

# Bank Opacity and Endogenous Uncertainty\*

Joachim Jungherr\*\*

Institut d'Anàlisi Econòmica (CSIC) and Barcelona GSE

February 2014

PRELIMINARY AND NOT FOR CIRCULATION

## Abstract

Why are banks opaque? Is there a need for policy? What is the optimal level of bank transparency? In this model, banks are special because the product they are selling is superior information about investment opportunities. Intransparent balance sheets turn this public good into a marketable private commodity. Voluntary public disclosure of this information translates into a competitive disadvantage. Bank competition results in a “race to the bottom” which leads to complete bank opacity and a high degree of aggregate uncertainty for households. Households do value public information as it reduces aggregate uncertainty, but the market does not punish intransparent banks. Policy measures can improve upon this market outcome by imposing minimum disclosure requirements on banks. Complete disclosure is socially undesirable as this eliminates all private incentives for banks to acquire costly information. The social planner chooses optimal bank transparency by trading off the benefits of reducing aggregate uncertainty for households against banks’ incentives for costly information acquisition.

**Keywords:** bank opacity, information externality, bank competition, bank regulation.

**JEL classifications:** E44, G14, G21, G28.

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\* I am grateful to Árpád Ábrahám, Ramon Marimon, and Vincenzo Quadrini for useful discussions and suggestions. I appreciate helpful comments from Elena Carletti, Wouter den Haan, Piero Gottardi, Christian Hellwig, Hugo Hopenhayn, Peter Kondor, Omar Licandro, Gyöngyi Lóránth, Guido Lorenzoni, Bartosz Maćkowiak, Albert Marcet, Vincent Maurin, Cyril Monnet, David Pothier, Tano Santos, Joseph Schroth, and seminar participants at the 2013 Barcelona GSE Winter Workshops.

\*\* Institut d'Anàlisi Econòmica (CSIC) and Barcelona GSE - joachim.jungherr@iae.csic.es

# 1. Introduction

When asked about the origins and severity of the 2007-09 Financial Crisis, most observers point towards a high degree of uncertainty about the quality of individual banks' balance sheets.<sup>1</sup> Indeed, there is some empirical evidence that financial firms are particularly opaque.<sup>2</sup> Banks are also subject to special public disclosure requirements which have recently been further strengthened.<sup>3</sup>

At the same time, observers acknowledge that it "is important to protect proprietary business models and incentives to innovate. Public disclosure of a firm's positions also raises concerns about predatory or copycat trading by competitors" (Squam Lake Report, 2010). Implemented disclosure requirements reflect this warning by specifying deliberate time lags and a suitable degree of aggregation. However, some commentators resolutely contest the socially beneficial role of proprietary information.<sup>4</sup>

These observations raise three research questions: (1.) Why are banks opaque? (2.) Is there a need for policy? (3.) What is the optimal level of bank transparency? Existing contributions usually assume some exogenous ad-hoc cost of public disclosure<sup>5</sup> or they find that opacity increases the liquidity of certain assets in an environment of asymmetrically informed traders.<sup>6</sup> While in the policy debate proprietary information is often named as a potential limit of transparency, this point has not yet been formally studied in the economic literature. One reason for this is that existing models of financial opacity do not feature strategic competition among intermediaries.

## Preview of the Model and Results

In this model, financial intermediaries assume a socially valuable role by spending resources in order to learn more about the profitability of a set of investment projects. One interpretation of this assumption is that relationship lenders can monitor borrowers at some cost and thereby acquire information which is not available to outsiders at the beginning of the investment project.

Importantly, information is a public good if intermediaries' balance sheets are transparent since there is a one-to-one mapping between information about investment opportunities and an intermediary's optimal portfolio choice. This is of no concern in a

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<sup>1</sup>The Squam Lake Report (2010) identifies a critical lack of information about the risk exposure of financial firms. Bernanke (2010) agrees with the perception of opaqueness as one of the "structural weaknesses in the shadow banking system."

<sup>2</sup>See for example Morgan (2002), Iannotta (2006), or Flannery, Kwan and Nimalendran (2013).

<sup>3</sup>Pillar 3 of the 2004 Basel II Accords specifies public disclosure requirements for banks including information on asset holdings and risk exposure. In the U.S., the Dodd-Frank Act of 2010 requires the Federal Reserve to publish a summary of the results of its annual supervisory stress test of large bank holding companies. The published stress test results include company-specific measures of risk exposure to selected scenarios.

<sup>4</sup>Chamley, Kotlikoff and Polemarchakis (2012) warn of "the lethal mix of proprietary information and leverage."

<sup>5</sup>See for example Kurlat and Veldkamp (2012), or Alvarez and Barlevy (2013).

<sup>6</sup>This is the case in Pagano and Volpin (2012), Dang, Gorton, Holmström and Ordoñez (2013), and Monnet and Quintin (2013).

setup with a monopolistic intermediary. However, once financial intermediaries compete strategically for households' funds, information spillovers become an issue. This is true even if two intermediaries fund different projects as long as the returns to these two projects are not completely independent. Opaque balance sheets convert information about investment projects from a public good into a marketable private commodity. But this opaqueness comes at a social cost if the information gathered by relationship lenders through monitoring has a value for outsiders as well.

