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Deposit Contract Design with Preferences for Honesty*

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ABSTRACT

This study proposes a new selection mechanism to identify the efficient allocation of a deposit contract model by using agents' *preference for honesty*. The main result is that the efficient allocation is uniquely implementable through iterated elimination of strictly dominated strategies, while it is never implementable in ex-post equilibrium under a canonical environment without preferences for honesty. This result is obtained under small and weak preferences for honesty. Furthermore, a mechanism designer requires no information on whose preference it is.

Keywords: preference for honesty; implementation; mechanism design; behavioral economics; bank run; lying cost
JEL Classification: C72, D82, G21, Z13

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1 Introduction

Implementation theory has recently started considering *preferences for honesty*.[1] This study incorporates a preference for honesty into a deposit contract design. The main result states that the efficient allocation of a deposit contract model is uniquely implementable through iterated elimination of strictly dominated strategies if some agents have a preference for honesty.[2]

The implementation of deposit contracts has a distinguished feature: the *feasibility* of allocations. The set of feasible allocations depends on the profile of agents' actions, which contrasts standard implementation problems.[3] This feasibility problem makes it difficult to incentivize agents by manipulating allocations, because some undesirable actions eliminate a desirable allocation for other agents. This study shows that any efficient allocation is never implementable in ex-post equilibrium with only *material preferences*; that is, there is *no* mechanism that implements the efficient allocation in a canonical environment of deposit contracts.

Given this fact, I introduce into the environment a preference for honesty for some agents. An honest agent prefers to reveal his own *type* (a material preference) if his action does not influence a social allocation. This preference for honesty depends on other agents' actions. The point of the preference is that *whenever an honest agent behaves dishonestly, he prefers to do so only after some other agents of the same type have done so.* The honest preference is "weak" in that he only wants to keep behaving honestly until other agents of the same type behave dishonestly.[4]

In a banking model, typical dishonest behavior is a premature withdrawal by an agent who does not require funds immediately, whom I refer to as *patient*. The honest patient agent hesitates to withdraw his deposits before maturity. However, the preference for honesty implies that this hesitation disappears if he recognizes that other *patient* agents have already withdrawn

[1]For example, Matsushima (2008a [23], 2008c [25]), Dutta and Sen (2012 [12]), Kartik and Tercieux (2012 [19]), Kartik et al. (2014 [20]), and Ortner (2015 [28]).

[2]Hereafter, I refer to "implementation" as a full implementation: any equilibrium outcome coincides with a desirable outcome.

[3]An exception is Hurwicz et al. (1995 [18]).

[4]Matsushima (2013 [26]) assumes a similar preference on implementation theory.

their deposits before his first attempt at premature withdrawal. I represent this preference as a *psychological cost.* The honest agent incurs a psychological cost against a premature withdrawal, but the cost disappears for dishonest actions of other agents.

This *cost-reduction property* comes from studies in social psychology. Wilson and Kelling (1982 [33]) propose the *broken windows theory,* which states that people tend to become vandals when they observe small signs of social disorder. Keizer et al. (2008 [21]) tested this hypothesis in field experiments and concluded that the hypothesis is statistically significant. They show empirically that a norm violation in a society by some people causes subsequent norm violations by other people. I incorporate this phenomenon into the psychological cost as its reduction.[5] This cost and its reduction can be *arbitrarily small* as long as the cost is positive.

The main result is that using this preference, the efficient allocation of a deposit contract model is implementable through iterated elimination of strictly dominated strategies. Remarkably, the mechanism is not only simple but also *detail-free* (Matsushima (2008b [24])) in that a planner need not know who the honest agent is.[6]

1.1 The bank-run problem

This research posts several issues on the *bank-run problem.* As is widely known, Diamond and Dybvig (1983 [11], hereafter DD) show that a deposit contract achieves a socially efficient allocation but may fail to be achieved for some actions of depositors. This failure is referred to as a *bank run.* DD propose two schemes for solving the problem. One is referred to as the *suspension of convertibility* scheme. If the number of premature withdrawals reaches some threshold, the bank immediately closes a window. Clearly, this scheme can achieve the efficient allocation only if the bank knows the

[5]Matsushima (2013 [26]) incorporates the results of *obedience* or *conformity* experiments in social psychology.

[6]For example, Kartik et al. (2014 [20])) establish affirmative results on general implementation theory. However, their results considerably owe to the assumption that the planner knows who the honest agent is. This study shows that a model of deposit contracts does not require that assumption.

number of *impatient* agents. The other is a *deposit insurance* scheme. It is applicable when the bank does not know the number of impatient agents, which is currently referred to as *aggregate uncertainty*. DD show that using the deposit insurance scheme, the efficient allocation is implementable in dominant strategies.

