* $(\gamma = 0)$ *is defined as follows:*

$$\begin{aligned} EU^{*\gamma=0} = & \ \varepsilon^{*\gamma=0}u\left[\left(1-\frac{\alpha_3}{\sigma_F^{*\gamma=0}}\right)L_B-\beta rL\right] + (1-\varepsilon^{*\gamma=0})u\left[\left(1-\frac{\alpha_2}{\sigma_I^{*\gamma=0}}\right)L_B-\beta rL\right] \\ & -(1-\varepsilon^{*\gamma=0})u(L_G-rL) - \varepsilon^{*\gamma=0}u\left[\left(1-\frac{\alpha_1}{\sigma_I^{*\gamma=0}}\right)L_G-\beta rL\right]. \end{aligned} \tag{14}$$

Proposition says the fact that the IMF concerns about the debtor country's welfare does not necessarily force the debtor country to be idle in performing its policy actions.

Definition 4 *The expected utility of the debtor country when the IMF take care of safeguarding of resources and country welfare* ($\gamma \in (0,1]$) *is defined as follows*:

$$\begin{aligned} EU^{*\gamma} &= \varepsilon^{*\gamma} u\left[\left(1 - \frac{\alpha_3}{\sigma_F^{*\gamma}}\right) L_B - \beta r L\right] + (1-\varepsilon^{*\gamma}) u\left[\left(1 - \frac{\alpha_2}{\sigma_I^{*\gamma}}\right) L_B - \beta r L\right] \\ &\quad -(1-\varepsilon^{*\gamma}) u(L_G - rL) - \varepsilon^{*\gamma} u\left[\left(1 - \frac{\alpha_1}{\sigma_I^{*\gamma}}\right) L_G - \beta r L\right]. \end{aligned} \tag{15}$$

Proposition 4 *If* $EU^{*\gamma=0} > (<) EU^{*\gamma}$, *Then the optimal level of policy effort satisfy* $e^{*\gamma=0} > (<) e^{*\gamma}$.

Consider the case when the IMF considers country welfare ($\gamma \neq 0$). If the difference level of the expected utility of the debtor country corresponding to the good and bad outcomes is smaller, the debtor country makes less effort to overcome the crisis. It implies that mandating the IMF to care about the country welfare as well as safeguarding its resources does not necessarily mean the debtor country will exerts less efforts.

The following proposition tells that when γ is not zero, depending on x, the amount of resources available to the IMF, the optimal contract can vary.

Proposition 5 *When* $x \to \infty$, *then the intervention level* (σ_I *and* σ_F) *gets also large to the maximum volume: When* $x \to 0$, *then the intervention level is also small to the minimum volume.*

The amount of the resources available to the IMF is important. When the resource of the IMF is large enough, the disutility from intervention cost will be very small. However, the utility of the debtor country will increase significantly by the help of the IMF and it in turn becomes the IMF's utility depending on γ.

On the other hand, when the resources of the IMF are small, the utility of the IMF increases substantially by reducing the intervention cost given the concavity of the utility function.

4 Conclusion

This paper tries to derive the optimal contract between the IMF and the debtor country in the presence of moral hazard problem and the noise of the signal. In section 2, we analyze the relationship between the policy effort and the noise. In section 3, we find the optimal contract level between the intervention level and the noise.

The main findings concering of policy effort and the noise are as follows: first, we find when the net loss between accurate signal and noise under good fundamental is higher than the net gain under bad fundamental, the debtor country exerts less effort as the noise effect becomes larger. Therefore the IMF should minimize the noise so that the country becomes more willing to take large policy actions. Secondly, when the net loss in good fundamental is smaller than the net gain in the bad fundamental, accurate signal may give rise to the moral hazard problem. Intentional concealing of the information may have positive effects to solve this problem. Thirdly, when the marginal utility from the intervention of the IMF is higher on bad fundamentals than on good fundamentals, the higher ability of the IMF to mitigate the crisis will elicit a less policy effort from the country. On the other hand, when the economy has higher marginal utility in case of good fundamentals, deeper intervention of the IMF offers an incentive of a greater policy effort to the country: although the noise let the economy face the shock, higher intervention mitigates the shock, so the country is induced a larger policy response.

The main findings of the optimal contract under the noise are as follows: Mandating the IMF to care about the country welfare as well as safeguarding its resources, does not necessarily mean the debtor country will exerts less efforts.

It is arguable that the action of the investors is very simplified. In line with Morris and Shin (2000), we can specify the strategic interaction among investors. Furthermore, the model is basically divided into three periods: before the shock, the interim period, and the final period. It would be interesting to extend the timing of intervention more dynamically, which can reduce the loss by the incorrect signal.

Appendix A: Proof for Proposition 1

From (7), $\frac{\partial e^*}{\partial \varepsilon}$ equals :

$$-\frac{\theta'[u((1-\frac{\alpha_3}{\sigma_F})L_B-\beta rL)-u((1-\frac{\alpha_2}{\sigma_I})L_B-\beta rL)+u(L_G-rL)-u(1-\frac{\alpha_1}{\sigma_I})L_G-\beta rL)]}{\theta''[\epsilon u((1-\frac{\alpha_3}{\sigma_F})L_B-\beta rL)+(1-\epsilon)u((1-\frac{\alpha_2}{\sigma_I})L_B-\beta rL)-(1-\epsilon)u(L_G-rL)-\epsilon u(1-\frac{\alpha_1}{\sigma_I})L_G-\beta rL)]-v''}.$$

Since the denominator and θ' are negative, the sign wholy depends on the terms in the bracket in the numerator. Therefore, only if the net loss is bigger than the net benefit,

$$\left\{u(L_G-rL)-u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G-\beta rL\right]\right\}-\left\{u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B-\beta rL\right]-u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B-\beta rL\right]\right\}>0,$$

$\frac{\partial e^*}{\partial \varepsilon}<0$.