In principle, households value information about investment projects as it helps them to decide on how much resources to hand over to intermediaries. But if households can choose between investing in a fully transparent intermediary and an opaque competitor, then each single household will paradoxically choose the latter. Why is it that the socially harmful behavior of opaque intermediaries gets rewarded by the market? The opaque intermediary can rely on its private information as well as on the information publicly shared by its transparent competitor, while the transparent intermediary only participates in its own information set. Hence, the opaque intermediary knows more about the profitability of investment projects than its transparent competitor and therefore its portfolio choice will be better. In this situation, households face a prisoner's dilemma: if they could coordinate to invest only in transparent intermediaries, each one of them would be better off as in this case there would be no incentive for intermediaries to hide information from the public. But once an intermediary reduces disclosure, it earns a competitive advantage over the transparent rival because of its superior information and it becomes profitable for households to invest in the opaque intermediary. Strategic competition between the two intermediaries results in a "race to the bottom" which leads to complete opacity and a high degree of aggregate uncertainty for households.<sup>7</sup>

Policy measures can improve upon this market outcome by imposing minimum disclosure requirements on banks. Complete disclosure is socially undesirable as this eliminates all incentives for intermediaries to spend resources on the monitoring of investment projects. The social planner optimally chooses an intermediate level of transparency by trading off the benefits of reducing aggregate uncertainty for households (Blackwell effect<sup>8</sup>) against the incentives for costly monitoring (Grossman-Stiglitz effect<sup>9</sup>).

## Related Literature

The main argument used in support of mandatory public disclosure is improved market discipline. Public information about the expected profitability of individual banks helps financial markets to allocate resources efficiently across financial firms. Allegedly, it also prevents bank managers from excessive risk taking and thereby contributes to financial stability. These points seem to be very much in line with plain common sense and

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<sup>7</sup>Because of information spillovers and strategic competition, the familiar unravelling argument by Grossman and Hart (1980) does not apply here.

<sup>8</sup>Blackwell (1951) shows that for a single decision maker more information about fundamentals is always desirable.

<sup>9</sup>Grossman and Stiglitz (1976, 1980) demonstrate that full transparency eliminates all incentives for costly information acquisition.

this might be the reason why economic research has tended to focus on the potential costs of financial transparency rather than on its social benefits.<sup>10</sup> There are only a few examples of formal models which explain why market forces on their own are not capable of creating a sufficient level of bank transparency.

These models are generally of recent vintage. Chen and Hasan (2006) show that bank managers may want to delay disclosure in order to avoid efficient bank runs. Mandatory disclosure rules can restore market discipline in this case. An important assumption here is that bank managers cannot commit to a pre-selected timing of disclosure. This would remove the need for policy intervention.

The experience of the Financial Crisis 2007-2008 is reflected in an increased interest in the topic. In Bouvard, Chaigneau, and de Motta (2012), depositors know the health of the average bank in the economy but only a regulator knows the asset quality of each individual bank. During normal times, informational opacity prevents inefficient bank runs. However, if investors observe that the financial sector is hit by a crisis, public information about individual banks is desirable in order to prevent a run on the whole financial system. Only the regulator can provide this information, as banks' announcements are not verifiable. A similar result is found by Spargoli (2012). During normal times, there is no policy need as banks with high quality assets can separate themselves from low quality banks. However, during a financial crisis separation becomes too costly and financial markets are unable to discriminate between banks of different quality.

Also Alvarez and Barlevy (2012) study an endogenous lack of information about the location and size of bank losses. Banks form a financial network in this model which exposes them to the credit risk of their counterparties. This gives rise to an information externality as information about the financial health of one bank is also valuable with respect to the risk exposure of its counterparties. Crucial for the authors' results is an exogenous fixed cost of public disclosure.

The contributions cited above do not model banks' portfolio choice and there is no feedback effect from public disclosure to a bank's market share and the quality of its assets. In contrast, this paper introduces the problem of costly information acquisition to the analysis which endogenizes the costs of public disclosure.

As mentioned above, the social costs of bank transparency have been studied at least as extensively as the potential benefits. For instance, Moreno and Takalo (2012) find that negative spillovers of bank failures result in an oversupply of voluntary disclosure. If anything, policy should induce banks to disclose less information to the public than they would like to. Also Dang, Gorton, Holmström and Ordoñez (2013) warn of the perils of bank transparency. In their model, it is precisely the role of banks to collect socially valuable information about asset quality without disclosing it to the public. The negative role of public information in this model is related to Hirshleifer (1971).<sup>11</sup> Consumers are exposed to liquidity shocks. This makes them unwilling to invest in risky

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<sup>10</sup>This is true also for two recent review articles on the trade-offs involved in financial transparency. See Landier and Thesmar (2011) and Goldstein and Sapra (2012).

<sup>11</sup>Hirshleifer (1971) shows that disclosure is socially harmful whenever its primary effect is to redistribute wealth among agents.

projects if information about project losses become public. A bank which can hide these project losses from the public is able to shut down the Hirshleifer effect and to channel households' savings to investment projects. Banks allow households to share both the risks of production and of stochastic liquidity needs. More opacity is better in this environment.

Pagano and Volpin (2012) address the phenomenon of intransparent securities traded on secondary markets rather than intransparent bank balance sheets. Also here banks can increase liquidity through opacity. But in contrast to the findings of Dang, Gorton, Holmström and Ordoñez (2013), imposing mandatory disclosure rules can be welfare increasing in Pagano and Volpin (2012). The authors study the problem of a bank which offers asset-backed securities of heterogeneous quality. The quality of these securities is unknown to the bank. The fact that sophisticated investors can learn the quality of these securities renders them unattractive for unsophisticated potential buyers. The bank can increase the liquidity of its securities in this case by rendering them intransparent and hard to assess even for sophisticated investors. But this might create a problem of adverse selection on a secondary market triggering social costs which the issuing bank does not fully internalize.

