ON THE SOCIAL VALUE OF ACCOUNTING OBJECTIVITY IN BANK STABILITY*

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Abstract

In this paper, we analyze the social value of accounting objectivity in maintaining bank stability. Building on an early, influential accounting work by Ijiri and Jaedicke (1966), we operationalize two informational properties, objectivity and accuracy, in a correlated information structure and embedded them into a model of bank runs. We show that, when compared with the accuracy property, the objectivity property exhibits a comparative advantage in mitigating inefficient panic-based bank runs. In fact, it is possible that improving objectivity discourages while improving accuracy encourages such runs. Our model also sheds light on the design of optimal accounting rules to enhance objectivity. We find that, in order to generate a more objective accounting report, the accounting rule should be made less admissible to evidence that is subject to managerial intervention.

Keywords: bank stability, accounting objectivity, higher-order beliefs, differential interpretation, correlated signals

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1 Introduction

The recent turmoil in financial markets has renewed some interests in studying bank runs and coordination problems in general (Gorton and Metrick, 2012). An ongoing debate is on whether improving bank transparency stabilizes runs (Bushman, 2015). Some argue that better information about banks improves market discipline and monitoring by regulators, hence enhancing bank stability (Morgan, 2002; Acharya and Ryan, 2015). Others argue that opacity is central to money creation by banks and thus banking institutions are optimally opaque (Dang et al, 2014). Viewing bank runs as a coordination failure, the higher-order beliefs literature argues that whether better information improves coordination depends on the public/private nature of the information (Morris and Shin, 2001). A key insight from this literature is that in settings where the socially optimal level of coordination is higher than the equilibrium level of coordination, more precise public information is more socially beneficial than more precise private information (Angeletos and Pavan, 2007). This insight in turn implies that more precise public information is desirable in bank runs where coordination is socially more valuable.

In our paper, we show that the structure of the underlying information environment plays a critical role in determining how information affects panic-based bank runs and bank stability. Building on an accounting measurement framework by Ijiri and Jaedicke (1966), we develop a correlated information structure in which each agent’s signal contains a public noise and a private noise, distinct from the standard information structure consisting of pure-public signals (whose noises are common among individuals) and pure-private signals (whose noises are idiosyncratic among individuals). Our information structure, in a parsimonious manner, models the degree of disagreement among individual decision makers, captured by the precision of the private noise, independently from the collective knowledge in the economy, captured by the precision of the public noise. We show that while reducing disagreements always discourages panic-based bank runs, increasing collective knowledge may actually disrupt coordination, thus encouraging runs. This stands in contrast to standard results that improving the precision of the public noise facilitates coordination and mitigates runs as obtained under the standard information structure.

In addition, our model sheds light on the optimal design of accounting system in order to mitigate panic runs because our informational structure is readily micro-founded and interpreted...
in the Ijiri-Jaedicke accounting measurement framework. Following Ijiri and Jaedicke (1966), we show that collective knowledge and disagreement can be separately connected to the accuracy and objectivity, respectively, of an accounting measurement system. Our analysis shows in weighting the tradeoff between accuracy and objectivity, the optimal accounting system should be designed to tolerate noises associated with random errors in the system but to minimize noises stemming from intentional managerial intervention.

Specifically, we modify the standard information environment by considering correlated private signals. While signals differ from each other by an idiosyncratic/private noise, they also correlate with each other, because these signals are subject to a common/public noise. With this structure, the precision of the public noise captures the collective knowledge about the fundamentals while, separately, the precision of the private noise captures the disagreement within the economy. We embed the correlated private information structure into a simple bank-run model in the spirit of Morris and Shin (2001). Each depositor makes the withdraw decision (or run the bank) based on a signal it receives. Critically, each depositor rationally uses the signal to infer both (1) the underlying fundamental health of the bank (the fundamental value of information) and (2) the likely signal other depositors have received in order to gauge the likelihood they would run the bank (the strategic value of information). The key message from the analysis is that, although improvements in both the precision of the private and the public noises increase the fundamental value of the depositors’ signals, improving the precision of the private noise enhances while improving the precision of the public noise impairs the strategic value of the signals. Furthermore, due to their different roles on the strategic value of information, improving the precision of the private noise exhibits a comparative advantage in mitigating panic-based bank runs relative to improving the precision of the public noise. In fact, we find that, increasing the precision of the private noise always discourages panic-based runs while increasing the precision of the public noise can actually encourage panic-based runs, when the prior information about the bank-asset fundamentals is sufficiently precise.

Our result is distinct from the standard insights in the previous literature that increasing the public signal precision makes depositors more homogenous, thus improving the strategic value of information and facilitating coordination, while increasing the private signal precision makes depositors more heterogeneous, hence reducing the strategic value of information and disrupting coordination (Angeletos and Pavan, 2007). The distinction between our model and the standard
model is due to the different mechanisms through which informational properties influence posterior beliefs. Under the standard information structure, the information properties affect the posterior through changing the Bayesian weights each individual allocates to public and private signals. When the public signal becomes more precise, each individual places relatively more weight on the public signal and less weight on the private signal, which makes the individual beliefs more homogenous. As a result, it becomes easier to forecast others' beliefs and the strategic value of information increases. In our information structure, the key economic force there is that changing the precision of the common and idiosyncratic noises alters the correlation between different depositors' signals. Specifically, from an individual depositor's perspective, she knows that her signal is driven by three components, the fundamentals, a common noise and an idiosyncratic noise. When the precision of the common noise increases, the common variation in the signal decreases and thus the signal is driven more by the idiosyncratic variation. As a result, the signal becomes less correlated with others' signals and has a lower strategic value in forecasting others' beliefs. Differently, when the precision of the idiosyncratic noise increases, the idiosyncratic variation of the signal gets smaller and thus the signal is driven more by the common variation. As a result, the signal becomes more correlated with others' signals and has a higher strategic value in forecasting others' beliefs.

To shed light on the types of information environment suitably captured by our information structure, we build a micro-model of the accounting measurement process, which connects collective knowledge and disagreement to the accuracy and objectivity, respectively, of an accounting measurement system. A key insight from Ijiri and Jaedicke (1966) is that objectivity can be operationally defined as interpersonal consensus/agreement. That is, a more objective information source invites less subjective interpretations among the same group of decision makers, thus causing fewer disagreements and a higher consensus. Building on this insight, we introduce an accounting measurement model in which an accounting system generates multiple pieces of evidence about the fundamentals, with each evidence subject to a noise associated with errors in the accounting system as well as intervention by a manager. The set of evidence is thereafter aggregated to form an accounting report in accordance with some accounting rules. Errors in the accounting system naturally introduce a common noise in the report and we term the precision of the common noise accuracy. In addition, an important assumption we make is that different outsiders hold different beliefs about the manager's intervention incentive. As a result, outsiders disagree on interpreting
the same accounting report since they disagree on how much the manager may have intervened. Such disagreement in turn leads to an idiosyncratic noise in each outsider’s interpretation of the report. Following Ijiri and Jaedicke (1966), we termed the agreement (the precision of the idiosyncratic noise) objectivity. Our analysis shows that the objectivity and the accuracy property can be derived endogenously as functions of the measurement rules, the properties of the measurement system, and the heterogeneity among the outsiders. In particular, we find that in order to generate an objective report that helps to stabilize runs, the accounting rule should be made less admissible to evidence that is subject to managerial intervention.

Our paper contributes to the literature on role of information in a decentralized economy in which each individual is strategically interdependent (see Angeletos and Pavan, 2007; Chen, Huang and Zhang, 2014; Arya and Mittendorf, 2014). A majority of the previous literature adopts the standard information structure with a purely-public and a purely-private signals. In practice, however, a pervasive feature of public information is that receivers of a public disclosure (such as earnings announcements or Federal reserve policy announcements) interpret what the announcement means differently by an agent-specific noise term while the announcement itself is affected by a common noise-source. What the agent receives is her own interpretation of the announcement which is affected by both noises, rather than the announcement per se (see e.g., Varian, 1989 and Myatt and Wallace, 2012). In this light, our correlated information structure captures the differential interpretations among individuals. In addition, from a modelling perspective, two sufficient statistics describing an information environment are collective knowledge of all individuals and the disagreement among the individuals. Under the standard information structure, collective knowledge is perfect through aggregating pure private signals and the precision of private and public signals only contribute to the disagreement, making a decomposition of collective knowledge and disagreement infeasible. Our model, by contrast, provides a parsimonious structure to model them separately.

Aside from the benefits of being more descriptive and offering additional modelling flexibility, this departure from the standard structure also enjoys the benefit of better explaining some empirical observations. In fact, previous research deploys similar information structure to explain risk-sharing-motivated firm disclosure decision (Indjejikian, 1991) and why trading volume increases with disclosure, as in Kim and Verrecchia (1997) and Kondor (2012). In our paper, the predictions
can potentially shed light on the increasing popularity of Tangible Common Equity (TCE) during the recent financial crisis in which financial institutions faced severe runs by investors (Gorton, 2008). Two alternative disclosure practices of banks’ well-being came to the limelight: Tier-I capital and TCE. Arguably, Tier-I capital may be more accurate measure of bank equity than TCE. But TCE is more likely to induce less “disagreements” among investors given its simplicity (i.e., more objective in Ijiri-Jaedicke sense) while Tier-I capital may be subject to many interpretations given its many-layered construction. In the comparison between the Tier-I capital and TCE, our model will predict that the more objective, albeit less accurate, disclosure of TCE can help to stabilize runs. One phenomenon, which then could be consistent with the spirit of our findings, was that financial institutions began voluntarily emphasizing TCE measures toward their shareholders. For example, Citigroup began formally disclosing and commenting its TCE measures in their 10K reports for fiscal year 2008.

The rest of paper is organized as follows. Section 2 provides a model of the information environment. Section 3 presents the analytic results of the paper in a bank run model. Section 4 provides a micro-foundation of objectivity property based on the accounting measurement process. Section 5 analyzes the roles of objectivity and accuracy in other strategic settings. Section 6 reviews related accounting and economics literature. Section 7 concludes.

2 A Model of Information Environment

In this section, we describe in detail the information environment in which each decision maker operates. We focus on two distinct properties of the environment, accuracy and objectivity and give an explicit account on how our information model differs from the standard information structure.

2.1 Accuracy and Objectivity of Accounting Measures

Consider a continuum of decision makers, indexed by $i \in [0, 1]$, facing decision under uncertainty. Suppose the payoff-relevant state-of-nature (or fundamentals) is denoted $\tilde{r} \sim N(\bar{r}, \frac{1}{\alpha})$. Each decision maker receives a private signal, denoted $\tilde{x}_i$, with the following information property:

$$\tilde{x}_i = \tilde{r} + \tilde{\eta} + \tilde{\varepsilon}_i,$$  \hspace{1cm} (1)
where $\tilde{\eta} \sim N(0, \frac{1}{\gamma})$ and $\tilde{\varepsilon}_i \sim N(0, \frac{1}{\beta})$ for all $i$. In the section 4, we show that this information structure can arise endogenously from a two-step representation of the accounting measurement process which derives such signal $\tilde{x}_i$ as a result of each decision maker optimally combining a public announcement (common to all decision makers) and his own private knowledge (heterogeneous among decision makers). Accordingly, precision parameters $\gamma$ and $\beta$ are endogenously derived as functions of the measurement rules, the properties of the measurement system and the heterogeneity among the decision makers.\footnote{\textsuperscript{1}}

The information environment of the economy is described completely by $X$, where

$$X = \{\tilde{x}_i = \tilde{r} + \tilde{\eta} + \tilde{\varepsilon}_i | i \in [0, 1]\}. \tag{2}$$

The informational properties of environment-$X$ is completely described by the parameter set $\{\tilde{r}, \alpha, \gamma, \beta\}$. Notice that at the economy level, the collective knowledge about the underlying state $\tilde{r}$ is equivalent to an aggregate signal $\tilde{x}_p \equiv \tilde{r} + \tilde{\eta}$ as all idiosyncratic noises sum to zero at the limit. Denote the information set for each individual as $I_i$ and thus $I_i = \{\tilde{x}_i\}$.

Our information structure is related to the standard information structure in two aspects. First, at the individual signal level, this information structure incorporates the standard information structure as a special case. To see this, consider the standard structure (Morris and Shin, 2002; Angeletos and Pavan, 2004) where each agent receives a public signal $\tilde{z} = \tilde{r} + \tilde{\eta}'$, where $\tilde{\eta}' \sim N\left(0, \frac{1}{\gamma}\right)$ and a private signal $\tilde{x}'_i = \tilde{r} + \tilde{\varepsilon}'_i$, where $\tilde{\varepsilon}'_i \sim N\left(0, \frac{1}{\beta}\right)$. Notice that, in our information structure, when $\beta = +\infty$, the signal becomes $\tilde{z}$ and purely public while when $\gamma = +\infty$, the signal becomes $\tilde{x}'_i$ and is purely private. Second, at the aggregate information level, our information structure departs from standard structure in a substantive manner. Consider two features of the aggregate information environment: (1) how much do the agents in the economy collectively know about the fundamental, i.e., $E[\tilde{r}|X]$? (2) how much do their private posterior beliefs, i.e., $E[\tilde{r}|I_i]$, disagree among themselves? The following table summarizes the collective knowledge and disagreements within the standard information structure and our structure, respectively.
<table>
<thead>
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<th>Collective knowledge</th>
<th>Disagreement of posteriors</th>
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<td>Standard structure</td>
<td>infinitely precise</td>
<td>indexed by $\beta'$ and $\gamma'$</td>
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<tr>
<td>Our structure</td>
<td>indexed by $\gamma$ only</td>
<td>indexed by $\beta$ only</td>
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The table shows that our formulation enjoys an advantage of modelling the economy’s collective knowledge, captured by the common noise precision $\gamma$, independently from the degree of disagreement among individual decision makers in the economy, captured by the idiosyncratic noise precision $\beta$. Conversely, in the standard information structure, collective knowledge is perfect through aggregating all the private signals and the disagreement is jointly determined by the public and the private precision.