However, this deposit insurance scheme has been controversial. Wallace (1988 [31]) points out that this scheme violates a *sequential service constraint* introduced by DD themselves. He considers a finite-agent model that addresses DD's sequential service constraint and shows that the deposit insurance scheme fails to implement DD's efficient allocation. Although his criticism is important, his result crucially hinges on the assumption that the bank and its depositors can communicate *only once*. The sequential service constraint itself requires only that "a bank must service its customers sequentially, on a first-come, first-served basis" (Wallace (1988 [31]), p. 3). There is no reason to assume that a socially efficient allocation should include only one communication phase. Furthermore, the truly efficient allocation of Wallace's model differs from the efficient allocation of DD. See Green and Lin (2003 [16]) for an example.[7]

The second controversial point is that public deposit insurance schemes suffer from bank *moral hazard*. Cooper and Ross (2002 [9]) establish a model under which a deposit insurance scheme encourages excessive risk-taking by banks. Martin (2006 [22]) shows that a *liquidity provision policy* of a central bank can prevent bank runs without creating moral hazard problems. The moral hazard problem is an important issue for financial system regulations; however, concerning the resolution of the bank-run problem, these public policies imply *financial assistance* by third parties, which softens the bank's budget constraint and makes it easy to solve.

Given these observations, I reconsider the framework of DD with a sequential service constraint under aggregate uncertainty and without third parties. The only difference of the DD model is the introduction of a prefer-

[7] The difficulty of a unique implementation of the efficient allocation in Wallace's framework is observed. See Ennis and Keister (2009a [13])). I show that there is no mechanism that implements the efficient allocation in DD's framework with only material preferences. See Section 5.1 and the Appendix.

ence for honesty. I establish that the efficient allocation of the framework is implementable through iterated elimination of strictly dominated strategies, while the efficient allocation is never implementable in ex-post equilibrium without preferences for honesty. In particular, the mechanism uses neither information other than that assumed by DD nor specific information on honest agents. This study proposes a potential for *improving* deposit contract design using aspects of human behavior.

The remainder of the paper is organized as follows. Section 2 proposes an example that briefly describes the main result. Section 3 formally describes a deposit contract model and the definitions used in the model, including the preference for honesty. Section 4 states the main result, and Section 5 presents a discussion. Section 6 concludes the paper. Some technical report appears in the Appendix.

2 An Example

Suppose that there are three risk-neutral agents. Each agent is endowed a unit of an asset. They can use an investment opportunity that yields $4x$ in period t_1 per x units of input if and only if the investment level is maintained at $x \geqq 1.5$. They recognize that some of the agents need the asset before maturity, say t_0. For convenience, I refer to agents who need the asset at t_0 as *impatient* and those who do not as *patient*. Suppose that they sign a contract whose payment plans are summarized as Table 1.

θ	x	y
0	0	4
1	1.5	3
2	1	1
3	1	0

Table 1: The payment plan for each agent, where θ is the number of impatient agents, x is the payment at t_0, and y is that at t_1.

Consider the state in which agent 1 is impatient and agents 2 and 3 are patient. I assume that all agents have common knowledge about this state. Given the contract, a Nash equilibrium exists where agents behave honestly to their own types. Yet, it is easy to see that premature withdrawals by all agents also constitute a Nash equilibrium, which is well-known as a *bank-run equilibrium* in the banking literature.

Here, I propose an allocation mechanism that contains three provision phases in t_0 and that designates each agent's message space to be $M_i = \{0,1\} \times \{0,1\} \times \{0,1\}$. Let $m_i = (m_i^1, m_i^2, m_i^3) \in M_i$ denote agent i's message, where $m_i^k = 0$ (1) means a withdrawal tender (the continuation of deposits) in Phase k.

- **Phase 1.** The mechanism provides $b/2$ to any withdrawal tender i if $m_i^1 = 0$, where $b \in (0,1)$. The mechanism also counts the number of withdrawal tenders, denoted by θ_1.
- **Phase 2.** The mechanism provides $b/2$ to any withdrawal tender i if $m_i^2 = 0$.
- **Phase 3.** Let

$$(x(\theta_1), y(\theta_1)) = \begin{cases} (0,4) & \text{if } \theta_1 = 0 \\ (1.5,3) & \text{if } \theta_1 = 1 \\ (1,1) & \text{if } \theta_1 = 2 \\ (1,0) & \text{if } \theta_1 = 3. \end{cases}$$

  The provision to agent i is determined by the following rules.

  - **Rule 1.** If $m_i = (0,0,0)$, the mechanism provides $x(\theta_1) - b$.
  - **Rule 2.** If m_i is either $(1,0,0)$ or $(0,1,0)$ and $\theta_1 > 1$, the mechanism provides $x(\theta_1) - b/2$. If $\theta_1 \leqq 1$ while $m_i = (1,0,0)$ or $m_i = (0,1,0)$, the mechanism provides nothing. If $m_i = (0,0,1)$, the mechanism provides nothing.
  - **Rule 3.** If $m_i = (1,1,0)$, $(1,0,1)$, $(0,1,1)$, or $(1,1,1)$, the mechanism provides nothing.

At t_1, the mechanism provides $y(\theta_1)$ to any agent i if $m_i = (1, 1, 1)$; otherwise, it provides nothing.