In Kurlat and Veldkamp (2012), a risky asset in fixed supply is sold on a market consisting of rational investors and noise traders. The price-insensitive noise traders systematically lose money as they move the asset return against themselves. The sensitivity of the asset return to noise demand is increasing in uncertainty. This is because uncertainty about asset quality increases the price of arbitrage performed by rational investors. The option of rational investors to respond with their demand to the actions of noise traders introduces a convexity to their objective function which makes them effectively risk-loving. Public disclosure reduces uncertainty and therefore also the opportunity of investors to benefit from noise traders' erratic actions. This result is overcome in case of an equilibrium with asymmetric information among rational investors. Noise traders always benefit from public disclosure.

The setup used by Kurlat and Veldkamp (2012) relates to earlier contributions by Admati and Pfleiderer (1988, 1990). These authors consider the problem of a single agent with an exogenous endowment of socially valuable information. They show that under certain conditions the information monopolist may find it profitable to act as a financial intermediary for uninformed investors. Admati and Pfleiderer (1988, 1990) and Kurlat and Veldkamp (2012) differ from our model in the assumption that assets are not in perfectly elastic supply and therefore asset prices partially reveal information. Furthermore, these contributions do not consider the endogenous production of information nor the role of competition in determining its supply to the public.

This paper is also related to the more general role of public information in shaping market outcomes. Morris and Shin (2002) study the social value of public information in an environment prone to coordination failures. Whenever public information is sufficiently imprecise, this impedes social coordination and can be welfare decreasing. In the model studied below, coordination failures play no role for the analysis of bank transparency. Vives (2012) examines a general setting in which agent's actions are partly reflected by a public signal. He finds that the precision of public information always

improves the market allocation.

While the formal analysis of public disclosure is a fairly recent phenomenon in the banking context, it can build on an extensive tradition in the literature on corporate finance and accounting. This literature has generally acknowledged that even in the absence of policy intervention, there are good reasons to expect a considerable degree of voluntary disclosure by firms which compete for funds on capital markets (see for instance Grossman and Hart, 1981). Diamond (1985) shows that public disclosure is preferred by shareholders because it prevents investors from wasting resources on private information acquisition.

We have seen above that existing models of bank transparency abstract from the costs of releasing proprietary information. This is at odds with the central role which is generally attributed to confidential information in banking services. In the context of non-financial firms, proprietary information has been considered by the accounting literature from very early on. Verrecchia (1983) studies the trade-off between transparency and an exogenous fixed proprietary cost of information disclosure. A similar trade-off is examined by Dye (1986). Darrough and Stoughton (1990) endogenize the private costs of proprietary disclosure in an entry game. However, these models do not allow for a formal welfare analysis of eventual policy interventions.

Information externalities as a justification of mandatory disclosure rules are considered in an early contribution by Foster (1980). In a formal model, Dye (1990) demonstrates that in the presence of externalities (e.g. due to proprietary information) mandatory and voluntary disclosure tend to diverge. Likewise, Admati and Pfleiderer (2000) study information externalities. Since there are private costs to increasing the precision of public signals, the supply of public information is inefficiently low in their model. These models are tailored primarily to non-financial firms and do not capture the peculiarities of the financial sector which are examined below.

## Outline

The rest of the paper is organized as follows. The model is set up in section 2. Section 3 characterizes the equilibrium allocation on the market for financial intermediation in the absence of mandatory disclosure rules. Optimal bank transparency is studied in section 4. Section 5 concludes the paper with a short discussion of potential enhancements of the model.

## 2. Model Setup

Consider a simple model economy inhabited by many small and identical households of unit mass. Households aim at smoothing consumption over time by investing in two different banks. These two banks have access to risky investment opportunities.

## 2.1. Households

In period  $t$ , the representative household owns a certain amount  $w_t$  of the the numéraire good. She decides how to allocate consumption over time. Her preferences regarding any consumption path  $\{c_{t+i}\}_{i=0}^{\infty}$  may be described by the function:

$$\mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}) \mid \mathbb{Q}_t^H \right\}, \quad (1)$$

where  $\mathbb{E}$  is the expectation operator conditional on the date  $t$  information of the representative household  $\mathbb{Q}_t^H$ , and  $\beta \in [0, 1]$  gives the rate of time preference. The function  $u : [0, \infty] \rightarrow \mathbb{R}$  is increasing, strictly concave and satisfies the Inada conditions. In addition, we assume non-increasing absolute risk aversion. This implies:  $u'''(c) > 0$ .

Households have no direct access to investment projects. They can invest in the two banks which are active in this model economy. Accordingly, the household's budget constraint is given by:

$$c_t + b_{t+1}^A + b_{t+1}^B \leq b_t^A r_t^A + b_t^B r_t^B + T_t^A + T_t^B \equiv w_t, \quad (2)$$

where  $b_t^A$  and  $b_t^B$  indicate the amount of securities bought from bank  $A$  and bank  $B$ , respectively. The associated gross returns are indicated by  $r_t^A$  and  $r_t^B$ . The households are the joint owners of the two banks. Accordingly, eventual bank profits  $T_t^A$  and  $T_t^B$  are uniformly distributed among households.

## 2.2. Banks

In contrast to households, banks have access to risky investment projects in addition to common storage. These projects are completely homogeneous and in perfectly elastic supply. The return to risky investment projects is perfectly correlated across projects. Return risk is therefore systematic and not insurable.<sup>12</sup> Banks spend resources in order to learn about the future performance of these risky projects. They maximize the expected utility of their owners as given by (1) subject to the budget constraint:

$$T_{t+1}^j = (b_{t+1}^j - k_{t+1}^j) + k_{t+1}^j R_{t+1} - b_{t+1}^j r_{t+1}^j - g_{t+1}^j, \quad \text{for } j = A, B. \quad (3)$$

Bank  $j$  manages an amount  $b_{t+1}^j$  of the numéraire good lent to it by households. The amount of funds invested in risky projects by bank  $j$  is indicated by  $k_{t+1}^j$ . These funds yield an uncertain return of  $R_{t+1}$ . The remainder  $(b_{t+1}^j - k_{t+1}^j)$  is put into riskless storage. Resources spent on learning about  $R_{t+1}$  are given by  $g_{t+1}^j$ .