More specifically, on one hand, a higher $\gamma$ places the beliefs of all decision makers closer to the payoff-relevant state-variable ($\tilde{r}$). When $\gamma$ approaches positive infinity ($\gamma = +\infty$), the consensus of all decision makers’ beliefs would perfectly reveal $\tilde{r}$ but each decision maker remains unsure about the beliefs of the others. That is, $\gamma$ independently describes the collective knowledge of the economy. On the other hand, a higher $\beta$ places the beliefs of different decision makers closer to one another. When $\beta$ approaches positive infinity ($\beta = +\infty$), all decision makers agree on their private posterior beliefs about the fundamentals $\tilde{r}$ and each decision maker is able to forecast perfectly the beliefs of every other decision maker. That is, $\beta$ independently measures the degree of disagreement among the individual. Notice that even at $\beta = +\infty$, aggregating all the signals does not necessarily reveal $\tilde{r}$ perfectly.

We use the term objectivity to label $\beta$, the precision of idiosyncratic noise and the term accuracy to label $\gamma$, the precision of the common noise. The terminology we adopt follows both classic accounting and recent information-economics work. The objectivity term originates from Ijiri and Jaedicke (1966) and accuracy term originates from Myatt and Wallace (2012). Specifically, as discussed in the introduction, Ijiri and Jaedicke (1966) define “objectivity” as interpersonal agreement (as opposed to agreement with the “true” state), a position with earlier origins in psychology. Myatt and Wallace (2012) define accuracy of an information source as “how precisely it identifies the state.” (page 340). For the rest of the paper, we stipulate these usage of the terms objectivity and accuracy.
2.2 The Statistical Distinction between Accuracy and Objectivity

Before moving to our exact economic model, it is instructive to explore the statistical distinction between objectivity and accuracy and its implication in decision-making generally. We describe how accuracy and objectivity assist decision maker \( i \) in making inference about the fundamentals \( \bar{r} \) and about the beliefs of other decision makers \( E[\bar{r}|\bar{x}_j] \). Statistically, how well signal \( \bar{x}_i \) informs about \( \bar{r} \), is measured by conditional precision of \( \bar{r} \) given \( \bar{x}_i \), which is given by

\[
\frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} = \alpha + \frac{\beta \gamma}{\beta + \gamma}.
\]

(3)

Intuitively, objectivity and accuracy affect the fundamental value of the signal \( \frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} \) in a symmetric manner. At an extreme, when \( \beta = \gamma \equiv c \), a marginal improvement in accuracy (higher \( \gamma \)) increases \( \frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} \) exactly the same as a marginal improvement in objectivity (\( \beta \)):

\[
\frac{\partial}{\partial \gamma} \left( \frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} \right) = \frac{\partial}{\partial \beta} \left( \frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} \right) = \frac{1}{4}.
\]

(4)

Alternatively, we can appreciate mootness of objectivity as the fact that the conditional precision is unchanged between measurement system with \( \langle \beta = c_1, \gamma = c_2 \rangle \) and another measurement system \( \langle \beta = c_2, \gamma = c_1 \rangle \) for \( c_1 \neq c_2 \). The symmetry implies that objectivity plays no distinct and separate role from accuracy in a single-person decision setting where each decision-maker makes a decision only based on their own belief about the fundamentals \( \bar{r} \), not on others’ belief about \( \bar{r} \).

Now consider how well signal \( \bar{x}_i \) informs about others’ beliefs about the fundamentals \( E[\bar{r}|\bar{x}_j] \).

The relevant measure here is the conditional precision of estimating \( E[\bar{r}|\bar{x}_j] \) given \( \bar{x}_i \), which is given by

\[
\frac{1}{\text{Var}[E[\bar{r}|\bar{x}_j]|\bar{x}_i]} = \frac{1}{\left( \frac{1}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} \right)^2 (1 - \rho^2) \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right)},
\]

(5)

where \( \rho = \frac{1}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} \) denotes the correlation between different agents’ signals. Notice objectivity and accuracy affect the strategic value of the signal \( \frac{1}{\text{Var}[E[\bar{r}|\bar{x}_j]|\bar{x}_i]} \) in an asymmetric manner through \( \rho \): \( \beta \) increases \( \rho \) while \( \gamma \) decreases \( \rho \). As a result, holding the total informativeness of \( x_i \), \( \frac{1}{\text{Var}[\bar{r} | \bar{x}_i]} \), constant, increasing \( \beta \) increases \( \rho \) and decreases \( \text{Var}[E[\bar{r}|\bar{x}_j]|\bar{x}_i] \) while increasing \( \gamma \) decreases \( \rho \) and increases \( \text{Var}[E[\bar{r}|\bar{x}_j]|\bar{x}_i] \). That is, improving objectivity \( \beta \) increases while improving accuracy \( \gamma \).
decreases the strategic value of information. This asymmetry implies that objectivity can play a divergent role from accuracy in settings with strategic interactions where each decision-maker makes a decision not only based on their own belief about the fundamentals \( \bar{r} \), but also on others’ belief about \( \bar{r} \).

### 2.3 Difference from the Standard Information Structure

To see precisely the difference between our information structure and the standard structure, notice that in the standard information model, the fundamental value of the information \( \{ \bar{x}_i', \bar{z} \} \) is measured by the conditional precision of \( \bar{r} \) given the signals, which is given by

\[
\frac{1}{\text{Var}[\bar{r}|\bar{x}_i', \bar{z}]} = \alpha + \beta' + \gamma',
\]

that is, both \( \beta' \) and \( \gamma' \) play symmetric roles in improving the fundamental value of information, similar to the implications in our information model. However, the implications from the standard model and our model differ once we analyze of the strategic value of information. In the standard model, the strategic value of information is measured by the conditional precision of estimating others’ beliefs \( E[\bar{r}|\bar{x}_j', \bar{z}|\bar{x}_i', \bar{z}] \) given one’s own signals \( \{ \bar{x}_i', \bar{z} \} \), which is given by

\[
\frac{1}{\text{Var}[E[\bar{r}|\bar{x}_j', \bar{z}|\bar{x}_i', \bar{z}]]} = \frac{1}{\frac{\beta'^2}{(\alpha + \beta' + \gamma')^2} \left( \frac{1}{\beta'} + \frac{1}{\alpha + \beta' + \gamma'} \right)},
\]

thus holding the fundamental value of information \( \text{Var}[\bar{r}|\bar{x}_i', \bar{z}] = \frac{1}{\alpha + \beta' + \gamma'} \) fixed, increasing \( \beta' \) increases \( \text{Var}[E[\bar{r}|\bar{x}_j', \bar{z}|\bar{x}_i', \bar{z}] \) while increasing \( \gamma' \) decreases \( \text{Var}[E[\bar{r}|\bar{x}_j', \bar{z}|\bar{x}_i', \bar{z}] \). That is, increasing the public signal precision increases the homogeneity among decision makers, which improves the strategic value of information, while increasing the private signal precision increases the heterogeneity among decision makers, which decreases the strategic value of information, an insight often discussed in the literature (e.g., Angeletos and Pavan, 2004). Notice that, however, this insight is opposite to the roles played by \( \beta \) and \( \gamma \) in our model. For future references, we summarize the difference between the role of information in our model and that in the standard model in the proposition below.

**Proposition 1** *Holding the total informativeness constant (\( \frac{\beta \gamma}{\beta + \gamma} \) and \( \frac{1}{\alpha + \beta + \gamma} \) fixed), in the standard*
information model with a public and a private signals, increasing the public signal precision increases
while increasing the private signal precision decreases the strategic value of information:

\[
\frac{d\text{Var}\left[E[\bar{r}|\bar{x}_j, \bar{z}]|\bar{x}_i, \bar{z}\right]}{d\beta'} > 0 \quad \frac{d\text{Var}\left[E[\bar{r}|\bar{x}_j, \bar{z}]|\bar{x}_i, \bar{z}\right]}{d\gamma'}.
\] (8)

In the model with correlated signals, \(\bar{x}_i = \bar{r} + \bar{\eta} + \bar{\zeta}_i\), improving objectivity (the precision of the idiosyncratic noise) increases while improving accuracy (the precision of the common noise) decreases the strategic value of information:

\[
\frac{d\text{Var}\left[E[\bar{r}|\bar{x}_j]|\bar{x}_i\right]}{d\beta} < 0 \quad \frac{d\text{Var}\left[E[\bar{r}|\bar{x}_j]|\bar{x}_i\right]}{d\gamma}.
\] (9)

The distinction between the standard model and our model is due to the different mechanisms through which the informational properties influence posterior beliefs. In the standard information model, the information properties \(\beta'\) and \(\gamma'\) affect the posterior through changing the Bayesian weights each individual allocates to the two signals. When the private information precision \(\beta'\) increases, each individual places relatively more weight on the private signal and less weight on the public signal, which makes the individual beliefs more heterogeneous. As a result, it becomes more difficult to forecast others’ beliefs and the strategic value of information decreases. The positive role of the public information precision \(\gamma'\) on the strategic value can be understood similarly.

In our model, the key economic force there is that changing the information properties, \(\beta\) and \(\gamma\), alters the sizes of the common and idiosyncratic noises, which affects the correlation between different decision makers’ signals. Specifically, from an individual decision maker’s perspective, she knows that her signal is driven by three components, the fundamentals, a common noise and an idiosyncratic noise. When the accuracy of the signal \(\gamma\) increases, the variation of the common noise decreases and thus the signal is driven more by the variation of the idiosyncratic noise. As a result, the signal becomes less correlated with others’ signals and has a lower strategic value in forecasting others’ beliefs. Differently, when the objectivity of the signal \(\beta\) increases, the variation of the idiosyncratic noise decreases and thus the signal is driven more by the variation of the common noise. As a result, the signal becomes more correlated with others’ signals and has a higher strategic value in forecasting others’ beliefs.
3 An Economic Model of Bank Runs

In this section, we analyze the role of objectivity and accuracy in a model of bank runs in which multiple depositors need to coordinate with each other. We will show that with the strategic interaction among the depositors, the distinction between objectivity and accuracy becomes critical because of their different effects on the strategic value of information. The model has four dates, a continuum of depositors, and a bank endowed with an investment project (an illiquid loan). At date 0, the bank finances the project by issuing deposits to the depositors. At date 1, depositors learn an intermediate signal $\tilde{x}_i$. At date 2, depositors decide whether to withdraw their deposits from the bank. At date 3, the project yields a stochastic payoff that depends on both the fundamentals of the project and the amount of deposits withdrawn. The time line of the model is shown below.

\begin{figure}[h]
\centering
\begin{tabular}{c c c c}
\hline
$t=0$ & $t=1$ & $t=2$ & $t=3$
\hline
The bank raises deposits from depositors and invests. & Depositors learn a signal $\tilde{x}_i$. & Depositors decide whether to withdraw their deposits. & The investment outcome $\tilde{P}$ is realized.
\hline
\end{tabular}
\caption{Time line.}
\end{figure}

We now describe and explain the decisions and events at each date in more detail.

**Date 0**

At date 0, the bank is endowed with an investment project that yields a stochastic gross rate of return, $\tilde{R} = e^{\tilde{r}}$ realized on date-3 where $\tilde{r}$ is normally distributed with a mean $\bar{r}$ and a variance $\frac{1}{\sigma}$. $\alpha$ measures the precision of depositors’ common prior about $\bar{r}$. We assume that $0 < \bar{r} \leq \frac{1}{2}$.\footnote{As we will show later, assuming $\bar{r} \leq \frac{1}{2}$, the bank’s disclosure of information helps to reduce the risk of bank runs. However, when the common prior about the bank’s project is sufficiently good (i.e., $\bar{r} > \frac{1}{2}$), the release of information actually exacerbates the risk of runs, which prevents the bank from disclosing in the first place. This is because, in such cases, the bank prefers the depositors to rely more on the favorable prior rather than to respond to new information, which is likely to be worse than the prior.}

The bank finances the project by attracting deposits from a group of depositors, with unit mass and indexed by the unit interval $[0, 1]$, each of whom contributes 1 unit of the consumption good.
All depositors have the log utility function such as:

$$u_i = \log(c_{i2} + c_{i3}),$$  \hspace{1cm} (10)

where $c_{i2}$ and $c_{i3}$ denote depositor $i$’s consumption at date 2 and at date 3 respectively. The bank invests all the deposits in its project.