Suppose that agent 2 has a small preference for honesty. This preference is defined on the set of outcomes and the set of messages. The honest behavior is $m_2^* = (1, 1, 1)$. The honest preference is as follows. If agent 2 act dishonestly and he is the first dishonest person between patient agents, he incurs a psychological cost denoted by c; otherwise, he does not incur the cost even if he acts dishonestly. Formally, for a fixed m_{-2}, suppose that m_2 and m_2' are not equal to m_2^* but the final outcome is the same. The only difference between m_2 and m_2' is that m_2 makes agent 2 the first "liar" between agents 2 and 3. Then, m_2 makes agent 2 cost c and m_2' does not do so. Equivalently, if agent 3 has already behaved dishonestly before agent 2's first dishonest action, agent 2 does not hesitate to behave dishonestly.

I show that bank runs never occur in equilibrium with this mechanism and the preference for honesty. Suppose that all agents send $(0, 0, 0)$. Then, $\theta_1 = 3$. Here, $(1, 0, 0)$ makes $\theta_1 = 2$ but $x(2) = x(3) = 1$. Hence, agent 2's payoff is

$$(b/2 + b/2 + x(3) - b) - c = x(3) - c$$

via Rule 1. If agent 2 unilaterally changes his message to $(1, 0, 0)$, the cost c vanishes and agent 2's payoff turns to $x(2)$. Hence, the change to $(1, 0, 0)$ is better for agent 2. As a result, $\theta_1 = 2$. Then, agent 3 is better off changing his message to $(1, 1, 1)$, because his deviation changes θ_1 to 1 and he can obtain $y(\theta_1) = 3$ at t_1. Given this result, agent 2's payoff turns to zero because of Rule 2. Then, agent 2 wants to change his message again to $(1, 1, 1)$ and to obtain 3 at t_1. Agent 1 has no incentive to deviate from $(0, 0, 0)$. Consequently, the bank run does not occur and the optimal allocation is realized in equilibrium.

This reasoning is valid if and only if $c > 0$. If $c = 0$, the bank-run equilibrium is still alive in the mechanism because this mechanism only separates the provision of return into sub-periods.[8]

[8] Abreu and Matsushima (1992 [3], 1994 [4]) use a mechanism that requires agents to announce messages multiple times, but the final outcome is provided once through a *lottery*, including a degenerate one. The mechanisms used in this study require agents

This simple example suggests that (*i*) mechanism design and the preference for honesty are both important; (*ii*) the positive cost for dishonest behavior can be arbitrarily small; (*iii*) the mechanism is *detail-free* in that it is not necessary for the designer to know who the honest agent is.

3 The Model

3.1 Environment

The economy comprises two periods, t_0, t_1. Players are a principal and agents. The set of agents is $I = [0,1]$. There is a single asset in the economy. Each agent is endowed a unit of the asset and has already deposited it to the principal. The principal has an investment opportunity that yields $R > 1$ units of the asset at t_1 per a unit of input before t_0. Premature liquidation at t_0 is possible without any cost, but it returns a unit of the asset at t_0 per unit of liquidation.[9]

At the commencement of t_0, a fraction $\theta \in [0,1]$ of the agents become *impatient*. They obtain utility only in t_0, whereas the remaining $1-\theta$ agents, referred to as *patient*, obtain utility in both t_0 and t_1. Let $\theta_i \in \Theta_i = \{0,1\}$ denote an agent i's *type*, where 0 and 1 indicate impatient and patient, respectively. To avoid an unimportant discussion, I make two assumptions on θ: (1) The aggregation of types coincides with the state, that is, $\theta = \mu(\{i \in I \mid \theta_i = 0\})$, where μ is the Lebesgue measure; (2) If $\theta = 1$ or $\theta = 0$, $\theta_i = 0$ or $\theta_i = 1$ *for all* $i \in I$, respectively.[10] *Throughout the paper, any set is assumed to be measurable.*

Each agent has a von Neumann–Morgenstern utility function on assets, denoted by $u : \mathbf{R}_+ \to \mathbf{R}_+$. For simplicity, $u(0) = 0$ and $u(\cdot)$ satisfy the same

to announce their own type three times, and outcomes according to their reports are separately provided each time. Ohashi (2015 [27]) uses a similar mechanism to that in this study and establishes a positive result for a deposit model with costly liquidation.

[9] Many previous studies have assumed liquidation costs, such as Cooper and Ross (1998 [8]), Allen and Gale (1998 [1], 2000 [2]), Ennis and Keister (2009b [14]), and Ohashi (2015 [27]).

[10] Mathematically, it may be possible if $\theta = 1$, but there are a *countable* number of agents with $\theta_i = 1$. This second assumption rules out such a case.

assumptions as in DD.

Assumption 1 $u'(a) > 0$, $u''(a) < 0$ *and* $-au''(a)/u'(a) > 1$ *for all* $a > 0$; $\lim_{a \to 0} u'(a) = \infty$ *and* $\lim_{a \to \infty} u'(a) = 0$.

Let a_k denote the amount of the asset that an agent obtains in t_k. The *material utility* of a type-θ_i agent for an allocation $a = (a_0, a_1)$ is defined as $v_i(a, \theta) \equiv u(a_0 + \theta_i a_1)$. I follow a *consequentialist* premise in that only the final outcome is of relevance to agents.