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<sup>12</sup>Alternatively, one could think of a single risky project with a linear return.

### 2.3. Projects and Information

The gross return on risky projects is persistent over time:

$$R_{t+1} = \zeta_0 + \zeta_1 R_t + \varepsilon_{t+1},$$

where  $\zeta_0 > 0$ ,  $0 < \zeta_1 < 1$ , and  $\varepsilon_{t+1} \sim \mathcal{N}(0, \sigma^2)$ . All agents in the economy, households and bankers, publicly observe  $R_t$  after it is realized. In addition to  $R_t$ , each bank observes at time  $t$  also a second signal  $\hat{R}_{t+1}^j$  which likewise contains information about  $R_{t+1}$ :

$$\hat{R}_{t+1}^j \sim \mathcal{N}(R_{t+1}, \Sigma_{t+1}^j), \quad \text{for } j = A, B.$$

The precision of this additional signal can be improved at a cost:

$$\Sigma_{t+1}^j = \frac{1}{f(g_{t+1}^j)}, \quad \text{for } j = A, B,$$

where  $f(g)$  is increasing, strictly concave and satisfies the Inada conditions. That is,  $f(0) = 0$  and zero expenditures on signal precision result in a bank signal which does not contain any information about  $R_{t+1}$ . If a bank acquires a lot of information, this informational advantage might result in a certain degree of market power. In order to protect it, a bank may choose to hide its current portfolio choice from its competitor. We assume that a bank is able to costlessly hide its current investment policy from outsiders. This is important, because a bank's portfolio choice could reveal its private information about future project returns.

Informational opacity of bank balance sheets may protect a bank's market power but it also creates additional uncertainty for households. If banks wish to reveal some part of their superior information, they can use a costless signal which is transmitted to the public:

$$Q_{t+1}^j \sim \mathcal{N}(\hat{R}_{t+1}^j, \hat{\Sigma}_{t+1}^j), \quad \text{for } j = A, B.$$

In this manner, banks are free to give away any part of their informational advantage to the public. A perfect correlation between  $Q_{t+1}^j$  and  $\hat{R}_{t+1}^j$  ( $\hat{\Sigma}_{t+1}^j = 0$ ) corresponds to complete transparency and consequently also zero uncertainty for outsiders about bank  $j$ 's current portfolio choice. On the other hand, zero correlation ( $\hat{\Sigma}_{t+1}^j = \infty$ ) is equivalent to complete opacity of bank  $j$ 's balance sheet and a maximum level of information asymmetry.

### 2.4. Timing

The timing is as follows. Bank  $A$  and bank  $B$  enter period  $t$  with a predetermined portfolio of riskless storage and risky investment projects. At the beginning of period  $t$ , the gross return  $R_t$  is realized and publicly observed by all agents in the economy. Households who invested in bank  $j$  last period receive a cash flow of  $b_t^j r_t^j$  in return. Eventual bank profits are distributed among households. Banks choose how much resources  $g_{t+1}^j$  to spend on information acquisition and they choose how much of this information to



share with others. Private and public signals of the future return are realized. Households divide their wealth between consumption and bank investment. The two banks  $A$  and  $B$  choose a portfolio of investment projects and storage.

### 3. Equilibrium

**Definition** Given some initial wealth level of households  $w_t$ , a competitive equilibrium in this economy consists of values for  $\hat{\Sigma}_{t+i+1}^A$  and  $\hat{\Sigma}_{t+i+1}^B$ , of prices  $r_{t+i+1}^A$  and  $r_{t+i+1}^B$ , and quantities  $c_{t+i}$ ,  $b_{t+i+1}^j$ ,  $k_{t+i+1}^j$ ,  $g_{t+i+1}^j$ ,  $T_{t+i+1}^j$ , for  $j = A, B$  and  $i = 0, 1, 2, \dots$ , such that for all histories: (1.) households solve their individual optimization problem, (2.) bank  $A$  and bank  $B$  maximize the expected utility of households subject to price competition in the market for financial intermediation, and (3.) the market for financial intermediation clears.

Households observe the performance of the bank's chosen portfolio of intermediated funds:

$$\Pi_{t+1}^j = \frac{(b_{t+1}^j - k_{t+1}^j) + k_{t+1}^j R_{t+1}}{b_{t+1}^j}, \quad \text{for } j = A, B.$$

Hence, the return on bank securities  $r_{t+1}^j$  can condition on this information. In principle, the remuneration of banks for providing financial services could take on many forms. In the following, we consider contracts of financial intermediation of the following class:

**Assumption** Households' return on bank funding is given by  $r_{t+1}^j = \Pi_{t+1}^j - \delta_{t+1}^j$ , where  $\delta_{t+1}^j$  is a non-negative scalar which is known at time  $t$  with certainty.

This assumption is without loss of generality. Since households are both the holders of bank securities as well as the owners of the two banks, no insurance contract between households and banks can be profitable. Ultimately, households bear all the risk associated with  $R_{t+1}$ , no matter how it is divided between banks and households. It follows that a non-stochastic price of banking services  $\delta_{t+1}^j$  is optimal.