**Date 1**

At date 1, each depositor $i$ base the withdraw decision on an individual signal $\tilde{x}_i$ with the following informational properties:

$$\tilde{x}_i = \tilde{r} + \tilde{\eta} + \tilde{\varepsilon}_i,$$

where the various noise terms are all independently distributed with $\tilde{\eta} \sim N(0, \frac{1}{\gamma})$ and $\tilde{\varepsilon}_i \sim N(0, \frac{1}{\beta})$. As previously described, we use the term objectivity to label $\beta$, and the term accuracy to label $\gamma$.

**Date 2**

Based on the information $\tilde{x}_i$, depositor $i$ updates her beliefs about the project’s fundamentals and other depositors’ beliefs and decides whether to withdraw her deposit or not. Following Morris and Shin (2001), we assume that if depositor $i$ withdraws, she is repaid at the face value, 1 unit of the consumption good. Further, the bank’s project is illiquid and the net rate of return obtainable at date 3 is decreasing in the proportion of the deposit withdrawn at date 2, as denoted by $l \in [0, 1]$. Specifically, we assume that at date 3, the net rate of return is:

$$\tilde{P} = \tilde{R} e^{-l} = e^{\tilde{r} - l},$$

where the term $e^{-l} < 1$ captures the cost of liquidating the illiquid project to meet the depositors’ withdrawals.

**Date 3**

The net rate of return $\tilde{P}$ is realized and the proceeds from the project is distributed to the depositors.
3.1 The First-Best Benchmark

We first solve for the first-best in our model as a benchmark. Consider a situation in which the bank’s project is financed by only one depositor whose information set contains all the private signals, \( \tilde{x}_i \). Aggregating all the private signals removes all idiosyncratic notice and perfectly reveals the common underlying signal \( \tilde{x}_p = \tilde{r} + \tilde{\eta} \), since

\[
\int_0^1 \tilde{x}_i \, di = \tilde{r} + \tilde{\eta} + \int_0^1 \tilde{z}_i \, di = \tilde{x}_p.
\]

\( \tilde{x}_p \) is also a sufficient statistic to the depositor’s liquidating decision. For expositional purpose, denote the “demeaned” value of the signal \( \tilde{x}_p \) as \( \bar{y}_p = \tilde{x}_p - \tilde{r} \). It is straightforward to verify that, without loss of generality, only one kind of strategy, a switching strategy, needs to be considered, where the depositor chooses to withdraw if and only if she observes a \( \bar{y}_p \) below some threshold \( y^{FB} \):

\[
s(\bar{y}_p) = \begin{cases} 
\text{Withdraw} & \text{if } \bar{y}_p \leq y^{FB}, \\
\text{Not to Withdraw} & \text{if } \bar{y}_p > y^{FB}.
\end{cases}
\] (13)

Consider a marginal depositor whose signal \( \bar{y}_p \) is exactly equal to \( y^{FB} \). If the depositor withdraws, her expected utility is \( \log(1) = 0 \). If she chooses not to withdraw, she earns the rate of return, \( \tilde{R} \), and her expected utility conditional upon the signal \( \bar{y}_p = y^{FB} \) is:

\[
E[\log(\tilde{R})|\bar{y}_p = y^{FB}] = E[\tilde{r}|\bar{y}_p = y^{FB}] = \tilde{r} + \frac{1}{\frac{\alpha}{\gamma} + \frac{1}{\delta}} y^{FB}.
\] (14)

In equilibrium, the marginal depositor is indifferent between staying and withdrawing:

\[
\tilde{r} + \frac{1}{\frac{\alpha}{\gamma} + \frac{1}{\delta}} y^{FB} = 0,
\] (15)

which gives,

\[
y^{FB} = -\frac{(\frac{1}{\alpha} + \frac{1}{\gamma}) \tilde{r}}{\frac{1}{\alpha} + \frac{1}{\gamma}} = -\left(1 + \frac{\alpha}{\gamma}\right) \tilde{r}.
\] (16)

\(^3\)We can also interpret this benchmark as a situation in which a bank regulator acquires all the information from the depositors and provides them with full deposit insurance. Upon receiving the information, the regulator decides whether to liquidate the bank.
We summarize the equilibrium in the first-best benchmark in the lemma below.

**Lemma 1** In the first-best benchmark, the depositor withdraws if and only if \( \bar{y}_p \leq y^{FB} = -\frac{(\frac{1}{\alpha} + \frac{1}{\beta}) \phi}{\phi} \).

### 3.2 The Equilibrium

We now solve for the equilibrium in our model. As shown in Morris and Shin (2001), it suffices to consider only the switching strategy where the depositor chooses to withdraw if and only if she observes a \( \bar{y}_i \) below some threshold \( y^* \):

\[
s(\bar{y}_i) = \begin{cases} 
\text{Withdraw} & \text{if } \bar{y}_i \leq y^*, \\
\text{Not to Withdraw} & \text{if } \bar{y}_i > y^*. 
\end{cases}
\]  
(17)

Consider a marginal depositor whose signal \( \bar{y}_i \) is exactly equal to \( y^* \). If she withdraws, her expected utility is 0. If she chooses not to withdraw, her expected utility is equal to:

\[
E[\log(\bar{P})|\bar{y}_i = y^*] = E[\bar{r} - l|\bar{y}_i = y^*].
\]  
(18)

The depositor’s updated belief of \( \bar{r} \) conditional upon the signal \( \bar{y}_i = y^* \) is:

\[
E[\bar{r}|\bar{y}_i = y^*] = \bar{r} + \frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} y^*.
\]  
(19)

Denote \( k_1 = \frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} \) and \( k_1 \) measures the importance of the marginal depositor’s signal \( y^* \) in estimating the fundamentals. Notice that the objectivity \( \beta \) and the accuracy \( \gamma \) are symmetric in affecting the fundamental value of the information, \( k_1 \).

We now compute, from the marginal depositor’s perspective, the portion of depositors who choose to withdraw \( E[l|\bar{y}_i = y^*] \). Since the noises are all independently distributed, the expected portion of depositors who withdraw is equal to the probability that a particular depositor \( j \) withdraws. Since depositor \( j \) also follows the same switching strategy, she withdraws if and only if her signal \( \bar{y}_j \leq y^* \). Thus we have,

\[
E[l|\bar{y}_i = y^*] = \Pr(\bar{y}_j \leq y^*|\bar{y}_i = y^*).
\]  
(20)
Given the marginal depositor’s signal $\tilde{y}_i = y^*$, she thinks that depositor $j$’s signal is normally distributed with a mean $\rho y^*$ and a variance $(1 - \rho^2) \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right)$, where $\rho = \frac{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} + 1}$ denotes the correlation between the signals of the marginal depositor and depositor $j$. Therefore,

$$\Pr(\tilde{y}_j \leq y^*|\tilde{y}_i = y^*) = \Pr\left( \frac{\tilde{y}_j - \rho y^*}{\sqrt{(1 - \rho^2) \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right)}} \leq \frac{y^* - \rho y^*}{\sqrt{(1 - \rho^2) \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right)}} | \tilde{y}_i = y^* \right)$$

$$= \Phi \left( k_2 y^* \right),$$

where $k_2 \equiv \sqrt{\frac{1 - \rho}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} + 1}}$ and the correlation $\rho$ in $k_2$ measures the importance of the marginal depositor’s signal $y^*$ in estimating the risk of bank runs (the expected proportion of depositors who withdraw). We have

$$E[l|y^*] = \Phi \left( k_2 y^* \right). \quad (22)$$

In equilibrium, the depositor who observes a $\tilde{y}_i$ equal to $y^*$ is indifferent between staying and withdrawing:

$$E[\bar{r} - l|y^*] = 0, \quad (23)$$

which can be reduced into:

$$\bar{r} + k_1 y^* = \Phi \left( k_2 y^* \right). \quad (24)$$

In the following proposition, we show that for $\alpha$ sufficiently small, there exists a unique equilibrium in our model.

**Proposition 2** Define $\alpha_H$ as the unique positive solution to

$$k_1 = k_2 \sqrt{\frac{1}{2 \pi}}, \quad (25)$$

Given that $\alpha \leq \alpha_H$, there exists a unique equilibrium such that every depositor withdraws if and only if $\tilde{y}_i < y^*$, where $y^*$ is the unique solution to

$$\bar{r} + k_1 y^* = \Phi \left( k_2 y^* \right). \quad (26)$$

\footnote{The derivations regarding the conditional distribution are included in the Appendix I.}
Proposition 2 shows that when the common prior among depositors is sufficiently diffuse, the equilibrium in a bank run game becomes unique, which often appears in the higher-order beliefs and global game literature (Morris and Shin, 1998, 2001, 2002; Plantin, Sapra and Shin, 2008). This result shows that the occurrence of bank runs depends critically on the information disclosed by the bank: a depositor withdraws upon receiving a bad signal about the bank’s project. In addition, we find that the depositor tends to withdraw more often in equilibrium than in the first-best benchmark. That is, \( y^* > y^{FB} \), as summarized in the corollary below.

**Corollary 1** Given that \( \alpha \leq \alpha_H \), in equilibrium, every depositor tends to withdraw more often than in the first-best benchmark,

\[
y^* \geq 0 > y^{FB}.
\]  
(27)

Corollary 1 depicts the coordination failure in the bank run situation. Since a depositor is concerned with the risk of runs by other depositors, she will withdraw when anticipating others will withdraw, even if the bank’s project yields an expected payoff higher than its liquidation value. As a result, in equilibrium, the project is liquidated more often than what is optimal in the first-best (\( y^* > y^{FB} \)). This observation also suggests that since all depositors hold a common pessimistic prior \( \bar{r} \leq \frac{1}{2} \), a depositor will choose not to withdraw only when she receives an updated signal that is sufficiently more favorable than her prior (that is, \( \tilde{y}_i - \bar{r} > y^* \geq 0 \)). This point turns out to be of critical importance in understanding the roles of improving the accuracy and objectivity in affecting the risk of bank runs.

### 3.3 Equilibrium Analysis

Identifying the unique equilibrium in the bank-run game allows us to analyze the properties of the equilibrium in which we focus on studying the role of two important properties of information, the accuracy \( \gamma \) and the objectivity \( \beta \), in affecting the threshold for withdrawals \( y^* \). We believe such analyses can shed light on the optimal design of the information system in order to reduce the occurrences of inefficient bank runs (i.e., runs where \( y \in (y^{FB}, y^*) \)).

We first show that improving both of the accuracy and the objectivity of the information system can help to reduce the threshold for withdrawals in the following proposition.

**Proposition 3** Given that \( \alpha \leq \alpha_H \), the following holds:
1. Improving the objectivity always decreases the threshold for withdrawals,

$$\frac{\partial y^*}{\partial \beta} < 0; \quad (28)$$

2. There exists a threshold $$\alpha_L \in [0, \alpha_H]$$, such that for $$\alpha < \alpha_L$$, improving the accuracy decreases the threshold for withdrawals,

$$\frac{\partial y^*}{\partial \gamma} < 0. \quad (29)$$

Proposition 3 characterizes the roles of the accuracy and the objectivity of the information disclosure in affecting the risk of bank runs. We find that improving the objectivity always reduces the withdrawal threshold and identify a sufficient condition for the accuracy to be reducing inefficient bank runs: the common prior $$\alpha$$ needs to be sufficiently imprecise. While Proposition 3 points to the similarity between objectivity and accuracy, the next two focus on their distinction. Specifically, Proposition 4 shows improving the objectivity is more effective than improving the accuracy in terms of reducing runs and in Proposition 5, we show improving the accuracy can actually increase the risk of runs when the common prior is sufficiently precise.

**Proposition 4** For $$\beta \leq \gamma$$, improving the objectivity always dominates improving the accuracy in terms of decreasing the threshold for withdrawals, i.e.,

$$\frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma}; \quad (30)$$

for $$\beta > \gamma$$, there exists a $$\Delta > 1$$, such that $$\frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma}$$ if $$\frac{\beta}{\gamma} < \Delta$$, that is, the degree of objectivity is too large relative to the degree of accuracy.

Proposition 4 indicates the superiority of improving the objectivity to improving the accuracy in mitigating the risk of bank runs, as long as the objectivity of the information is not too large such that the marginal benefit of further improving the objectivity becomes minimal. This proposition also sheds some light on the trade-off between accuracy and objectivity in terms of policy implications for designing the optimal information system. Our results suggest that in scenarios that have conflicts between objectivity and accuracy, it could be welfare-enhancing to sacrifice accuracy to improve objectivity, especially when reducing the risk of bank runs is the central concern. Notice
that this comparison result between objectivity and accuracy stands in contrast to the result under
the standard information structure that improving the precision of public information is superior
to improving the precision of private information (Morris and Shin, 2001).

To understand the intuition behind the results in Proposition 3 and 4, it is illuminating to
return to the equation that determines the threshold for withdrawal:

\[ \bar{r} + k_1 y^* = \Phi(k_2 y^*). \]  

Equation (31) illustrates well that, from the marginal depositor’s standpoint, her information \( \tilde{y}_i = y^* \) serves two purposes: on the left-hand side of the equation, \( y^* \) is used to estimate the fundamentals of project, where the importance of this usage is characterized by \( k_1 \); on the right-hand side, \( y^* \) is used to forecast the probability that other depositors will withdraw (the risk of bank runs), where the importance of this usage is characterized by \( k_2 = \sqrt{\frac{1 - \rho}{\rho}} \frac{1}{\alpha + \frac{1}{\beta + \gamma}} \), which depends crucially on the correlation between different depositors’ signals, \( \rho \). We call the first value of the information a fundamental value and the second a strategic value.