A socially efficient allocation is defined as the solution to the following optimization problem:

$$\max_{a_0, a_1} \; \theta u(a_0) + (1-\theta)u(a_1)$$
$$s.t. \; (1-\theta)a_1 \leqq R(1-\theta a_0).$$

For each $\theta \in (0, 1)$, Assumption 1 ensures that an optimal solution, denoted by $(a_0(\theta), a_1(\theta))$, uniquely exists and satisfies $1 < a_0(\theta) < a_1(\theta) < R$.[11] If $\theta \in \{0, 1\}$, $a_0(1) = 1$ and $a_1(0) = R$, whereas $a_0(0)$ and $a_1(1)$ are indeterminate.

Assumption 2 $a_0(0) = a_1(1) = 0$.

This assumption is plausible because the principal has to provide $a_0(1) = 1$ at t_0 to achieve efficiency; therefore the principal has no assets at t_1. Using the same reasoning, to provide $a_1(0) = R$ to all agents, we have to set $a_0(0) = 0$. Moreover, this assumption is necessary to describe the bankruptcy model.[12]

3.2 Preference for Honesty

Let Y denote the set of all possible outcomes, let M_i denote the set of *messages* of an agent i, and set $M = \times M_i$ to be the direct product of M_i over

[11] The first-order condition implies that $a_0(\theta) < a_1(\theta)$ for each $\theta \in (0, 1)$. The order $1 < a_0(\theta) < a_1(\theta) < R$ is led by the assumption that $-au''(a)/u'(a) > 1$ for all $a > 0$. For details, see DD.

[12] One may think that the principal could offer any amount of the asset in t_1 because there is no agent in t_1. Mathematically, it would be possible to offer any positive amount of the asset to at most "zero-measured" agents. However, if we allow this view, the DD model (and my model) are free from bankruptcy without any honest preference. See the Appendix for details.

I. Similarly, $M_{-i} = \times_{j \neq i} M_j$ denotes the direct product of M_j other than i. A mapping $g : M \to Y$ is said to be an *outcome function*. A mechanism $\mathcal{M}$ is defined as $\mathcal{M} = (M, g)$. I identify an outcome $g(m)$ with a corresponding allocation (a_0, a_1).[13]

Let $\mathcal{P}(I)$ denote a *partition* of I, the set of agents. A preference for honesty is defined on $(M, \mathcal{P}(I))$. I write $J = J(i)$ if $i \in J \in \mathcal{P}(I)$. Let $U_i(g(m), m, \theta)$ denote the payoff function of agent i including a preference for honesty under message profile m and state θ. I write $U_i^g(m, \theta)$ for short. I consider a mechanism such that $M_i = \Theta_i \times \Theta_i \times \Theta_i$ for each $i \in I$. For convenience, I write $m_i = (m_i^1, m_i^2, m_i^3)$. For each $i \in I$ and $k \in \{1, 2, 3\}$, let $m_i^{*k}(\theta_i) = \theta_i$ for each $\theta_i \in \Theta_i$. I denote $m_i^*(\theta_i) = (\theta_i, \theta_i, \theta_i)$ for convenience. For each $i \in I$, $\theta_i \in \Theta_i$, and $m_i \in M_i$, I define a number $k_i(\theta_i, m_i)$ such that $k_i(\theta_i, m_i) = \min\{k \mid \theta_i \neq m_i^k\}$ if $m_i \neq m_i^*$ and $k_i(\theta_i, m_i) = 4$ if $m_i = m_i^*$.

Definition 1 *An agent i has a* preference for honesty *on $(M, \mathcal{P}(I))$ if for any $g : M \to Y$ and $\theta \in \Theta$: For any $m_{-i} \in M_{-i}$, $m_i \in M_i$, and $m_i' \in M_i$, if*

$$v_i(g(m), \theta) = v_i(g(m_i', m_{-i}), \theta) \tag{1}$$

and

$$k_i(\theta_i, m_i) < k_i(\theta_i, m_i') \tag{2}$$

and

$$k_i(\theta_i, m_i) \leqq k_j(\theta_j, m_j) \leqq k_i(\theta_i, m_i') \tag{3}$$

for all $j \in J(i)$,

$$\begin{aligned} U_i^g(m, \theta) &= v_i(g(m), \theta) - c \\ &< v_i(g(m_i', m_{-i}), \theta) = U_i^g(m_i', m_{-i}, \theta) \end{aligned}$$

for some $c > 0$; otherwise, $U_i^g(m, \theta) = U_i^g(m_i', m_{-i}, \theta)$.

I refer to the agents who have this preference for honesty as *honest* agents, whereas I refer to agents who do not have such preference as *standard* agents.

[13] This notation implicitly assumes that agents are equally treated. For more general allocation rules, see the Appendix.

Definition 1 implies that if the outcomes are the same for two different messages (Equation (1)) but one of the messages is different from an honest one (Equation (2)) and the former message makes agent i be one of the first dishonest agents of the same type (Equation (3)), agent i incurs a positive cost if he chooses the former message. Definition 1 also implies that agent i's cost for "lying" vanishes if some other agent of the same type has already lied *even if he lies*, that is, $k_j(\theta_j, m_j) < k_i(\theta_i, m_i)$ for some $j \in J(i)$ implies $c = 0$, but both m_i and m_i' may not be equal to m_i^*.