The model economy described above may be understood as a team decision problem as defined by Marschak (1955) and Radner (1962). Households and banks pursue a common objective function by maximizing expected lifetime utility of households. To this end, households choose a consumption and savings policy, while banks invest in information acquisition, decide on how much of this information to share with other agents, set a price of financial intermediation, and select an investment portfolio on the basis of the information available to them. In principle, it would be desirable in this environment of costless communication that every agent knows all information available in the model economy at any given point in time. In the following, we will see that bank competition in combination with the public good character of information puts severe restrictions on the information allocations which are compatible with a competitive equilibrium.

### 3.1. Households

In period  $t$ , the representative household divides her wealth  $w_t$  between consumption and risky bank securities:

$$\begin{aligned} & \max_{c_t, b_{t+1}^A, b_{t+1}^B \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}) \mid Q_{t+1}^A, Q_{t+1}^B, R_t \right\} \\ & \text{subject to: } c_{t+i} + b_{t+i+1}^A + b_{t+i+1}^B \leq b_{t+i}^A r_{t+i}^A + b_{t+i}^B r_{t+i}^B + T_{t+i}^A + T_{t+i}^B \equiv w_{t+i}. \end{aligned}$$

The information  $\mathbb{Q}_t^H = \{Q_{t+1}^A, Q_{t+1}^B, R_t\}$  on which her decision at time  $t$  is based depends on the quality of information collected by banks as well as on the precision of  $Q_{t+1}^A$  and  $Q_{t+1}^B$ , i.e. bank transparency. More precise information reduces the exposure of households' consumption plans to aggregate uncertainty. The intertemporal Euler equation is given by:

$$u'(c_t) = \beta \mathbb{E} \left\{ u'(c_{t+1}) r_{t+1}^j \mid Q_{t+1}^A, Q_{t+1}^B, R_t \right\}, \quad \text{for } j = A, B.$$

Households demand bank securities with high and safe returns.

### 3.2. Banks: Exogenous Transparency

Consider first bank behavior for the special case that exogenously  $\hat{\Sigma}_{t+1}^A = \hat{\Sigma}_{t+1}^B = 0$ . There is no asymmetry of information in this economy, as  $Q_{t+1}^A$  and  $Q_{t+1}^B$  are perfect signals of  $\hat{R}_{t+1}^A$  and  $\hat{R}_{t+1}^B$ . Consequently, all agents share identical expectations about the distribution of future project returns. Bayesian inference yields as the updated probability distribution of future project returns:

$$R_{t+1} \sim \mathcal{N} \left( \mathbb{E} \{ R_{t+1} \mid \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \}, \frac{\sigma^2 \Sigma_{t+1}^A \Sigma_{t+1}^B}{\sigma^2 \Sigma_{t+1}^A + \sigma^2 \Sigma_{t+1}^B + \Sigma_{t+1}^A \Sigma_{t+1}^B} \right).$$

The optimal portfolio choice by banks is perfectly inferable for everyone. In this sense, banks' balance sheets are completely transparent.

The two bankers play a Bertrand game. Their intermediation services are perfect substitutes, as both banks have access to the same information set. Hence, also their portfolio choice and the distribution of future bank returns are identical. If the two banks charge the same price  $\delta_{t+1}^A = \delta_{t+1}^B$ , we assume that the households' demand is split evenly between them. The resulting equilibrium allocation shows a number of characteristics which are familiar from the literature on Bertrand competition games.

**Lemma 3.1.** *In equilibrium, both banks make exactly zero profits:  $T_{t+1}^j = 0$ , which implies:  $b_{t+1}^j \delta_{t+1}^j = g_{t+1}^j$ , for  $j = A, B$ . They both choose a portfolio of intermediated funds which maximizes the expected utility of households subject to the available information.*

*Proof.* The proof works by contradiction. Consider first equilibrium bank profits.

1. *Banks make exactly zero profits:* Assume that bank  $A$  makes positive profits. In this case, bank  $B$  can capture the whole demand for financial intermediation by choosing the same portfolio as bank  $A$  and charging  $\delta_{t+1}^B = \delta_{t+1}^A - \eta$  (with  $\eta > 0$ ). If  $\eta$  is sufficiently small, this increases bank  $B$ 's profit. This excludes the possibility that banks make positive profits in equilibrium.
2. *Banks choose a portfolio which maximizes the expected utility of households:* Assume that bank  $A$  chooses a portfolio which does not maximize the expected utility of households, taking as given banks' expenditures  $g_{t+1}^A$  and  $g_{t+1}^B$ . In this case, bank  $B$  can choose a portfolio which caters more to the needs of households. Note that there is an  $\eta > 0$ , such that bank  $B$  charges a spread  $\delta_{t+1}^B = \delta_{t+1}^A + \eta$  and still captures the complete demand for financial intermediation. Bank  $B$  makes positive profits in this case. This excludes the possibility that banks choose a portfolio which does not maximize the expected utility of households.