The effects of improving the two informational properties on the risk of bank runs depends
critically on their effects on the two usages of the information. Recall that, as we discussed in the
first-best benchmark, improving the accuracy and the objectivity are symmetric in affecting the
fundamental value of the information. Improving either of the two increases the precision of the
marginal depositor’s signal and as a result, the marginal depositor places a larger weight (a higher
\( k_1 \)) on the signal. Recall that in our model, the marginal depositor holds a pessimistic prior and
will choose not to withdraw only upon receiving a new signal that is sufficiently more favorable
than the prior (that is, \( y^* = x^* - \bar{r} \geq 0 \)). Therefore, as the marginal depositor places a larger weight
on the favorable signal \( y^* \), she forms a more optimistic expectation about the project’s return. As
a result, at the previous withdrawal threshold \( y^* \), she now prefers to leave her money within the
bank, which means the solvency threshold needs to lower for the depositor to be indifferent. These
analyses show that through magnifying the fundamental value of the marginal depositor’s favorable
information, both improving the objectivity and the accuracy reduce the withdrawal threshold.

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\(^5\)In their original 2001 paper, only a pure private signal is available for each depositors. One can show that adding a pure public signal in their setting, increasing the precision of the public signal is superior to increasing the precision of the private signal in reducing panic-based runs, holding the realization of the public signal equal to the bank run threshold of the private signal.
Improving the accuracy and the objectivity have the opposite impacts on the strategic value of the information. The disclosure of more objective information facilitates the depositor’s ability to forecast others’ actions while more accurate information impairs her forecasting ability. This is because the accuracy and the objectivity affect differently the correlation between depositors’ signals $\rho = \frac{\frac{1}{\alpha} + \frac{1}{\beta}}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}$, which is the key determinant of the strategic value of the information. On one hand, an improvement in the objectivity reduces the degree of disagreement among depositors’ interpretation of the bank’s disclosure and hence shrinks the magnitude of the individual noise $\varepsilon_i$. Drawing an analogy between our model and the theory of CAPM, enhancing the objectivity decreases the relative portion of the idiosyncratic component $\left(\frac{1}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}\right)$ in the information while increasing the portion of the systematic one $\left(\frac{\frac{1}{\alpha} + \frac{1}{\beta}}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}\right)$. As a result, the depositor’s signal is of greater importance in predicting others’ actions as the depositors’ signals become more correlated (a higher $\rho$). On the other hand, however, making the disclosure more accurate only diminishes the size of the systematic noise while leaving the idiosyncratic noise unaffected. As a result, in each depositor’s information, the idiosyncratic component takes a larger weight at the expense of reducing the weight on the systematic one, which in turn diminishes the strategic value of the information (a lower $\rho$).

Now consider how these changes in the strategic value of the information affect the withdrawal threshold. For a marginal depositor with a more favorable signal than her prior, when improving the objectivity enhances the value of the information in forecasting others’ actions, her signal indicates that a larger portion of the other depositors also receive favorable signals and hence will choose to stay. As a result, from the marginal depositor’s perspective, the risk of bank runs is lower and hence she prefers to stay at the previous threshold before the improvement in the objectivity. That is, improving the objectivity, through amplifying the strategic value of the marginal depositor’s favorable information, reduces the withdrawal threshold. Similarly, improving the accuracy decreases the strategic use of the marginal depositor’s favorable signal and induces her to believe that the others will be more likely to withdraw. In response, she will prefer to withdraw at the previous threshold before the change, which means the withdrawal threshold needs to be higher.

When combined, our analyses suggest that improving the objectivity increases both the fundamental and the strategic value of the information, which collectively reduce the withdrawal thresh-
old; however, the effect of improving the accuracy is non-monotonic, depending on the trade-off between the increase in the fundamental value of the information and the decrease in its strategic value. This non-monotonicity implies that there may exist a region in which improving the objectivity yields the opposite effect on the risk of bank runs to improving the accuracy, which we show in the proposition below.

**Proposition 5** Consider a case where \( \tilde{r} \) is sufficiently close to \( \frac{1}{2} \) and given that \( \alpha \leq \alpha_H \), the following holds:

1. For \( \alpha < \alpha_L \), improving the objectivity and the accuracy both decrease the threshold for withdrawals,
   \[
   \frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma} < 0; \tag{32}
   \]

2. For \( \alpha_L < \alpha \leq \alpha_H \), improving the objectivity decreases the threshold for withdrawals, while improving the accuracy increases the threshold for withdrawals,
   \[
   \frac{\partial y^*}{\partial \beta} < 0 < \frac{\partial y^*}{\partial \gamma}. \tag{33}
   \]

Proposition 5 summarizes the main policy implications of our findings. The proposition shows that in a case where the depositor’s prior is sufficiently close to \( \frac{1}{2} \), when the depositors’ prior information about the bank is poor (\( \alpha < \alpha_L \)), improvements in the objectivity and the accuracy both decrease the risk of bank runs. However, when the depositors have good prior information (\( \alpha > \alpha_L \)), there is a striking difference between the effects of the objectivity and the accuracy on bank runs: making the information disclosed more objective reduces bank runs while more accurate disclosure actually increases bank runs. The intuition behind this result is as follows. When the depositors’ prior is sufficiently diffuse, the systematic component \( \left( \frac{1}{\alpha} + \frac{1}{\beta} \right) \) already takes a significant portion in the depositors’ information. A variation in the accuracy hence will not substantially change the systematic component and its impact on the strategic value of the information is small. As a result, with the fundamental value of the information as the dominant force, the roles of the objectivity and the accuracy are similar. It is until the depositors’ prior becomes sufficiently precise that changing the accuracy has a considerable impact on the strategic value of the information.
Only with this additional effect do the roles of the objectivity and the accuracy differ from each other.

The two cases characterized in Proposition 5 can be interpreted as the descriptions of two types of bank runs. The case of poor prior information \((\alpha < \alpha_L)\) can be viewed as depicting “old-fashioned,” ordinary depositors’ runs on traditional commercial banks, such as the ones that occurred repeatedly in the 19th century (Allen and Gale, 1998). Our results imply that in mitigating these runs, it makes no qualitative difference between improving objectivity and accuracy of banks’ disclosure; the trade-off between objectivity and accuracy hence may seem moot. The other case in which the depositors hold much better prior information \((\alpha > \alpha_L)\) can be related to the “modern-day” runs on shadow banks (Shin, 2009). The group of “depositors” in these shadow banks are primarily contained with sophisticated institutional investors, such as mutual funds, investment banks and hedge funds. Different from ordinary depositors, these depositors are trained professional investors well equipped with prior knowledge about shadow banks’ operations. In the recent financial turmoil, shadow banks had experienced catastrophic runs by their investors, which led to severe liquidity dry-ups and economic downturns. Our results suggest that in dealing with these modern-day runs, it is of vital importance to understand the trade-off between objectivity and accuracy. Our model predicts that the disclosure of highly objective information helps to stabilize investors’ runs. Our results also serve at least as a message of caution regarding regulatory initiatives that aim solely at improving the accuracy of disclosure, since such initiatives can have the “unintended” consequence of triggering runs. An illuminating example related to this point is the popular disclosure of the tangible common equity (TCE) by banks during the recent crisis.\(^6\) Although the TCE is an extremely simple measure and hence may not reflect banks’ operating status fairly accurately, it is the same simplicity that limits the room for disagreements among market participants and hence makes the TCE highly objective. Our findings suggest that banks may choose to disclose this somewhat inaccurate but highly objective information in the hope of stabilizing runs by investors.

\(^6\)See an example of reporting the TCE by Citibank at http://online.wsj.com/news/articles/SB123577012189796905.
3.4 Social Welfare Analysis

In the previous analysis, we examine the effects of accuracy and objectivity on the threshold of bank runs. In this section, we analyze the effects of these information properties on social welfare. Since we are mostly interested in comparing the effects of improving the accuracy and the objectivity, we will focus on the case $\beta = \gamma$ to "level the playing field." We also numerically verify that as long as $\beta$ is not too large relative to $\gamma$, our main result on the superiority of objectivity to accuracy holds qualitatively.

The social welfare of our economy $W$ is equal to the aggregate of the depositors' utilities:

$$W = \int_{0}^{1} u_i di,$$

where the $l$ portion of the depositors who withdraw obtain a utility of $\log(1) = 0$, and the rest of the depositors who stay obtain a utility of $\log(e^{\tilde{r} - l}) = \tilde{r} - l$. Therefore, conditional on the fundamental $\tilde{r}$, the social welfare is:

$$W(\tilde{r}) = l(\tilde{r}) 0 + (1 - l(\tilde{r})) (\tilde{r} - l) = (1 - l(\tilde{r})) (\tilde{r} - l(\tilde{r})),
$$

and the ex ante social welfare is

$$W = E_{\tilde{r}}[W(\tilde{r})].$$

In the corollary below, we identify a condition in which improving objectivity dominates accuracy in terms of increasing social welfare. In addition, numerical analysis shows that this condition holds for a large set of parameter values.

**Corollary 2** Consider a symmetric case $\beta = \gamma$. The marginal effect of improving objectivity on social welfare is greater than improving accuracy, $\frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma}$, if and only if

$$\tilde{r} > 2 \Phi \left( \frac{Y}{\sqrt{(\tau^2 + 1)(2\tau^2 + 1)}} \right) - \frac{\tau Y}{\sqrt{\alpha(\tau^2 + 1)}} - 1,$$

where $\tau = \sqrt{\frac{\beta \gamma}{\alpha(\beta + \gamma)}}$ and $Y = \sqrt{\frac{\beta \gamma}{\beta + 1}} y^*$. In particular, this condition holds for either 1) $\tilde{r}$ close to $\frac{1}{2}$; 2) $\alpha$ close to 0.
4 A Model of Accounting Measurement

In this section, we offer a micro-model of the accounting measurement process which, in turn, gives rise to the informational properties modeled in the main setup (i.e., equation (1) on page 5). Deriving this accounting measurement model also sheds light on possible measures to affect the objectivity and accuracy properties.\(^7\)

Consider a two-step representation of the accounting measurement system.\(^8\) Suppose the payoff-relevant state-of-nature (or fundamentals) is denoted by \(\bar{r} \sim N(\bar{r}, \frac{1}{\alpha})\). In the first step of the accounting measurement process, a collection of \(K\) pieces of evidence about the fundamentals is generated. If the accounting measurement process is not intervened by the manager, we represent the \(k\)th piece of evidence, denoted by \(s_k\), as
\[
\tilde{s}_k = \bar{r} + \mu_k \tilde{\epsilon},
\]
where \(\tilde{\epsilon} \sim N(0, \phi)\) denotes an uninfluenced noise stemming from measurement errors in the imperfect accounting system and \(\phi\) measures the size of the errors. Different evidence is affected by the errors differently, measured by \(\mu_k \geq 0\). In addition, the manager can also intervene and influence the outcome of the accounting system by an action \(b\). After the intervention, each influenced evidence, denoted by \(\tilde{e}_k\), becomes
\[
\tilde{e}_k = \bar{r} + \mu_k \tilde{\epsilon} + \lambda_k b,
\]
where \(\tilde{\epsilon} \sim N(0, \phi)\) denotes an uninfluenced noise stemming from measurement errors in the imperfect accounting system and \(\phi\) measures the size of the errors. Different evidence is affected by the errors differently, measured by \(\mu_k \geq 0\). In addition, the manager can also intervene and influence the outcome of the accounting system by an action \(b\). After the intervention, each influenced evidence, denoted by \(\tilde{e}_k\), becomes
\[
\tilde{e}_k = \bar{r} + \mu_k \tilde{\epsilon} + \lambda_k b,
\]

\(^7\)The first measurement model of objectivity is given by Ijiri and Jaedicke (1966). In their influential work on reliability, Ijiri and Jaedicke proposed a simple, elegant model which decomposes the so-called reliability property (of accounting measurement system) into two components: objectivity and bias. Suppose \(n\) measurers are asked to measure an object (e.g., the performance of a firm) using a given measurement system \(\eta\). Let \(x^*\) be the true value of the object (e.g., the economic income of the firm) and \(x_i^\eta\) be the outcome (e.g., the net income of the firm) reported by measurer \(i\) by operating the measurement system \(\eta\) (e.g., a historical-cost based measurement system). Ijiri and Jaedicke (1966) proposed that the reliability of the measurement system \(\eta\) is given as
\[
R_\eta = \frac{1}{n} \sum_{i=1}^{n} (x_i^\eta - x^*)^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - x^\eta)^2 + (x^\eta - x^*)^2
\]
\[= V_\eta + B_\eta,
\]
where \(\bar{x}^\eta\) is the average outcome among \(n\) measurers. Accordingly, \(V_\eta = \frac{1}{n} \sum_{i=1}^{n} (x_i^\eta - x^\eta)^2\) is defined as the inverse of the objectivity of the measurement system \(\eta\) and \(B_\eta = (\bar{x}^\eta - x^*)^2\) is defined as the bias of the measurement system \(\eta\).