Let J_t denote the set of type-t agents, that is, $J_t = \{i \in I \mid \theta_i = t\}$. I set $\mathcal{P}(I) = \{J_0, J_1\}$. Let $J_t^* \subset J_t$ denote the set of honest type-t agents on $(M, \mathcal{P}(I))$. I assume $J_0^* = J_0$ and $\mu(J_1^*) > 0$.[14] I refer to the environment that the preference for honesty holds as *environment* $\mathcal{E}^*$ for short.

3.3 Solution Concepts

Let $s_i : \Theta_i \to M_i$ denote agent i's *strategy* and let S_i denote the set of all strategies of i. I write $S = \times S_i$ and $S_{-i} = \times_{j \neq i} S_j$. Let $s(\theta) = (s_i, s_{-i})(\theta) \equiv (s_i(\theta_i), s_{-i}(\theta_{-i}))$ for convenience. Similarly, $(m_i, s_{-i})(\theta)$ denotes a message profile such that agent i reports $m_i = s_i'(\theta_i)$ while any other agent j reports $s_j(\theta_j)$. A strategy profile s is said to be *ex-post equilibrium* if

$$U_i^g(s(\theta), \theta) \geqq U_i^g((m_i, s_{-i})(\theta), \theta)$$

for all $i \in I$, $\theta \in \Theta$, and $m_i \in M_i$. A message m_i is *strictly dominated against* $S'_{-i} \subset S_{-i}$ *at* θ if for all $s'_{-i} \in S'_{-i}$, there is a message m_i' such that

$$U_i^g((m_i, s_{-i})(\theta), \theta) < U_i^g((m_i', s_{-i})(\theta), \theta).$$

A strategy s_i is strictly dominated against $S'_{-i} \subset S_{-i}$ at θ if the message $s_i(\theta_i)$ is strictly dominated against S'_{-i} at θ. For a given $\theta \in [0, 1]$, consider a decreasing sequence of sets, $(S_i^k)_{k \in \mathbf{N}}$, such that the following hold: $(i) S_i^0 = S_i$; $(ii) S_i^{k+1} \subset S_i^k$ for each $k \in \mathbf{N}$; (iii) any strategy $s_i \in S_i^k \setminus S_i^{k+1}$ is strictly

[14] That is, all impatient agents are honest. In general, impatient agents always request withdrawal in t_0, and hence, this assumption is a very mild requirement.

dominated at θ against S^k_{-i}. Given such a decreasing sequence, a set of strategies S^*_i is said to be *iteratively undominated at* θ if $S^*_i = \bigcap_k S^k_i$ holds. An allocation $(a_0(\theta), a_1(\theta))$ is *implementable through iterated elimination of strictly dominated strategies* if for all $\theta \in [0,1]$, each agent i has an iteratively undominated set S^*_i at θ and $g(s^*(\theta)) = (a_0(\theta), a_1(\theta))$ for *all* $s \in S^*$.[15]

4 The Main Result

Theorem 1 *The efficient allocation* $(a_0(\theta), a_1(\theta))$ *is implementable through iterated elimination of strictly dominated strategies under the environment* $\mathcal{E}^*$.

Proof. Let $\mathcal{M}^*$ denote the mechanism I consider. The $\mathcal{M}^*$ has three provision phases in t_0. Let $m_i = (m^1_i, m^2_i, m^3_i) \in \Theta_i \times \Theta_i \times \Theta_i$ denote a message of agent i. I write $g^k_i(m)$ for agent i's component of the allocation $g(m)$ on Phase k. Let $\theta_1 = \mu(\{i \in I \mid m^1_i = 0\})$.
Phase 1: If $m^1_i = 0$,

$$g^1_i(m) = b/2,$$

where $b \in (0,1)$. Otherwise, $g^1_i(m) = 0$.
Phase 2: For any message profile (m^1_i, m^2_i),

$$g^2_i(m) = \begin{cases} b/2 & \text{if } (0,0) \\ b & \text{if } (1,0) \\ 0 & \text{if } (0,1) \text{ or } (1,1). \end{cases}$$

Phase 3: For any message profile (m^1_i, m^2_i, m^3_i),

$$g^3_i(m) = \begin{cases} a_0(\theta_1) - b & \text{if } (0,0,0) \text{ or } (1,0,0) \\ a_0(\theta_1) - b/2 & \text{if } (0,1,0) \text{ or } (1,1,0) \\ 0 & \text{if } m^3_i = 1. \end{cases}$$

[15] This definition requires that all agents be served an efficient allocation. de Nicoló (1996 [10]) investigates a run-proof mechanism that provides the efficient allocation to $1-\delta$ agents with δ being close to zero.

If $\theta_1 < 1$, the mechanism provides the asset $a_1(\theta_1)$ in t_1 whenever $m_i = (1,1,1)$; if $\theta = 1$, nothing is provided in t_1.

Because of the consequentialist view, agents identify $g_i(m)$ with $g_i^1(m) + g_i^2(m) + g_i^3(m)$ in t_0. By Assumption 2, $(a_0(0), a_1(0)) = (0, R)$ and $(a_0(1), a_1(1)) = (1, 0)$. Hence, it does not matter when the true state is $\theta = 0$ or $\theta = 1$. We must only consider the case of $\theta \in (0, 1)$.