□

What does this imply for banks' investment policy? Bank  $j$  chooses its portfolio of investment projects according to:

$$\max_{k_{t+1}^j \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}) \middle| \mathbb{Q}_t \right\}$$

$$\text{subject to: } c_{t+1} + b_{t+2}^A + b_{t+2}^B \leq b_{t+1}^A (\Pi_{t+1}^A - \delta_{t+1}^A) + b_{t+1}^B (\Pi_{t+1}^B - \delta_{t+1}^B),$$

$$b_{t+1}^j (\Pi_{t+1}^j - \delta_{t+1}^j) = (b_{t+1}^j - k_{t+1}^j) + k_{t+1}^j R_{t+1} - g_{t+1}^j, \quad \text{for } j = A, B,$$

$$\mathbb{Q}_t = \{ \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \}, \quad \text{and}$$

$$\hat{R}_{t+1}^j \sim \mathcal{N}(R_{t+1}, \Sigma_{t+1}^j), \quad \text{with: } \Sigma_{t+1}^j = \frac{1}{f(g_{t+1}^j)}, \quad \text{for } j = A, B.$$

The chosen portfolio is characterized by the following first order condition:

$$\mathbb{E} \left\{ \frac{\partial u(c_{t+1})}{\partial c_{t+1}} (R_{t+1} - 1) \middle| \mathbb{Q}_t \right\} = 0. \quad (4)$$

Some part of the risk associated with investment projects is endogenous, as banks can spend resources to reduce uncertainty. Proposition 3.2 describes the market allocation of information expenditures.

**Proposition 3.2.** *In equilibrium, uncertainty about future project returns is maximum:  $g_{t+1}^A = g_{t+1}^B = 0$ . This implies:  $\Sigma_{t+1}^A = \Sigma_{t+1}^B = \infty$ .*

*Proof.* Assume that bank  $A$  spends  $g_{t+1}^A > 0$  on reducing public uncertainty about future project returns. In this case, also bank  $B$  must spend  $g_{t+1}^B = g_{t+1}^A$  on information

acquisition in equilibrium. Otherwise, one bank could charge a lower spread than the other bank and make positive profits.

Consider now an equilibrium with  $g_{t+1}^A = g_{t+1}^B > 0$ . In this case, bank  $A$  can reduce  $g_{t+1}^A$  somewhat and charge  $\delta_{t+1}^A = \delta_{t+1}^B - \eta$  (for  $\eta > 0$ ). Uncertainty is higher now and total demand for bank securities lower. But bank  $B$ 's forecast is hurt by this in the same way as bank  $A$ 's prediction of future returns. Hence, bank  $A$  captures the whole demand for bank securities. If  $\eta$  is sufficiently small, this increases bank  $A$ 's profit. This excludes the possibility that  $g_{t+1}^A > 0$  or  $g_{t+1}^B > 0$  in equilibrium.  $\square$

The public signals  $\hat{R}_{t+1}^A$  and  $\hat{R}_{t+1}^B$  provided by banks contain no information at all:  $\mathbb{E}\{R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\} = \mathbb{E}\{R_{t+1} | R_t\}$ . Precision of the public signal  $\hat{R}_{t+1}^j$  is a public good. If bank  $A$  spends resources on improving its signal, this increases the information set for bank  $A$  in the same way as for bank  $B$  (as well as for all the households). Bertrand competition between the two banks does not permit bank  $A$  to incur these extra costs, which reduce the return on its securities but which do not translate into a competitive advantage with respect to bank  $B$ . Atomistic bank investors do not internalize that their investment behavior influences the quality of public information in this economy.

A social planner would choose the precision of the public signals  $\hat{R}_{t+1}^A$  and  $\hat{R}_{t+1}^B$  by solving the following optimization program:

$$\max_{g_{t+1}^A, g_{t+1}^B \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \mid R_t \right\}$$

$$\text{subject to: } c_{t+i}^* = (b_{t+i}^* - k_{t+i}^*) + k_{t+i}^* R_{t+i} - b_{t+i+1}^* - g_{t+i}^A - g_{t+i}^B,$$

$$b_{t+i+1}^* = b(\hat{R}_{t+i+1}^A, \hat{R}_{t+i+1}^B, R_{t+i}), \quad k_{t+i+1}^* = k(\hat{R}_{t+i+1}^A, \hat{R}_{t+i+1}^B, R_{t+i}),$$

$$\text{and } \hat{R}_{t+i+1}^j \sim \mathcal{N}(R_{t+i+1}, \Sigma_{t+i+1}^j), \quad \text{with: } \Sigma_{t+i+1}^j = \frac{1}{f(g_{t+i+1}^j)}, \quad \text{for } j = A, B.$$

At that point in time when the planner chooses  $g_{t+1}^A$  and  $g_{t+1}^B$ , she anticipates the benefits of observing more reliable signals  $\hat{R}_{t+1}^A$  and  $\hat{R}_{t+1}^B$ . The amount of savings  $b_{t+1}^*$  and the investment policy  $k_{t+1}^*$  can both be set more precisely when information is better. Proposition 3.3 describes the solution to this problem.

**Proposition 3.3.** *The first best level of information expenditures is positive:*

$$0 < g_{t+1}^{A*} = g_{t+1}^{B*} < \infty.$$

A proof of this proposition can be found in Appendix A. But the result is quite intuitive. The first marginal unit of resources spent on information acquisition has a very high marginal impact on the precision of the respective signal. This reduction in aggregate uncertainty is valuable as it allows for a more precise savings decision by the planner. Only an interior choice can be optimal as the marginal impact of an additional

increase in information expenditures is falling towards zero. The concavity of  $f(g)$  implies that the planner will optimally invest equal amounts in the precision of both signals.

A high degree of risk aversion increases the marginal benefit of an additional unit of the numéraire good spent on information acquisition. Likewise, high uncertainty, e.g. because of a high value of  $\sigma^2$ , and the efficiency of learning, as measured by the steepness of  $f(g)$ , contribute to a high optimal level of information expenditures.

We have seen how the planner chooses the optimal level of signal precision. The market allocation under full transparency of bank balance sheets falls short of this first best level of public information. Expectations about the future are perfectly homogeneous across all agents in the model economy, but these expectations are based on a minimum amount of information.