Two points are worth noting. First, in our information model, objectivity \(V_\eta = \int_0^1 (\bar{x}_i - \bar{x}^\eta)^2 di = \int_0^1 \bar{x}_i^2 di = \frac{1}{\beta}\) that is, \(\beta\) exactly corresponds to the notion of objectivity in Ijiri and Jaedicke. Second, the Ijiri-Jaedicke measurement model is agnostic about the source of measurement bias and disagreement among measurers. Our measurement model gives rise to these dimensions by examining accounting system errors and managerial influences.

\(^8\)In developing this two-step representation, we owe our inspiration to the recent work summarized in Gao (2013).
where $\lambda_k \geq 0$ measures the extent to which the $k^{th}$ evidence is affected by the intervention. To rule out perfect evidence, we assume $\mu_k \lambda_k > 0$, for all $k$.

The $\{\mu_k, \lambda_k\}$ parameter-pair regulates how any given evidence ($\tilde{e}_k$) reveals information about the fundamentals. We interpret a parameter pair $\{\mu_k \neq 0, \lambda_k = 0\}$ as representing a completely uninfluenced evidence. Think of transactional evidence such as the amount of loans that are actually fully repaid, amount and length of time of loans that are past due, etc. While not perfectly describe the true underlying economic state, it provides non-discretionary indication about a firm’s prospect. When $\lambda_k \neq 0$, the evidence is influenced by the intervention action $b$; we interpret such evidence as containing managerial biases which could influence the reported financial metrics. One may think of the influenced evidence as those affected by interventions of the manager of the reporting entity, who influences these evidence by structuring transactions to qualify certain accounting treatment (e.g., structured finance products) or exercising their discretion in describing a transaction before the transaction is passed on to receive accounting treatment (e.g., managerial intent in accounting for trading versus available-for-sale classification).

In the second step, accounting measurement rules/procedures used by the reporting entity are applied to the evidence to create a public report $\tilde{X}$. In general, an accounting rules/procedure $R$ can be viewed as

$$\tilde{X} = f(\tilde{e}_1, \tilde{e}_2, ..., \tilde{e}_k, ..., \tilde{e}_K | R),$$

where the accounting rules $R$ describe how accounting professionals shall transform $\{\tilde{e}_k | k = 1, 2, ..., K\}$ into the accounting report $\tilde{X}$. For example, $R$ can include a recognition rule which specifies that certain evidence is inadmissible (i.e., $f(\cdot)$ is a constant function with respect to some $\tilde{e}_k$), or an impairment-style measurement rule (i.e., $f(\cdot)$ varies with $\tilde{e}_l$ only over the lower region of $\tilde{e}_l$ realizations).

For illustrative purposes, we assume that $\tilde{X}$ is a scalar and is given by a linear weighted-average aggregation rule (Dye and Sridhar, 2004),

$$\tilde{X} = \sum_{k=1}^{K} w_k \tilde{e}_k = \tilde{r} + \tilde{\eta} + \lambda \tilde{b},$$

where $w_k$ denotes the weight on the $k^{th}$ piece of evidence with $\sum_{k=1}^{K} w_k = 1$, $\tilde{\eta} \equiv \tilde{c} \left( \sum_{k=1}^{K} w_k \mu_k \right)$. 


\( N \left( 0, \frac{1}{\gamma} \right), \gamma \equiv \frac{1}{\phi(\sum_{k=1}^{K} w_k \mu_k)} \), and \( \lambda = \sum_{k=1}^{K} w_k \lambda_k \). The choice of \( \{w_k\}_{k=1}^{K} \) can be interpreted as the accountant’s decisions on aggregation and recognition (e.g., \( w_k = 0 \) means not recognizing the \( k^{th} \) piece of evidence). Combining the two steps in the accounting process, the reporting is described as a triple \( \{\tilde{X}, \gamma, \lambda\} \) to the outside decision makers, which includes the report, the precision of aggregate uninfluenced noise, and the precision of the aggregate influenced noise.

Following Dye and Sridhar (2004), we assume that, in choosing her intervention, the manager always prefers a higher report \( \tilde{X} \) and incurs a cost of intervention, \( \frac{1}{2} \left( b - \tilde{\theta} \right)^2 \). This cost can be interpreted as potential litigation costs, manager’s mental sufferance from misreporting, etc. Importantly, the intervention cost depends on a parameter \( \theta \), which is privately known only to the manager. For instance, the potential punishment for misreporting may be highly uncertain from an outsider’s perspective, especially when a part of this punishment comes from the manager’s mental sufferance. Given the nature of \( \tilde{\theta} \), we assume that it has an improper prior. The manager’s payoff is then given by

\[
\tilde{X} - \frac{1}{2} \left( b - \tilde{\theta} \right)^2 ,
\]

the FOC on \( b \) gives the manager’s equilibrium intervention \( b^* \left( \tilde{\theta} \right) \) as,

\[
b^* \left( \tilde{\theta} \right) = \tilde{\theta} + \lambda .
\]

Notice that in a rational expectation equilibrium, the functional form of \( b^* \left( \tilde{\theta} \right) \) is perfectly conjectured by outsiders and thus in order to estimate \( b \), one only needs to estimate \( \tilde{\theta} \). We assume that, in processing the report, a decision maker \( i \) “interprets” the public report by combining the report \( \tilde{X} \) with her own private signal/beliefs about \( \tilde{\theta} \) denoted by

\[
\tilde{s}_i^\theta = \tilde{\theta} + \tilde{\varepsilon}_i^* ,
\]

where \( \tilde{\varepsilon}_i^* \sim N (0, \delta) \). That is, depending on her own private signal (based on each decision maker’s education and experience etc.), each decision maker draws different inference about the manager’s intervention incentive. From decision maker \( i \)’s perspective, the public report \( \tilde{X} \) is interpreted
privately as \( \tilde{x}_i \) which is equal to,

\[
\tilde{x}_i = \bar{r} + \bar{\eta} + \lambda \left( \tilde{s}_i^0 - \tilde{z}'_i + \lambda \right).
\]

As in the main setting, consider a demeaned value of the report, \( \bar{y}_i \),

\[
\bar{y}_i = \tilde{x}_i - \bar{r} - \lambda \left( \tilde{s}_i^0 + \lambda \right)
\]

\( = \bar{r} - \bar{r} + \bar{\eta} - \lambda \tilde{z}'_i.\)

Let \( \tilde{\epsilon}_i = -\lambda \tilde{z}'_i \), we have

\[
\bar{y}_i = \bar{r} - \bar{r} + \bar{\eta} + \tilde{\epsilon}_i,
\]

where \( \tilde{\epsilon}_i \sim N \left( 0, \frac{1}{\beta} \right) \) and \( \beta \equiv \frac{1}{\delta \lambda^2} \). As a result, the accounting measurement process generates a public report which, when interpreted by each decision maker privately, contains a common noise \( \bar{\eta} \) with precision \( \gamma = \frac{1}{\phi \left( \sum_{k=1}^{K} w_k \mu_k \right)^2} \) (accuracy) and an idiosyncratic noise \( \tilde{\epsilon}_i \) with precision \( \beta = \frac{1}{\delta \left( \sum_{k=1}^{K} w_k \lambda_k \right)^2} \) (objectivity). Objectivity and accuracy are functions of the measurement rules \( \{w_k\}_{k=1}^{K} \), the properties of the measurement system, \( \{\lambda_k\}_{k=1}^{K}, \phi \) and \( \{\mu_k\}_{k=1}^{K} \), and the heterogeneity among the decision makers, \( \delta \). To investigate how different measures can affect accuracy and objectivity, we compute the comparative statics of \( \beta \) and \( \gamma \) in the proposition below.

**Proposition 6** The comparative statics of accuracy and objectivity is such that:

1. Information accuracy \( \gamma \) is strictly decreasing in the size of the measurement errors, \( \phi \), and decreasing in the degree to which each evidence is affected by the measurement errors, \( \mu_k \);

2. Information objectivity \( \beta \) is strictly decreasing in the heterogeneity among the decision makers, \( \delta \), and decreasing in the degree to which each evidence is affected by the managerial influence, \( \lambda_k \);

3. The role of the measurement rules \( \{w_k\}_{k=1}^{K} \) is as follows:

   - \( \gamma \) increases when the measurement rules move weight from an evidence \( i \) with high \( \mu_i > \mu_j \) to an evidence \( j \) with low \( \mu_j \).
• $\beta$ increases when the measurement rules move weight from an evidence $i$ with high $\lambda_i > \lambda_j$ to an evidence $j$ with low $\lambda_j$.

Proposition 6 can shed some light on the design of the accounting system and the measurement rules from the perspective of the objectivity-accuracy trade-off. First, when high accuracy is socially undesirable but high objectivity is socially desirable (as shown in our previous analysis), it is welfare enhancing to design an accounting system that is more subject to random errors (high $\phi$ and high $\mu_k$) but is less subject to managerial influence (low $\lambda_k$). Second, in designing the optimal measurement rules, there is a trade-off between accuracy and objectivity since both properties depend on the measurement rules $\{w_k\}_{k=1}^K$. On one hand, in order to generate a more objective report, one needs to put more weight on the set of evidence that is less affected by managerial influences (low $\lambda_k$); on the other hand, in order to generate a more accurate report, one needs to put more weight on the set of evidence that is less affected by random noises (low $\mu_k$), which may not coincide with the set of low-$\lambda_k$ ones. Examining this objectivity-accuracy trade-off may be suggestive about the underlying rationale for banking regulators to resist certain GAAP treatments based on objectivity grounds. Specifically, for regulatory accounting purposes, GAAP fair-value treatments of certain balance sheet items are disallowed under regulatory accounting principles (RAP). For instance, for the purpose of computing Tier-I capital, unrealized gains and losses due to available-for-sales (AFS) securities are removed from GAAP bank equity as well as unrealized gains and losses due to mark-to-market treatment of the bank’s own long-term debt and certain excess amount of servicing assets. In other words, bank regulators, who arguably are more sensitive to coordination problems associated with banks under their supervision, deploy a more objectivity-based recognition criteria. One can argue these GAAP fair value treatments do make the resulting GAAP equity measures more accurate so the fact they are removed for regulatory purposes may be attributed to the objectivity concerns (i.e., the bank regulators are concerned about these measures introducing more disagreement in interpretations among depositors about the bank’s fundamentals).

5 Extension to Other Strategic Settings

In the previous section, we showed that, in a model of bank runs, objectivity property plays a divergent role from the accuracy property due to their different effects on the strategic value of
information. In this section, we show that this result can be extended to other strategic settings of interests, including models with investment complementarity, beauty contest and oligopolistic competition. For simplicity, we will focus on the symmetric case $\beta = \gamma$.

**Investment Complementarity**  There are many settings, such as models of team incentives, cooperation, etc., examined in the accounting and economics literature that have investment complementarity, either assumed in the production technology or induced by incentive contracts (Che and Yoo, 2001; Arya, Fellingham and Glover, 1997; Liang, Rajan and Ray, 2008). To see how the objectivity and accuracy properties play in these settings, consider a canonical example developed in Angeletos and Pavan (2004). The model has a continuum of agents, indexed by $i$ in the unit interval $[0, 1]$. Each agent is risk neutral and has a utility

$$u_i = Aq_i - \frac{1}{2} q_i^2,$$

where $q_i$ denotes individual investment, $A$ denotes the investment return, and $\frac{1}{2} q_i^2$ is the investment cost. The aggregate investment $Q = \int_0^1 q_i di$. To introduce investment complementarity, we assume the return to investment is strictly increasing in the aggregate investment,

$$A = (1 - \kappa) \tilde{r} + \kappa Q,$$

where $\tilde{r}$ represents the exogenous fundamentals of the economy and $\kappa \in [0, \frac{1}{2}]$ represents the degree of complementarity among individual investments. The information structure is as in the bank-run model. The social welfare is given by aggregating the individual utilities:

$$W = E \left[ \int_0^1 u_i di \right] = E \left[ (1 - \kappa) \tilde{r}Q - (1 - 2\kappa) \frac{1}{2} Q^2 - \frac{1}{2} \text{var} \right],$$

where $\text{var} = \int_0^1 (q_i - Q)^2 di$ measures the heterogeneity among individual investments. Following Angeletos and Pavan (2004), we derive the equilibrium individual investment as follows:

$$q_i^* = \tilde{r} + \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} + \frac{1}{1 - \kappa} \tilde{y}_i,$$

28
where $\tilde{y}_i$ is the demeaned signal, $\tilde{y}_i = \tilde{x}_i - \bar{r}$ and $\rho = \frac{1}{\alpha + \frac{1}{\beta} + \frac{1}{\gamma}}$ measures the correlation between the individual signals. In Corollary 3, we find that in the setting with investment complementarity, improving objectivity yields larger social benefits than improving accuracy. This is because in settings with investment complementarities, coordination is more valuable for society than individual agents, as in the bank-run setting. As a result, more objective information facilitates the coordination among agents and improves social welfare. Notice that this result is opposite to the result under the standard information structure that improving public information precision is more socially desirable than improving private information precision (Angeletos and Pavan, 2004).