(1. Impatient agents): Let i be an impatient agent. I show that i always chooses $(0,0,0)$. For each m, $g_i(m) = a_0(\theta_1)$ if $m_i^3 = 0$ and $g_i(m)$ is less than 1 if $m_i^3 = 1$. Because $a_0(\theta_1) \geqq 1$, any message with $m_i^3 = 1$ is strictly dominated against S_{-i}:

$$S_i^1 = \{s_i \in S_i \mid s_i(0) = (\cdot, \cdot, 0)\}. \tag{4}$$

Given S^1, agent i obtains $a_0(\theta_1)$ regardless of his message. The *cost-reduction property* of the preference for honesty implies that any message with $m_i^1 = 1$ is strictly dominated against S_{-i}^1:

$$S_i^2 = \{s_i \in S_i^1 \mid s_i(0) = (0, \cdot, 0)\}. \tag{5}$$

Once again, under the cost reduction property, the following set survives the elimination of strictly dominated strategies against S_{-i}^2:

$$S_i^3 = \{s_i \in S_i^2 \mid s_i(0) = (0,0,0)\}. \tag{6}$$

(2. Patient honest agents): Let i be such an agent. The strategy set S^3 ensures that $\theta_1 > 0$. Suppose that m is such that $m_j^1 = 0$ for some $j \in J_1 \setminus \{i\}$. Both $m_i = (0,0,0)$ and $m_i' = (1,0,0)$ generate the same outcome, $a_0(\theta_1)$. Hence, the preference for honesty implies that

$$U_i^g(m_i, m_{-i}, \theta) = u(a_0(\theta_1)) - c$$

and

$$U_i^g(m_i', m_{-i}, \theta) = u(a_0(\theta_1)).$$

Next, suppose that m is such that $m_j^1 = 1$ for each $j \in J_1 \setminus \{i\}$. Then, agent i deduces $\theta_1 < 1$ because of $\mu(J_1^*) > 0$ and can definitely be served $a_1(\theta_1)$ in t_1. Hence, $s_i(1) = (0, 0, 0)$ is strictly dominated against S_{-i}^2. Define a subset of strategies for each $i \in J_1^*$ as follows:

$$S_i^4 = \{s_i \in S_i^3 \mid s_i(1) \neq (0, 0, 0)\} \tag{7}$$

and for each $j \in I \setminus J_1^*$, $S_j^4 = S_j^3$.

(3. Patient standard agents): Let i be such an agent. Because S^4 ensures $\theta_1 < 1$, agent i can be served $a_1(\theta_1) > a_0(\theta_1)$ in t_1. All strategies except for $s_i(1) = (1, 1, 1)$ are strictly dominated against S_{-i}^4. Define the following subset of strategies for each $i \in J_1 \setminus J_1^*$,

$$S_i^5 = \{s_i \in S_i^4 \mid s_i(1) = (1, 1, 1)\} \tag{8}$$

and $S_j^5 = S_j^4$ for all other agents.

(4. Patient honest agents): Because S^5 ensures $\theta_1 < 1$, we apply the same reasoning as for patient standard agents. For each $i \in J_1^*$,

$$S_i^6 = \{s_i \in S_i^5 \mid s_i(1) = (1, 1, 1)\} \tag{9}$$

and $S_j^6 = S_j^5$ for all other agents. The sets (4), (5), (6), (7), (8), and (9) constitute a monotone decreasing sequence, and the honest strategy is a unique iteratively undominated strategy for each agent. ■

I describe two remarks on the result. (1) : The key of the unique implementation is the existence of patient and *impatient* honest agents. The number of patient honest agents can be arbitrarily close to zero, whereas the number of impatient honest agents is θ.[16] This assumption is necessary for my mechanism. The point of the mechanism is to set the outcomes obtained through Phases 1 to 3 to be identical in order to use the preference for honesty. However, if there are standard impatient agents, they have in-

[16] The number of the agents who have "non-standard" preferences is an interesting issue. See Eliaz (2002 [15]) and Ortner (2015 [28]).

different preference on messages. Then, it may fail to convey the true state. For example, suppose that all impatient agents are standard and that $\theta/2$ impatient agents send $(0, 1, 0)$ and the remainder $\theta/2$ impatient agents send $(1, 0, 0)$. This results in $\theta_1 = \theta/2$ and fails to convey the true state. Fortunately, the assumption that all impatient agents are honest is harmless because dishonest behavior is never profitable for impatient agents.

(2): The mechanism uses neither the information regarding the size of the cost c nor details of who the honest agent is. The mechanism works well as long as the cost is positive and there are $\theta + \epsilon$ honest agents with arbitrarily small $\epsilon > 0$. It only requires splitting the provision.[17] Hence, this mechanism is *detail-free* (Matsushima (2008b [24])), practical, and easy to use. I do not use any information other than DD in constructing the mechanism. The equilibrium embodies a very plausible human behavior in deposit contracts: *I behave honestly in Phase 1. If $\theta_1 = 1$, I withdraw my deposit in Phases 2 and 3, otherwise I keep behaving honestly.* The result can be extended to a dynamic framework.[18]

5 Discussions

This section discusses three important topics.