On the other hand, if

$$\left\{u(L_G-rL)-u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G-\beta rL\right]\right\}-\left\{u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B-\beta rL\right]-u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B-\beta rL\right]\right\}<0,$$

then $\frac{\partial e^*}{\partial \varepsilon}>0$.

Q.E.D.

Appendix B: Proof for Corollary 1

$$\frac{\partial \theta(e^*)}{\partial \varepsilon}=\frac{\partial \theta(e^*)}{\partial e^*}\frac{\partial e^*}{\partial \varepsilon}>0.$$

Q.E.D.

Appendix C: Proof for Corollary 2

$$\frac{\partial \theta(e^*)}{\partial \varepsilon}=\frac{\partial \theta(e^*)}{\partial e^*}\frac{\partial e^*}{\partial \varepsilon}<0.$$

Q.E.D.

Appendix D: Proof for Proposition 2

From (7), $\frac{\partial e^*}{\partial \sigma_F}$ equals :

$$-\frac{\theta'[\varepsilon u'((1-\frac{\alpha_3}{\sigma_F})L_B-\beta rL)\frac{\alpha_3}{\sigma_F^2}]}{\theta''[\epsilon u((1-\frac{\alpha_3}{\sigma_F})L_B-\beta rL)+(1-\epsilon)u((1-\frac{\alpha_2}{\sigma_I})L_B-\beta rL)-(1-\epsilon)u(L_G-rL)-\epsilon u(1-\frac{\alpha_1}{\sigma_I})L_G-\beta rL)]-v''}.$$

Since $\varepsilon u'((1-\frac{\alpha_3}{\sigma_F})L_B-\beta rL)\frac{\alpha_3}{\sigma^2}$ is always positive, $\frac{\partial e^*}{\partial \sigma_F}<0$.

Q.E.D.

Appendix E: Proof for Proposition 3

From (7), $\frac{\partial e^*}{\partial \sigma_I}$ equals :

$$-\frac{\theta'[(1-\varepsilon)u'((1-\frac{\alpha_2}{\sigma_I})L_B - \beta rL)\frac{\alpha_2}{\sigma_I^2} - \varepsilon u'(1-\frac{\alpha_1}{\sigma_I})L_G - \beta rL)\frac{\alpha_1}{\sigma^2}]}{\theta''[\epsilon u((1-\frac{\alpha_3}{\sigma_F})L_B - \beta rL) + (1-\epsilon)u((1-\frac{\alpha_2}{\sigma_I})L_B - \beta rL) - (1-\epsilon)u(L_G - rL) - \epsilon u(1-\frac{\alpha_1}{\sigma_I})L_G - \beta rL)] - v''}.$$

Therefore, if

$$(1-\varepsilon)u'\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta rL\right]\frac{\alpha_2}{\sigma_I^2} > \varepsilon u'\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta rL\right]\frac{\alpha_1}{\sigma_I^2},$$

then $\frac{\partial e^*}{\partial \sigma_I} < 0$.

If

$$(1-\varepsilon)u'\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta rL\right)\frac{\alpha_2}{\sigma_I^2} < \varepsilon u'\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta rL\right]\frac{\alpha_1}{\sigma_I^2},$$

then $\frac{\partial e^*}{\partial \sigma_I} > 0$.

Q.E.D.

Appendix F: Proof for Proposition 4

Rearranging the first order condition of the debtor country, equation (7), we get

$$\begin{aligned}-\frac{v'(e)}{\theta'(e)} = \quad & (1-\varepsilon)u(L_G - rL) + \varepsilon u\left[\left(1-\frac{\alpha_1}{\sigma_I}\right)L_G - \beta rL\right] \\ & -\varepsilon u\left[\left(1-\frac{\alpha_3}{\sigma_F}\right)L_B - \beta rL\right] - (1-\varepsilon)u\left[\left(1-\frac{\alpha_2}{\sigma_I}\right)L_B - \beta rL\right].\end{aligned}$$

Defining $-\frac{v'(e)}{\theta'(e)} \equiv f(e)$, we can know $\frac{f(e)}{e} = -\frac{v''(e)\theta'(e) - \theta''(e)v'(e)}{\{\theta'(e)\}^2} > 0$.

Checking out that $f(e)$ is a strictly increasing function of effort, we can derive Proposition 4.

Q.E.D.

Appendix G: Proof for Proposition 5

Suppose $x \to \infty$. Then the first order conditions for the IMF becomes:

$$\begin{aligned}0 &= (1-\theta)\varepsilon\left\{\gamma\frac{\partial u[(1-\frac{\alpha_1}{\sigma_I})L_G - \beta rL]}{\partial \sigma_I}] + \theta(1-\varepsilon)[\gamma\frac{\partial u[(1-\frac{\alpha_2}{\sigma_I})L_B - \beta rL]}{\partial \sigma_I}\right\} \\ 0 &= \theta\varepsilon\left\{\gamma\frac{\partial u[(1-\frac{\alpha_3}{\sigma_F})L_G - \beta rL]}{\partial \sigma_F}\right\},\end{aligned}$$

since the final term in each equation converges to zero and $\frac{\partial u}{\partial \sigma} \to 0$. The right-hand side is positive and not close to zero.

Therefore to let the equations be equal to zero, $\sigma \to \infty$.

Q.E.D.

Suppose $x \to 0$. Then the first term in equation (12) and (13) increases negatively, close to ∞. Therefore, the let the equations equal zero, the second term should be close to ∞.

Q.E.D.

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