**Corollary 3** Consider a symmetric case $\beta = \gamma$. In the game with investment complementarity, the marginal effect of improving objectivity on social welfare is greater than improving accuracy, \( \frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma} > 0 \).

**Beauty Contest** Another set of settings of interests is beauty-contest settings in which participants in financial market try to forecast each other’s forecasts rather than simply forecasting the fundamental value of the asset (Gao, 2008; Brooke, Krische and Peecher, 2009). To see how the objectivity and accuracy properties play in these settings, we consider a beauty-contest game developed in Morris and Shin (2002). The model is populated by a continuum of agents, indexed by $i$ in the unit interval $[0, 1]$. Each agent has a payoff:

\[
u_i = -(1 - \kappa) (q_i - \bar{r})^2 - \kappa \left( L_i - \bar{L} \right),
\]

where $\kappa \in (0, 1)$ measures the degree of complementarity between agents’ actions $q_i$, and

\[
L_i = \int_0^1 (q_i - q_j)^2 dj,
\]

\[
\bar{L} = \int_0^1 L_j \, dj.
\]

The information structure is the same as discussed before. Following Morris and Shin (2002), the agent chooses an equilibrium action as:

\[
q_i^* = \bar{r} + \frac{1}{\alpha + \frac{1}{\beta} + \frac{1}{\gamma}} \rho + \frac{1}{\frac{1}{\alpha} - \frac{1}{\kappa}} \tilde{y}_i.
\]
The social welfare

\[ W = E \left[ \frac{1}{1 - \kappa} \int_0^1 u_i \, di \right]. \tag{55} \]

In Corollary 4, we find that in the beauty-contest setting, improving objectivity also yields larger social benefits than improving accuracy. This result may seem contrast to the standard result in Morris and Shin (2002) which state that more precise private information is more socially valuable than more precise public information. This difference comes from our modelling choice of combining public and private noises in a single signal.\(^9\) Specifically, since individual agents need to coordinate with each other, they overweight the common (public) prior and underweight the “semi-public” signal, which is inefficient since such coordination has no social value. As objectivity of the signal increases (the signal becomes more “public”), the agents rely more on the signal relative to their prior in making decisions, due to the higher strategic value of the information in inferring others’ decisions. The higher weight on the signal in turn improves social welfare by mitigating the inefficiency stemming from individual agents’ overweighting of the prior.\(^10\)

**Corollary 4** Consider a symmetric case \( \beta = \gamma \). In the beauty contest game, the marginal effect of improving objectivity on social welfare is greater than improving accuracy, \( \frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma} > 0 \).

**Oligopolistic Competition** We conclude the discussion on strategic settings with models of oligopolistic competition with demand uncertainties. Both Cournot and Bertrand competition have been examined extensively in the accounting and economics literature (Darrough and Stoughton, 1990; Wagenhofer, 1990; Vives, 2006). To see the effects of objectivity and accuracy in these models, consider, for instance, a Cournot model given in Angeletos and Pavan (2007). Each firm in the unit interval chooses the quantity it produces \( q_i \) facing a downward sloping demand curve,\(^11\)

\[ p_i = a_0 + a_1 \bar{r} - a_2 q_i - a_3 Q, \tag{56} \]

\(^9\)We thank Brian Mittendorf for bringing our attention to this point.

\(^{10}\)To formalize this intuition, one can consider a benchmark in which a social planner can perfectly control how an agent’s decision depends on her own information, but cannot make her decision depend on other agents’ private information, as suggested by Angeletos and Pavan (2007). This benchmark thus identifies the best the social planner could do if the agents were to internalize their payoff interdependencies and appropriately adjust their use of available information without communicating with one another. We find that, relative to this benchmark, the agents in equilibrium underweight the signal and increasing objectivity raises the individual weight on the signal, which reduces the discrepancy between individual decisions and socially optimal decisions and improves social welfare.

\(^{11}\)Notice that assuming a continuum of firms is without loss of generality. Our results remain qualitatively for a finite number of firms.
where \( a_0, a_1, a_2, a_3 > 0 \), \( \tilde{r} \) represents the fundamentals, and \( Q = \int_0^1 q_i di \) is the aggregate quantity produced in the economy. Each firm has a payoff

\[
u_i = p_i q_i - C(q_i),
\]

where \( C(q_i) = c_1 q_i + c_2 q_i^2 \) is the cost function with \( c_1, c_2 > 0 \). The information structure is the same as discussed before. Solving the model gives an equilibrium output as:

\[
q_i^* = m_0 + m_1 \tilde{r} + m_2 \tilde{x}_i,
\]

where \( m_0, m_1, m_2 \) are given in the appendix. The social welfare

\[
W = E \left[ \int_0^1 u_i di \right] = E \left[ a_1 \tilde{r} Q + (a_0 - a_1) Q - (a_2 + a_3 + c_2) Q^2 - (a_2 + c_2) \text{var} \right],
\]

where \( \text{var} = \int_0^1 (q_i - Q)^2 di \) measures the heterogeneity among individual outputs. In the corollary below, we show that improving accuracy yields larger social benefits than improving objectivity, different from the previous findings. This is because, in the Cournot model, firms’ output choices are strategic substitutes rather than complements to each other, making less consensus (more disagreements) socially desirable.

**Corollary 5** Consider a symmetric case \( \beta = \gamma \). In the Cournot game, the marginal effect of improving accuracy on social welfare is greater than improving objectivity, \( \frac{\partial W}{\partial \gamma} > \frac{\partial W}{\partial \tilde{r}} \).

6 Literature Review

In this section, we review the related literature on objectivity, disclosure by financial intermediary, and higher-order beliefs. The concept of objectivity has a long and varied standing in accounting theory going back to at least the famous Paton-Littleton 1940 monograph (page 18). Accounting scholars had since studied objectivity extensively. Bierman (1963) focused on objectivity of measurement as commonly pursued in other sciences and on its desirable role for measurement theory (e.g., Stevens 1959) played in accountants’ practice of financial reporting. Ijiri and Jaedicke (1966)
focused on inter-personal agreement and framed objectivity within statistical sampling setting.\textsuperscript{12} Ashton (1977) refined the objectivity concept by explicitly distinguishing multiple rules and multiple measurers. However, explicit economic consideration were not given under this more narrowly defined measurement approach to accounting.\textsuperscript{13}

Starting in the late 1960s and early 1970s, accounting researchers began linking accounting concepts to information economics concepts (see AAA monographs by Feltham 1972 and Mock 1976). The agenda is to build on the traditional approach under a purely measurement perspective and to tie the accounting measurement concepts to economic trade-off in decision making under uncertainty.\textsuperscript{14} For example, Feltham (1974) formalized many informational properties such as informativeness, timeliness, accuracy, all within a single-person decision context. The 1974 Trueblood committee report as well as the subsequent FASB conceptual framework had all explicitly adopted investor-decision-making context and made characteristics of information (such as relevance, reliability, freedom from bias, and neutrality) key criteria for accounting policy-making. In particular, the relevance and reliability trade-off have been studied by Kirshenheiter (1997), Dye and Sridhar (2004) and Glover and Levine (2015). More recently, a small, but emerging, strand of work in accounting, such as Gao (2008), Plantin, Sapra and Shin (2008), Gigler, Kanodia and Venugopalan (2013), Chen, Huang and Zhang (2014), and Arya and Mittendorf (2014), has begun to address issues of interests to accounting scholars within economic coordination settings where individuals care not only about information’s fundamentals value but also its strategic value.

Our paper contributes to accounting literature by providing a single economic framework where both information accuracy and objectivity, two properties from separate research traditions, have

\textsuperscript{12}Defining objectivity operationally as “agreement” among difference individuals can be traced as least to Guilford (1957) who declares “objectivity is one of the major goals of science. ... ‘objectivity’ means interpersonal agreement. Where many persons reach agreement as to observations and conclusions, the descriptions of nature are more likely to be free from biases of particular individuals.” (as quoted by Bierman 1963, page 502). Also see Burke (1964), Chambers (1964), and Wagner (1965) for additional discussions and see Ashton (1977) for some extensions of the Ijiri-Jaedicke formulation of objectivity as well as a brief description of the contrast between operational and conceptual definitions of objectivity.

\textsuperscript{13}The approach, mainly analytic, was to derive a measurement basis from some self-evident postulates (e.g., entity, continuity, periodicity). For example, on asset valuation side, historical cost was the key concept and on the income statement side, realization principle and matching are the key. Conservatism was the dominant rule in practice.

\textsuperscript{14}The shift in perspective was well articulated by the seminal work of Beaver and Demsiki (1979). They argued that income measurement loses its economic foundation in a world with imperfect and incomplete markets. They offer a reinterpretation of income reporting and accrual notions in terms of a “cost-effective” communication procedure (Beaver and Demsiki 1979, 38). Therefore, under this new information economics approach, the logical function for accounting in such a world is to carry information. The usual connotations attached to these accounting labels are of less significance. What is important are their informational properties.
the potential to play an economic role. Extending earlier measurement-based accounting research tradition, we place the objectivity into a multiple-person decision-making context and analyze its economic role in coordinating group behavior (such as bank runs). Extending the post 70’s information-based accounting research tradition, we expand the dimensions of information properties and open a different research avenue to study how accounting information affects economic outcome. That is, beyond providing accurate or inaccurate inference about the state-of-nature, our study of the objectivity property shows the significance of accounting measurements may be its impact on the level of agreement/consensus it generates (or eliminates) among different decision-makers. Given objectivity’s distinctive role persists across multiple economic settings, our paper points to a new avenue to evaluate the value of accounting measurement. That is, in addition to aiding decision makers by improving their knowledge about the fundamentals, accounting measurements may add much value to the society by improving decision makers’ knowledge about each other’s beliefs, leading to better coordination in the economy.

Our paper is also related to the extensive literature on information disclosure by financial intermediaries, which is reviewed in Goldstein and Sapra (2012). For a review of the related empirical literature, see Beatty and Liao (2014) and Acharya and Ryan (2015). Some recent studies examine the interaction between accounting disclosure and liquidity risk. For example, Allen and Carletti (2008) examine the trade-off between mark-to-market accounting and historical-cost accounting. They show that when financial institutions are subject to liquidity risk, using market-based accounting information to assess financial institutions’ solvency is undesirable, compared to historical-cost-based information. Similarly, Plantin, Sapra, and Shin (2008) study sales of securitized loans in an illiquid market and show that mark-to-market accounting injects artificial volatility into prices, which distorts real decisions. Other studies examine the disclosure of regulatory information. For instance, Prescott (2008) argues that requiring banks to disclose information might hurt regulators’ ability to collect information. Bond and Goldstein (2012) also show that disclosure of information by the government to the market might impair the government’s ability to learn from the market. Goldstein and Leitner (2013) study the welfare implication of disclosing stress test results. They find that in good times, no disclosure is optimal while in bad times, partial disclosure is optimal. Building on this literature, our paper examines the role of two properties of information disclosure, accuracy and objectivity, in reducing inefficient runs and improving bank instability. We find
that improving objectivity always discourages runs while improving accuracy sometimes encourages runs.

With respect to the economic literature of games with incomplete information, the information structure is critical and has been considered as one of the most important area of research (Morris and Shin 2001 discussion section). In a seminal paper, Diamond and Dybvig (1983) argue that banks play important roles in providing liquidity to the economy which, at the same time, exposes banks themselves to the risk of bank-runs. This fragility of banks is characterized by relying on a multiple-equilibrium: depending on the coordination among depositors, either a bank-run equilibrium or a socially optimal equilibrium prevails. However, which of these two equilibria occurs is either indeterminate or depends on extraneous variables (“sunspots”). This indeterminacy, albeit intuitively appealing and intellectually interesting, can be unsatisfactory and debilitating from a practical and policy stand point. For instance, Morris and Shin (2001) argue that such indeterminacy “runs counter to our theoretical scruples against indeterminacy” and generates “the obvious difficulties of any comparative-statics analysis.” A recent development in the global games literature (Carlsson and van Damme, 1993; Morris and Shin, 1998, 2001, 2002) provides a key insight that challenges the indeterminacy in multiple-equilibrium models. Key to the global games approach in the model of bank runs is to reconsider the stark information environment condition (i.e., the fundamentals of the project is known to all). Under the approach, even when depositors observe the final payoff with just a very small amount of idiosyncratic uncertainty, the indeterminacy will disappear and the equilibrium becomes unique. Identifying a unique equilibrium in turn allows the study of various comparative statics, which is of central importance in generating policy implications. Building on the global games approach, this paper focuses on developing the information structure in a bank-run situation. Our findings suggest that introducing informational issues to the model of bank runs not only results in the uniqueness of equilibrium, but the information properties also play important roles in determining the equilibrium outcomes.

7 Conclusion

In this paper, we analyze the roles of two information properties, objectivity and accuracy, in improving bank stability. We show that in a bank-run model, objectivity exhibits a comparative
advantage in mitigating inefficient, panic-based bank runs compared with accuracy. In fact, it is possible that improving objectivity discourages bank runs while improving accuracy encourages such runs. We find that the distinction between objectivity and accuracy also appears in other coordination settings. Our model also sheds light on the design of optimal accounting rules. We find that, in order to generate a more objective report, the accounting rules should be made less admissible to managerial intervention.