5.1 On the necessity of preferences for honesty

No efficient allocation is implementable with only material preferences. This section states this fact in a slightly informal manner (for a formal description, see the Appendix).

Suppose that all agents are standard. Any efficient allocation is $a_0(1) = 1$ by definition. Then, $a_1(1) = 0$ by Assumption 2. This makes early withdrawals of all agents constitute an ex-post equilibrium. To break this in-

[17] Ohashi (2015 [27]) uses such a separate-provision mechanism to achieve an efficient outcome under liquidation costs.

[18] Glazer and Rubinstein (1996 [17]) investigate the relation between the iteratively undominated outcomes of normal games and the backward induction outcomes of extensive games with perfect information.

efficient equilibrium, there must be a set of outcomes, Y', and a set of agents, $I' \subset I$, such that for each $i \in I'$, there exists $y_i \in Y'$ such that $v_i(y_i, \theta) > v_i((1,0), \theta)$. This y_i should be provided in t_0 because of Assumption 2. Hence, we can write $y_i = (y', 0)$ with $y' > 1$ without loss of generality. In any mechanism that breaks the inefficient equilibrium, there is a message, m_i', that realizes the outcome y_i. Clearly, this m_i' is different from a message, m_i^*, that provides $(1,0)$ to agent i. However, agent i always chooses m_i' whenever $\theta_i = 0$. If $\mu(I') = 0$, the outcome remains $(1,0)$, which is inefficient in any state $\theta \neq 0$. If $\mu(I') > 0$, a different allocation from the efficient one is achieved, because each $i \in I'$ is served y_i in any state $\theta \neq 0$.

If we abandon Assumption 2 and instead allow the mechanism to provide positive amount of assets to "zero-measured" agents in t_1 regardless of the provision of t_0, we can implement the efficient allocation. However, simultaneously, our model no longer describes bankruptcy. It is easy to see this. Suppose that the principal is ready to provide R units of the asset up to the countable number of agents in t_1 if and only if she has no asset in t_0. Then, any patient agent unilaterally wants to postpone withdrawals until t_1, and in the end, the principal successfully keeps some assets in hand in t_0, which implies no bankruptcy.

5.2 On the preference for honesty

The preference for honesty of an agent emerges if *pairwise* outcomes are indifferent for him regarding his material payoff. "Pairwise" means that for each m_{-i}, m_i, and m_i', if $m_i \neq m_i'$ and outcomes $g(m_i, m_{-i})$ and $g(m_i', m_{-i})$ are "materially indifferent," agent i strictly prefers the message between m_i and m_i' that makes him be a "later" dishonest agent under the profile of m_{-i}. On the other hand, Kartik et al. (2014 [20]; hereafter KTH) assume that a preference for honesty of an agent emerges if *all* outcomes are materially indifferent for him. That is, if $g(m_i, m_{-i})$ and $g(m_i', m_{-i})$ are materially indifferent *for all* m_i, m_i', *and* m_{-i}, agent i strictly prefers to send an "honest" message among his messages. Hence, the preference for honesty of my definition may emerge more often than in that of KTH, but my definition accepts more messages as "honest" compared to that of KTH. However, the implementation process is similar. (i) The preference for honesty plays a role of gathering the information on the realized state. (ii) After the true state is revealed, the mechanism has to incentivize standard agents to behave honestly. Although KTH assumes an environment where *separable punishment* is available to ensure the incentive compatibility for standard agents, my canonical environment of deposit contracts does not require this environment because the efficient allocation itself ensures incentive compatibility.

5.3 On sequential services

Wallace (1988 [31]) proposes a demand deposit model with finite agents to analyze a *sequential service* constraint. More recently, Green and Lin (2003 [16]), Peck and Shell (2003 [29]), Andolfatto et al. (2007 [6]), Andolfatto and Nosal (2008 [5]), and Ennis and Keister (2009a [13]) investigate a finite-agent model under the following constraints: (i) there is *aggregate uncertainty* on states and (ii) the principal and agents can communicate with each other *only once*. Hereafter, I refer to the second constraint as "One-Period-One-Communication" (OPOC).

Sequential service requires only that an outcome be allocated to agents "as a function of the history of transactions up until that point" (Peck and Shell (2003 [29]), p107). According to the definition, my mechanism satisfies the sequential service constraint. A phase-k provision to an agent j is determined by the history of transactions and messages up until the provision of j on Phase k.

Aggregate uncertainty implies that "the fraction of people who will turn out to be impatient is not known" before t_0 (Wallace (1990 [32]), p15). My mechanism is applicable to the environment with aggregate uncertainty without modifications.

Many previous studies, like those shown here, implicitly assume the OPOC constraint on sequential service. However, DD and my study investigate a continuum-agent model with aggregate uncertainty and sequential service *without* OPOC. It is true that the former models create an interesting problem of asset allocation, but we should distinguish their models from ours because the efficient allocations are different. In the finite-agent models, impatient agents obtain returns that are different from each other in equilibrium. However, under my model, the returns are the same.