### 3.3. Banks: Endogenous Transparency

So far we have assumed that banks' balance sheets are completely transparent and everybody can infer banks' expectations about future returns. Now, we consider the more general case which allows banks to choose the precision of their public signals  $Q_{t+1}^A$  and  $Q_{t+1}^B$  themselves. Proposition 3.4 states that banks will always choose a maximum level of informational opacity if they are free to do so.

**Proposition 3.4.** *In equilibrium, households' uncertainty about future project returns is maximum:  $\hat{\Sigma}_{t+1}^A = \hat{\Sigma}_{t+1}^B = \infty$ .*

*Proof.* Assume that bank  $A$  and bank  $B$  spend any amount  $g_{t+1}^A$  and  $g_{t+1}^B$  on improving the precision of the signals  $\hat{R}_{t+1}^A$  and  $\hat{R}_{t+1}^B$ . By reducing the precision of  $Q_{t+1}^A$ , bank  $A$  can costlessly reduce the precision of bank  $B$ 's forecast  $\mathbb{E}\{R_{t+1} - 1 | Q_t^B\}$ . Bank  $A$ 's forecast remains unaffected by the precision of  $Q_{t+1}^A$ . Since households observe the precision of the banks' signals  $Q_{t+1}^A$  and  $Q_{t+1}^B$  and information expenditures  $g_{t+1}^A$  and  $g_{t+1}^B$ , they know the forecast accuracy of banks. Ceteris paribus, households buy securities of the bank with more information about future project returns. This gives bank  $A$  a strong incentive to marginally decrease the precision of its signal  $Q_{t+1}^A$ . Bank  $B$  in turn can regain competitiveness by reducing the precision of  $Q_{t+1}^B$ . The only equilibrium allocation is given by  $Q_{t+1}^A = Q_{t+1}^B = \infty$ .  $\square$

Transparency implies that bank  $j$ 's signal  $\hat{R}_{t+1}^j$  is public information. By keeping an opaque balance sheet, the information of bank  $j$ 's private signal becomes private. This does not change bank  $j$ 's information set, but it creates more uncertainty for the competitor bank. Households like transparency, but the market does not punish a bank for being opaque if this bank has more information about future returns than the competitor bank. As information is private now, does this provide incentives for banks to invest in information about future returns? On the one hand, bank  $A$  securities lose in value as information expenditures are costs which depress the return. On the other

hand, bank  $A$ 's portfolio choice  $k(\hat{R}_{t+1}^A, R_t)$  benefits from the higher precision of  $\hat{R}_{t+1}^A$ :

$$b_{t+1}^A r_{t+1}^A = b_{t+1}^A [\Pi_{t+1}^A - \delta_{t+1}^A] = b_{t+1}^A + k(\hat{R}_{t+1}^A, R_t) [R_{t+1} - 1] - g_{t+1}^A.$$

Under Bertrand competition, bank  $A$ 's market share is extremely sensitive to the attractiveness of its intermediation services in comparison with the rival bank. Therefore, bank  $A$  invests in information acquisition in order to increase households' valuation of bank  $A$  securities relative to bank  $B$  securities:

$$\max_{g_{t+1}^A \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| R_t \right\} - \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^B) \middle| R_t \right\}$$

$$\text{subject to: } c_{t+i}^j = b(R_{t+i-1}) + k(\hat{R}_{t+i}^j, R_{t+i-1}) [R_{t+i} - 1] - b(R_{t+i}) - g_{t+i}^j,$$

$$\text{and } \hat{R}_{t+1}^j \sim \mathcal{N}(R_{t+1}, \Sigma_{t+1}^j), \quad \text{with: } \Sigma_{t+1}^j = \frac{1}{f(g_{t+1}^j)}, \text{ for } j = A, B.$$

**Proposition 3.5.** *Under full opacity, banks' investment in information about future returns is higher than the first best allocation under full transparency:*

$$0 < g_{t+1}^{A*} = g_{t+1}^{B*} < g_{t+1}^{A**} = g_{t+1}^{B**} < \infty.$$

The formal proof of Proposition 3.5 is deferred to the appendix. Bank opacity provides an environment in which it is profitable for banks to invest in the precision of their private signals. They even spend more resources on information acquisition than a planner would choose to in a world of complete transparency. Under transparency, one unit of the numéraire good spent on informational precision improves the portfolio choice of both banks as well as households' savings decision. In the opacity case, each bank observes only its own signal and households do not learn anything about  $R_{t+1}$  in addition to the observation of  $R_t$ . Therefore, a given level of information expenditures results in a much higher level of uncertainty under opacity than in the case of complete transparency. As the marginal value of information expenditures is increasing in uncertainty, this leads to the result of overproduction of information in combination with an undersupply of communication.

## 4. Optimal Opacity

From the previous analysis, it has become clear that there is a trade-off between information production and information transmission. Maximum transmission induces minimum production and vice versa. The problem of bank regulation is to find an intermediate level of bank opacity which sacrifices some degree of information production by banks in favor of a reduced level of uncertainty for households. Consider bank  $A$ 's

optimal choice of  $g_{t+1}^A$  for some intermediate level of opacity  $\hat{\Sigma}_{t+1}$ :

$$\max_{g_{t+1}^A \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| R_t \right\} - \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^B) \middle| R_t \right\}$$

$$\text{subject to: } c_{t+i}^j = b(Q_{t+i-1}^H) + k(Q_{t+i-1}^j) [R_{t+i} - 1] - b(Q_{t+i}^H) - g_{t+i}^j,$$

$$Q_{t+i}^H = \{Q_{t+i+1}^A, Q_{t+i+1}^B, R_{t+i}\}, \quad Q_{t+i}^A = \{\hat{R}_{t+i+1}^A, Q_{t+i+1}^B, R_{t+i}\},$$

$$Q_{t+i}^B = \{Q_{t+i+1}^A, \hat{R}_{t+i+1}^B, R_{t+i}\}, \quad Q_{t+1}^j \sim \mathcal{N}(\hat{R}_{t+1}^j, \hat{\Sigma}_{t+1}),$$

$$\text{and } \hat{R}_{t+1}^j \sim \mathcal{N}(R_{t+1}, \Sigma_{t+1}^j), \quad \text{with: } \Sigma_{t+1}^j = \frac{1}{f(g_{t+1}^j)}, \text{ for } j = A, B.$$

Each bank optimally invests more in information as the informational spillovers to its rival get reduced through increased opacity.