We believe this is only the beginning of a new line of accounting research that explores the role of accounting information in settings featuring coordination as the key economic tension. We hope future work would use our results as the building blocks to develop a theory of corporate disclosure based on the need to encourage or discourage coordination. Given public information plays a special role in coordination-based games, we believe there are much to learn about the role of accounting disclosure in these settings including what make accounting special compared to other information sources such as share price. This new line of research would complement current disclosure theories built on moral hazard and adverse selection tensions.

References


Appendix I: Derivations of the Conditional Distribution of $\tilde{y}_j$ Given $\tilde{y}_i = y^*$

In this appendix, we derive the conditional distribution of a depositor $j$’s signal $\tilde{y}_j$, given the marginal depositor’s signal $\tilde{y}_i = y^*$. The two signals are:

$$
\tilde{y}_i = \tilde{x}_i - \tilde{r} = \tilde{r} - \tilde{r} + \eta + \varepsilon_i,
$$

$$
\tilde{y}_j = \tilde{x}_j - \tilde{r} = \tilde{r} - \tilde{r} + \eta + \varepsilon_j.
$$

Since the random variables $\tilde{r} - \tilde{r}, \eta, \varepsilon_i,$ and $\varepsilon_j$ are independently normally distributed, their linear combinations $\tilde{y}_i$ and $\tilde{y}_j$ are jointly normally distributed such as,

$$
\begin{bmatrix}
\tilde{y}_i \\
\tilde{y}_j
\end{bmatrix} \sim N \left( \begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix}
\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} & \rho \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right) \\
\rho \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right) & \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}
\end{bmatrix} \right),
$$

(61)

where the correlation between the two signals $\rho = \frac{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}{\sqrt{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} \cdot \sqrt{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}}}$. As a result, the conditional distribution of $\tilde{y}_j$ given $\tilde{y}_i = y^*$ is also normally distributed with the conditional expectation

$$
E[\tilde{y}_j|\tilde{y}_i = y^*] = 0 + \frac{\rho \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right)}{\frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}} (y^* - 0) = \rho y^*,
$$

(62)

and the conditional variance

$$
Var[\tilde{y}_j|\tilde{y}_i = y^*] = (1 - \rho^2) \left( \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma} \right).
$$

(63)
Appendix II: Proofs

Proof of Proposition 2

Proof. As shown in the main text, the equilibrium threshold $y^*$ is given by the following equation,

$$\bar{r} + k_1 y^* = \Phi (k_2 y^*) .$$  \hfill (64)

It is straightforward to verify that $k_1/k_2$ is strictly decreasing in $\alpha$. Thus when $\alpha \leq \alpha_H$, $k_1/k_2 \geq k_1/k_2 |_{\alpha=\alpha_H} = \sqrt{1/2\pi}$. Therefore,

$$k_1 \geq k_2 \sqrt{1/2\pi} \geq k_2 \phi(k_2 y^*) ,$$  \hfill (65)

that is, the slope of the LHS of equation (64), $\bar{r} + k_1 y^*$, is always greater than the slope the RHS of equation (64), $\Phi (k_2 y^*)$, which guarantees a unique solution to the equation. As a result, for $\alpha \leq \alpha_H$, there exists a unique equilibrium such that every depositor withdraws if and only if $\tilde{y}_i < y^*$.  

Proof of Corollary 1

Proof. Given $y^{FB} = -\frac{(1/2 + 1/\alpha)^\beta}{\alpha}$, $y^{FB} < 0$. In addition, it can be verified that given $\bar{r} \leq 1/2$, $y^* \geq 0$. To see this, consider the function $f(y)$:

$$f(y) = \bar{r} + k_1 y - \Phi (k_2 y) ,$$  \hfill (66)

$f(y)$ is continuous in $y$, $f(0) = \bar{r} - 1/2 \leq 0$, and $f(\frac{1-\bar{r}}{k_1}) > 0$. Therefore, by the intermediate value theorem, the unique root of the equation $f(y) = 0$, $y^*$, must be between 0 and $\frac{1-\bar{r}}{k_1}$. That is, $y^* \geq 0$.  

Proof of Proposition 3

Proof. Since $y^*$ solves,

$$\bar{r} + k_1 y^* = \Phi (k_2 y^*) ,$$  \hfill (67)

using the implicit function theorem and taking the derivative with respect to $\beta$ and $\gamma$ on the both sides of the equation, we have,

$$k_1 \frac{\partial y^*}{\partial \beta} + y^* \frac{\partial k_1}{\partial \beta} = \phi(k_2 y^*) \left( k_2 \frac{\partial y^*}{\partial \beta} + y^* \frac{\partial k_2}{\partial \beta} \right), \quad m \in \{\beta, \gamma\} ,$$  \hfill (68)
which gives,

$$\frac{\partial y^*}{\partial m} = y^* \left( \phi(k_2 y^*) \frac{\partial k_2}{\partial m} - \frac{\partial k_1}{\partial m} \right), \quad m \in \{\beta, \gamma\}. \quad (69)$$

Since $\alpha \leq \alpha_H$,

$$k_1 \geq k_2 \sqrt{\frac{1}{2\pi}} \geq k_2 \phi(k_2 y^*), \quad (70)$$

and we have shown that $y^* \geq 0$ in Corollary 1, thus the denominator of $\frac{\partial y^*}{\partial m}$ is always positive.

It remains to check the sign of several derivatives, $\{\frac{\partial k_1}{\partial \beta}, \frac{\partial k_2}{\partial \beta}, \frac{\partial k_3}{\partial \gamma}, \frac{\partial k_2}{\partial \gamma}\}$. Denote $\frac{1}{q} = \frac{1}{\alpha} + \frac{1}{\beta} + \frac{1}{\gamma}$ as the variance of the private signal and $\rho = \left( \frac{1}{\alpha} + \frac{1}{\beta} \right) q = 1 - \frac{q}{\beta}$ the correlation among the private signals. As a result, $k_1 = \frac{1}{q} q$ and $k_2 = \sqrt{\frac{1-q}{1+\rho}} q$. Notice that improving $\gamma$ and $\beta$ affects $k_1$ and $k_2$ only through affecting $q$ (the fundamental value of information) and $\rho$ (the strategic value of information). We have

$$\phi(k_2 y^*) \frac{\partial k_2}{\partial \beta} - \frac{\partial k_1}{\partial \beta} \tag{71}$$

$$= \left[ \phi(k_2 y^*) \frac{\partial k_2}{\partial \rho} - \frac{\partial k_1}{\partial \rho} \right] \frac{\partial \rho}{\partial \beta} + \left[ \phi(k_2 y^*) \frac{\partial k_2}{\partial q} - \frac{\partial k_1}{\partial q} \right] \frac{\partial q}{\partial \beta}$$

$$= -\phi(k_2 y^*) \frac{\sqrt{\frac{1}{1+\rho}} q^2}{\sqrt{\frac{1}{1+\rho}} \beta^2} \left( \frac{1}{q} - \frac{1}{\beta} \right) + \left( \frac{k_2}{2} \phi(k_2 y^*) - k_1 \right) \frac{q}{\beta^2} < 0,$$

the last inequality is due to $k_1 \geq k_2 \phi(k_2 y^*) > k_2 q \phi(k_2 y^*)$. That is, improving $\beta$ increases both $\rho$ and $q$, leading to a lower $y^*$. As a result, $\frac{\partial y^*}{\partial \beta} < 0$. Similarly,

$$\phi(k_2 y^*) \frac{\partial k_2}{\partial \gamma} - \frac{\partial k_1}{\partial \gamma} \tag{72}$$

$$= \left[ \phi(k_2 y^*) \frac{\partial k_2}{\partial \rho} - \frac{\partial k_1}{\partial \rho} \right] \frac{\partial \rho}{\partial \gamma} + \left[ \phi(k_2 y^*) \frac{\partial k_2}{\partial q} - \frac{\partial k_1}{\partial q} \right] \frac{\partial q}{\partial \gamma}$$

$$= \phi(k_2 y^*) \frac{\sqrt{\frac{1}{1+\rho}} q^2}{\sqrt{\frac{1}{1+\rho}} \gamma^2} \frac{1}{\beta} + \left( \frac{k_2}{2} \phi(k_2 y^*) - k_1 \right) \frac{q}{\gamma^2},$$

where the first term is positive due to $\frac{\partial \rho}{\partial \gamma} < 0$ (improving $\gamma$ reduces the strategic value) and the second term is negative due to $\frac{\partial q}{\partial \gamma} > 0$ (improving $\gamma$ increases the fundamental value). Therefore, the sign of $\frac{\partial y^*}{\partial \gamma}$ is ambiguous and depends on the the trade-off between the strategic and the fundamental value of information. For $\frac{\partial y^*}{\partial \gamma} < 0$, we must have $\phi(k_2 y^*) \frac{\partial k_2}{\partial \gamma} - \frac{\partial k_1}{\partial \gamma} < 0$, which can be reduced into

$$g(\alpha) = \alpha \left( \frac{\sqrt{\frac{1}{1+\rho}} q^2}{\sqrt{\frac{1}{1+\rho}} \beta} + \frac{\sqrt{\frac{1-\rho}{1+\rho} \frac{1}{1+\rho \frac{q^2}{2}}} \phi(k_2 y^*)}{1} \right) < \frac{1}{\phi(k_2 y^*)}. \quad (73)$$
one can verify that the LHS \( g(\alpha) \) is strictly increasing in \( \alpha \). In addition, at \( \alpha = 0 \), the LHS is zero, i.e.,
\[
g(0) < \sqrt{2\pi} < \frac{1}{\phi(k_2 y^*)},
\]
while at \( \alpha = \alpha_H \), we verify that \( g(\alpha_H) > \sqrt{2\pi} \). Therefore, by the intermediate value theorem, there exists an \( \alpha_L \in [0, \alpha_H) \) such that \( g(\alpha_L) = \sqrt{2\pi} \). For \( \alpha < \alpha_L \),
\[
g(\alpha) < g(\alpha_L) = \sqrt{2\pi} < \frac{1}{\phi(k_2 y^*)},
\]
and thus we have \( \frac{\partial y^*}{\partial \gamma} < 0 \). ■

**Proof of Proposition 4**

**Proof.** From the proof of Proposition 3,
\[
\frac{\partial y^*}{\partial \beta} - \frac{\partial y^*}{\partial \gamma} = \frac{y^*}{k_1 - k_2 \phi(k_2 y^*)} \left[ \phi(k_2 y^*) \frac{\partial k_2}{\partial \beta} - \phi(k_2 y^*) \frac{\partial k_2}{\partial \gamma} + \phi(k_2 y^*) \frac{\partial k_1}{\partial \beta} - \phi(k_2 y^*) \frac{\partial k_1}{\partial \gamma} \right] - \phi(k_2 y^*) \frac{\sqrt{\frac{q^2}{\beta^2} \left( \frac{1}{q} - \frac{1}{\beta} \right) + \frac{q^2}{\gamma^2} \left( \frac{1}{q} - \frac{1}{\beta} \right) + \phi(k_2 y^*) \frac{\sqrt{1 - \frac{\rho q}{1 + \rho}} - 1}{\alpha} \left( \frac{q^2}{\beta^2} - \frac{q^2}{\gamma^2} \right)}{k_1 - k_2 \phi(k_2 y^*)},
\]
thus \( \frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma} \) if and only if
\[
-\phi(k_2 y^*) \frac{\sqrt{\frac{q^2}{(1 + \rho)^2} \left( \frac{1}{q} - \frac{1}{\beta} \right) + \frac{q^2}{\gamma^2} \left( \frac{1}{q} - \frac{1}{\beta} \right) + \phi(k_2 y^*) \frac{\sqrt{1 - \frac{\rho q}{1 + \rho}} - 1}{\alpha} \left( \frac{q^2}{\beta^2} - \frac{q^2}{\gamma^2} \right)}{k_1 - k_2 \phi(k_2 y^*)} < 0,
\]
where the first term is always negative. If \( \beta \leq \gamma \), \( \frac{q^2}{\beta^2} - \frac{q^2}{\gamma^2} \geq 0 \), and the second term is also negative. As a result, for \( \beta \leq \gamma \), \( \frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma} \). For \( \beta > \gamma \), \( \frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma} \) if and only if
\[
\frac{\left( \frac{\beta}{\gamma} \right)^2 - 1}{\frac{1}{q} - \frac{1}{\beta} + \left( \frac{\beta}{\gamma} \right)^2} < \frac{\phi(k_2 y^*) \sqrt{\frac{1}{(1 + \rho)^2}}}{\frac{1 - \frac{\rho q}{1 + \rho}}{\alpha} \phi(k_2 y^*) \sqrt{\frac{1}{1 + \rho} - \frac{1}{1 + \rho} q^2} \frac{1}{2}},
\]
where the LHS is strictly increasing in \( \frac{\beta}{\gamma} \). At \( \frac{\beta}{\gamma} = 1 \), the LHS is zero while the RHS is positive. At \( \frac{\beta}{\gamma} = \infty \), the LHS is 1. If RHS is always larger than 1, then for any \( \beta \) and \( \gamma \), we have the LHS smaller than the RHS, i.e., the threshold \( \Delta = \infty \) such that for \( \frac{\beta}{\gamma} < \Delta \), \( \frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma} \). If the RHS can
be smaller than 1, then by monotonicity of \( \frac{(\frac{\beta}{\gamma})^2 - 1}{1 - \frac{1}{\frac{\beta}{\gamma} + (\frac{\beta}{\gamma})^2}} \), for \( \frac{\beta}{\gamma} \) sufficiently close to 1, we have the LHS smaller than the RHS, i.e., there exists a \( \Delta > 1 \), such that for \( \frac{\beta}{\gamma} < \Delta \), \( \frac{\partial y^*}{\partial y} < \frac{\partial y^*}{\partial \gamma} \). ■