6 Concluding remarks

This paper introduced agents' preferences for honesty into a deposit contract model, à la Diamond and Dybvig (1983 [11]), in an environment with aggregate uncertainty on states and a sequential service constraint. The main result is that a fully efficient outcome is achievable while preventing self-fulfilling bank runs. The contribution to the bank-run problem is that an efficient allocation is implementable with honest agents and with a simple separate-provision and detail-free mechanism. It is also notable that the result is obtained without the need for public third-party organizations such as deposit insurance or a central bank.

A On the feasible allocations

This section formally defines the set of feasible allocations. Let $\chi_k : I \to \mathbf{R}_+$ denote a provision to agents in t_k. The total provision to agents in t_k is defined as $\int_{i\in I} \chi_k di \equiv \int_I \chi_k d\mu$.[19]

I describe the set of feasible allocations in t_0 as

$$Y_0 = \left\{ \chi_0 \;\middle|\; 0 \leqq \int_{i\in I} \chi_0 di \leqq 1 \right\}.$$

The set of feasible allocations in t_1 depends on the amount of withdrawn assets in t_0, that is, χ_0. Let $z : Y_0 \to [0, 1]$ denote a functional such that $z(\chi_0) = \int_{i\in I} \chi_0 di$. The principal can provide $R(1 - z(\chi_0))$ in total in t_1;

[19] See, for example, Rudin (1987 [30], p19).

hence, the set of feasible allocations in t_1 is described as

$$Y_1(\chi_0) = \left\{ \chi_1 \;\middle|\; 0 \leqq \int_{i \in I} \chi_1 di \leqq R(1 - z(\chi_0)) \right\}.$$

Let $Y_1 = \bigcup_{\chi_0 \in Y_0} Y_1(\chi_0)$. The set of all feasible allocations, Y, is defined as

$$Y = \left\{ (\chi_0, \chi_1) \in Y_0 \times Y_1 \;\middle|\; \chi_1 \in Y_1(\chi_0) \right\}.$$

The determination of $y \in Y$ is equivalent to the determination of (χ_0, χ_1). I write $v_i(y, \theta)$ instead of $u(\chi_0(i) + \theta_i \chi_1(i))$ if there is no confusion.

In the main body of this paper, I state as Assumption 2 that the principal can provide nothing in t_1 if she has liquidated all the investments in t_0, that is, $a_1(1) = 0$. This assumption is described as follows.

Assumption 3 *For any $\chi_0 \in Y_0$, if $z(\chi_0) = 1$,*

$$Y_1(\chi_0) = \{\chi_1 \mid \forall i \in I, \chi_1(i) = 0\}.$$

I impose this assumption on Y. I refer to the "material" environment as *environment $\mathcal{E}$*, where the interest of agents is only their own material payoffs.

The efficient allocation cannot be implementable in ex-post equilibrium under the environment $\mathcal{E}$ with Assumption 3. To confirm this, I introduce a celebrated monotonicity condition.

Definition 2 *An allocation $\boldsymbol{a}$ satisfies* ex-post monotonicity*, if for any type of reporting profile θ', if $\boldsymbol{a}(\theta) \neq \boldsymbol{a}(\theta')$, there exist $i \in I$ and $y \in Y$, such that*

$$v_i(y, \theta) > v_i(\boldsymbol{a}(\theta'), \theta), \tag{10}$$

while for every $\theta'_i \in \{0, 1\}$, if $\theta' = (\theta'_i, \theta'_{-i})$ is the true state,

$$v_i(y, \theta') \leqq v_i(\boldsymbol{a}(\theta'), \theta'). \tag{11}$$

Bergemann and Morris (2008, [7]) show that ex-post monotonicity is a necessary condition for the unique implementation of a social choice rule in ex-post equilibrium. It is easy to see that Equations (10) and (11) cannot be held simultaneously for the case of $\theta' = 1$. Because of Assumption 3, $\theta' = 1$ implies that $v_i(\boldsymbol{a}(\theta'), \theta) = u(1)$ regardless of θ_i. By the same reason, $v_i(y, \theta) = u(\chi_0(i))$. Hence, any mechanism has to provide $\chi_0(i) > 1$ for some agent i if he wishes. However, if $\theta'_i = 0$ and the true state is $\theta' = 1$, agent i prefers y to $\boldsymbol{a}(1)$, which contradicts Equation (11).

Assumption 3 is necessary for the environment $\mathcal{E}$ to model bankruptcy. Indeed, setting aside Assumption 3, the efficient allocation is implementable in ex-post equilibrium without preferences for honesty.

Proposition 1 *Under the environment $\mathcal{E}$ without Assumption 3, the efficient allocation $(a_0(\theta), a_1(\theta))$ is uniquely implementable in ex-post equilibrium.*

Proof. Suppose that all agents report $m_i = 0$ when the true state is $\theta < 1$. Then, all agents are paid $a_0(1) = 1$ and χ_0 satisfies $z(\chi_0) = 1$. Consider a mechanism that allocates $\chi_1(j) = a_1(1) > 1$ for each $j \in A \subset I \setminus \emptyset$ with $\mu(A) = 0$ if $z(\chi_0) = 1$ and $m_j = 1$. Because A is arbitrary, each patient agent wants to change his message unilaterally from $m_i = 0$ to $m_i = 1$ under this mechanism. ■

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