**Proof of Proposition 5**

**Proof.** In the proof of Proposition 3, we have shown \( \frac{\partial y^*}{\partial y} < 0 \) and for \( \alpha < \alpha_L \), \( \frac{\partial y^*}{\partial y} < 0 \). It thus remains to show that for \( \alpha_L < \alpha \leq \alpha_H \) and \( \tilde{r} \) sufficiently close to \( \frac{1}{2} \), \( \frac{\partial y^*}{\partial y} > 0 \). Notice first that when \( \tilde{r} \) is sufficiently close to \( \frac{1}{2} \), \( y^* \) approaches 0 and \( \phi(k_2 y^*) \) approaches \( \sqrt{\frac{1}{2\pi}} \). Also as shown in the proof of Proposition 3, for \( \alpha \in (\alpha_L, \alpha_H) \),

\[
g(\alpha) > g(\alpha_L) = \sqrt{2\pi},
\]

therefore, when \( \tilde{r} \) is sufficiently close to \( \frac{1}{2} \), \( \phi(k_2 y^*) \) approaches \( \sqrt{\frac{1}{2\pi}} \), and \( g(\alpha) > \frac{1}{\phi(k_2 y^*)} \) for \( \alpha \in (\alpha_L, \alpha_H) \). Hence we have \( \frac{\partial y^*}{\partial y} > 0 \). ■

**Proof of Corollary 2**

**Proof.** We first derive the equilibrium amount of withdrawals \( l \), which depends on the fundamentals \( \tilde{r} \). Specifically, given \( \tilde{r} \), depositor \( i \)'s signal \( \tilde{y}_i \) is normally distributed with a mean \( \tilde{r} - \bar{r} \) and a variance \( \frac{1}{\gamma} + \frac{1}{\beta} \). Thus given the withdrawal threshold \( y^* \), the portion of the depositors who withdraw is

\[
l(\tilde{r}) = \Pr(\tilde{y}_i \leq y^*) = \Phi \left( \sqrt{\frac{\beta\gamma}{\beta + \gamma} [y^* - (\tilde{r} - \bar{r})]} \right). \tag{80}
\]

Substituting the expression of \( l(\tilde{r}) \) into the conditional social welfare \( W(\tilde{r}) \) gives,

\[
W(\tilde{r}) = \left[ 1 - \Phi \left( \sqrt{\frac{\beta\gamma}{\beta + \gamma} [y^* - (\tilde{r} - \bar{r})]} \right) \right] \left[ \tilde{r} - \Phi \left( \sqrt{\frac{\beta\gamma}{\beta + \gamma} [y^* - (\tilde{r} - \bar{r})]} \right) \right], \tag{81}
\]

and the ex ante social welfare is

\[
W = E_\tilde{r}[W(\tilde{r})]. \tag{82}
\]

Recall that the prior of \( \tilde{r} \) is normally distributed with a mean \( \bar{r} \) and a variance \( \frac{1}{\gamma} \). Changing \( \tilde{r} \) with \( \bar{s} = \sqrt{\alpha}(\tilde{r} - \bar{r}) \) yields,

\[
W = E_{\bar{s}} \left[ 1 - \Phi \left( \sqrt{\frac{\beta\gamma}{\beta + \gamma} \left( y^* - \frac{\bar{s}}{\sqrt{\alpha}} \right)} \right) \right] \left[ \tilde{r} + \frac{\bar{s}}{\sqrt{\alpha}} - \Phi \left( \sqrt{\frac{\beta\gamma}{\beta + \gamma} \left( y^* - \frac{\bar{s}}{\sqrt{\alpha}} \right)} \right) \right], \tag{83}
\]

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where $\tilde{s} \sim N(0,1)$. We now compare the effects of improving the accuracy and objectivity on the social welfare. To level the playing field, we focus on the case $\beta = \gamma$. Taking the derivative of $W$ with respect to the accuracy and objectivity gives:

$$
\frac{\partial W}{\partial \gamma} = T_1 \frac{\partial y^*}{\partial \gamma} + \frac{1}{2} \sqrt{\frac{1}{\gamma}} \left(\frac{\beta}{\beta + \gamma}\right)^{\frac{1}{2}} T_2, \quad (84)
$$

$$
\frac{\partial W}{\partial \beta} = T_1 \frac{\partial y^*}{\partial \beta} + \frac{1}{2} \sqrt{\frac{1}{\beta}} \left(\frac{\gamma}{\beta + \gamma}\right)^{\frac{1}{2}} T_2.
$$

where

$$
T_1 = E_\tilde{s} \left[ \left( 2 \Phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) - 1 - \tilde{r} - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) \right], \quad (85)
$$

$$
T_2 = E_\tilde{s} \left[ \left( 2 \Phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) - 1 - \tilde{r} - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right].
$$

In the symmetric case $\beta = \gamma$, we have

$$
\frac{\partial W}{\partial \beta} - \frac{\partial W}{\partial \gamma} = T_1 \left( \frac{\partial y^*}{\partial \beta} - \frac{\partial y^*}{\partial \gamma} \right), \quad (86)
$$

Proposition 4 shows that $\frac{\partial y^*}{\partial \beta} < \frac{\partial y^*}{\partial \gamma}$. Therefore, $\frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma}$ if and only if $T_1 < 0$. We have

$$
T_1 = E_\tilde{s} \left[ \left( 2 \Phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) - 1 - \tilde{r} - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \phi \left( \sqrt{\frac{\beta \gamma}{\beta + \gamma}} \left( y^* - \frac{\tilde{s}}{\sqrt{\alpha}} \right) \right) \right]. \quad (87)
$$

Let $\tau = \sqrt{\frac{\beta \gamma}{\alpha(\beta + \gamma)}}$ and $Y = \sqrt{\frac{\beta \gamma}{\beta + \gamma}} y^*$, we have

$$
T_1 = \int_{-\infty}^{+\infty} \left[ 2 \Phi (Y - \tau \tilde{s}) - \frac{\tilde{s}}{\sqrt{\alpha}} - \tilde{r} - 1 \right] \phi (Y - \tau \tilde{s}) \phi (\tilde{s}) d\tilde{s} \quad (88)
$$

$$
= \int_{-\infty}^{+\infty} \left[ 2 \Phi (Y - \tau \tilde{s}) - \frac{\tilde{s}}{\sqrt{\alpha}} - \tilde{r} - 1 \right] \frac{1}{2\pi} e^{-\frac{\tau^2 \tilde{s}^2}{2} - \frac{\tau^2 Y^2}{2} - \frac{\tau^2 (\tau^2 + 1)}{2}} d\tilde{s},
$$

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and changing \( s = \frac{t}{\sqrt{\tau^2 + 1}} + \frac{\tau Y}{\tau^2 + 1} \) gives

\[
T_1 = e^{-\frac{Y^2}{2}(\frac{1}{\tau^2 + 1})} \int_{-\infty}^{+\infty} \left[ 2\Phi \left( \frac{Y}{\tau^2 + 1} - \frac{\tau t}{\sqrt{\tau^2 + 1}} - \frac{i}{\sqrt{\tau^2 + 1}} + \frac{\tau Y}{\tau^2 + 1} - \bar{t} - 1 \right) - \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt \right. \\
= e^{-\frac{Y^2}{2}(\frac{1}{\tau^2 + 1})} E_i \left[ 2\Phi \left( \frac{Y}{\tau^2 + 1} - \frac{\tau t}{\sqrt{\tau^2 + 1}} - \frac{i}{\sqrt{\tau^2 + 1}} + \frac{\tau Y}{\tau^2 + 1} - \bar{t} - 1 \right) - \frac{1}{\sqrt{2\pi}} e^{-\frac{t^2}{2}} dt \right. \\
= e^{-\frac{Y^2}{2}(\frac{1}{\tau^2 + 1})} \left[ 2\Phi \left( \frac{Y}{(\tau^2 + 1)(2\tau^2 + 1)} \right) - \frac{\tau Y}{\sqrt{\alpha(\tau^2 + 1)}} - \bar{t} - 1 \right],
\]

which suggests that \( T_1 < 0 \) if and only if

\[
\bar{t} > 2\Phi \left( \frac{Y}{(\tau^2 + 1)(2\tau^2 + 1)} \right) - \frac{\tau Y}{\sqrt{\alpha(\tau^2 + 1)}} - 1.
\]

Given \( \beta = \gamma \), the term \( 2\Phi \left( \frac{Y}{(\tau^2 + 1)(2\tau^2 + 1)} \right) - \frac{\tau Y}{\sqrt{\alpha(\tau^2 + 1)}} - \bar{t} - 1 \) becomes

\[
2\Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(\alpha + \gamma)} y^*} \right) - \frac{\gamma}{\gamma + 2\alpha} y^* - \bar{t} - 1,
\]

In addition, we have

\[
\bar{t} + k_1 y^* = \Phi(k_2 y^*),
\]

where at \( \beta = \gamma \), \( k_1 = \frac{\gamma}{\gamma + 2\alpha} \), and \( k_2 = \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(3\alpha + \gamma)}} \). Thus

\[
2\Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(\alpha + \gamma)} y^*} \right) - \frac{\gamma}{\gamma + 2\alpha} y^* - \bar{t} - 1 \]
\[
= 2\Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(\alpha + \gamma)} y^*} \right) - \Phi(k_2 y^*) - 1,
\]

and \( T_1 < 0 \) if and only if

\[
\Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(\alpha + \gamma)} y^*} \right) - \Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(3\alpha + \gamma)} y^*} \right) < 1 - \Phi \left( \sqrt[1]{\frac{\alpha^2 \gamma}{(2\alpha + \gamma)(\alpha + \gamma)} y^*} \right).
\]

Now consider two special cases. When \( \bar{t} \) is sufficiently close to \( \frac{1}{2} \), \( y^* \) approaches 0. Thus the LHS of the inequality (94) approaches 0, while the RHS approaches \( \frac{1}{2} \). Thus the inequality (94) holds and
$T_1 < 0$. On the other hand, when $\alpha$ is close to 0, $k_1$ approaches 1 and $k_2$ approaches 0, which gives $y^* = \frac{1}{2} - \bar{r} > 0$. Therefore, the LHS of the inequality (94) approaches 0, while the RHS approaches $\frac{1}{2}$. Thus the inequality (94) holds and $T_1 < 0$. ■

Proof of Corollary 3

Proof. This result can be verified by directly computing the derivatives. In particular, at $\beta = \gamma$,

$$\frac{\partial W}{\partial \beta} - 1 = \frac{2\kappa (2 \alpha + \gamma)}{(2 - 3\kappa) \alpha + \gamma (1 - \kappa)} > 0,$$

for $\kappa \neq 0$. In addition, it can be verified that $\frac{\partial W}{\partial \gamma} > 0$. Thus, $\frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma} > 0$. ■

Proof of Corollary 4

Proof. This result can be verified by directly computing the derivatives. In particular, at $\beta = \gamma$,

$$\frac{\partial W}{\partial \beta} - 1 = \frac{2\alpha \kappa^2}{(1 - \kappa) [(2 + \kappa) \alpha + \gamma (1 - \kappa)]} > 0,$$

for $\alpha, \kappa \neq 0$. In addition, it can be verified that $\frac{\partial W}{\partial \gamma} > 0$. Thus, $\frac{\partial W}{\partial \beta} > \frac{\partial W}{\partial \gamma} > 0$. ■

Proof of Corollary 5

Proof. The equilibrium parameters $\{m_0, m_1, m_2\}$ are given as:

$$m_0 = \frac{a_0 - c_1}{2a_2 + a_3 + 2c_2},$$

$$m_1 = \frac{\alpha a_1 [2 (\beta + \gamma) (a_2 + c_2) + \beta a_3]}{(2a_2 + a_3 + 2c_2) [2 (\beta \gamma + \alpha (\beta + \gamma)) a_2 + \beta (\alpha + \gamma) a_3 + 2 (\beta \gamma + \alpha (\beta + \gamma)) c_2]},$$

$$m_2 = \frac{\beta \gamma a_1}{2 (\beta \gamma + \alpha (\beta + \gamma)) a_2 + \beta (\alpha + \gamma) a_3 + 2 (\beta \gamma + \alpha (\beta + \gamma)) c_2}.$$

At $\beta = \gamma$, by directly computing the derivatives, we have,

$$\frac{\partial W}{\partial \beta} - \frac{\partial W}{\partial \gamma} = -\frac{2 (2 \alpha + \gamma) a_1^2 a_3 (a_2 + c_2)}{[2 (2 \alpha + \gamma) a_2 + (\alpha + \gamma) a_3 + 2 (2 \alpha + \gamma) c_2]^3} < 0,$$

for $a_3 > 0$ and $a_1 \neq 0$. ■