**Lemma 4.1.** *Banks' investment in information about future returns is strictly increasing in  $\hat{\Sigma}_{t+1}$ . Information expenditures become less sensitive as opacity tends towards infinity:*

$$\lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} g'(\hat{\Sigma}_{t+1}) = 0.$$

A proof of this lemma can be found in Appendix A. Under complete transparency (i.e.  $\hat{\Sigma}_{t+1} = 0$ ), investments in information benefit the rival bank just as much as the bank which actually pays for the improvements in public information. This public good character of information renders its costly acquisition unprofitable. As  $\hat{\Sigma}_{t+1}$  is growing, the rival bank participates less and less in improvements to bank  $A$ 's information set. The optimal choice of information expenditures increases in value until it converges to the solution to the bank's problem under complete opacity as derived above. For high values of opacity, the signal-to-noise ratio of banks' public signals becomes less and less responsive to additional changes in opacity. This is reflected by the vanishing sensitivity of  $g(\hat{\Sigma}_{t+1})$ .

Bank competition in combination with the public good character of information puts severe restrictions on the feasible allocations in this economy. The problem of the social planner is now to set an optimal level of bank transparency. By changing the information structure, the planner can indirectly influence the equilibrium outcome. The optimal choice trades off two effects: more transparency (1.) reduces the information asymmetry between households and banks, but it also (2.) results in less production of socially

valuable information by banks.

$$\begin{aligned} & \max_{\hat{\Sigma}_{t+1} \in \mathbb{R}_{\geq 0}} \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \mid \mathbb{Q}_t^H \right\} \\ \text{subject to: } & c_{t+i}^A = b(\mathbb{Q}_{t+i-1}^H) + k(\mathbb{Q}_{t+i-1}^A) [R_{t+i} - 1] - b(\mathbb{Q}_{t+i}^H) - g(\hat{\Sigma}_{t+1}), \\ & \mathbb{Q}_{t+i}^H = \{Q_{t+i+1}^A, Q_{t+i+1}^B, R_{t+i}\}, \quad \mathbb{Q}_{t+i}^A = \{\hat{R}_{t+i+1}^A, Q_{t+i+1}^B, R_{t+i}\}, \\ & Q_{t+1}^j \sim \mathcal{N}(\hat{R}_{t+1}^j, \hat{\Sigma}_{t+1}) \quad , \text{ and} \\ & \hat{R}_{t+1}^j \sim \mathcal{N}(R_{t+1}, \Sigma_{t+1}^j), \quad \text{with: } \Sigma_{t+1}^j = \frac{1}{f(g(\hat{\Sigma}_{t+1}))}, \text{ for } j = A, B. \end{aligned}$$

Recall that households regard both banks as equally well informed in equilibrium. Therefore, the two types of bank securities are perfect substitutes. Without loss of generality, here we will consider the impact of changes in opacity on the expected value of bank  $A$  securities. The same reasoning holds for the case of bank  $B$  securities. Proposition 4.2 states that the optimal degree of bank transparency has no corner solution. It must therefore differ from the market allocation.

**Proposition 4.2.** *The socially optimal choice of bank opacity is  $0 < \hat{\Sigma}_{t+1}^* < \infty$ .*

A formal proof of Proposition 4.2 is deferred to Appendix A. In the neighborhood of complete transparency, a local increase in opacity actually decreases uncertainty. This is because the positive effect of opacity on information production outweighs the increase in noise of banks' public signals. The opposite is true for high levels of opacity. Here, a marginal reduction of opacity reduces aggregate uncertainty for households without affecting information production by banks in any significant way.

Proposition 4.2 demonstrates the potential gains from policy intervention. Imposing minimum transparency requirements on banks leads to a Pareto improvement in this environment. The optimal degree of bank transparency generally depends on the functional form of  $f(g)$  which determines the social value of costly information acquisition by banks. If this function is very steep, then society has a lot to lose from reductions in information expenditures by banks and the optimal level of bank transparency will be relatively low. The same is true for high levels of fundamental uncertainty ( $\sigma^2$ ) and risk aversion, as these two factors likewise increase the social benefit of costly information acquisition. Note however one interesting aspect of bank opacity in general: an increase in the degree of asymmetry of information between households and banks may result in a welfare gain.



## 5. Discussion

We have seen that the private costs of public disclosure of banks' asset positions and risk exposure are particularly high if proprietary information becomes public. The mechanism described above applies to a wide range of credit decisions and asset classes. The problem of opacity becomes particularly severe whenever (1.) bank competition is fierce, and whenever (2.) investment in information acquisition by banks can result in a considerable information advantage.

Note that bank competition is part of the problem in this model and not part of the solution. The equilibrium allocation does not change qualitatively whether two banks compete for households' savings or a large number of  $N$  banks. On the other hand, a monopolist banker in a non-contestable market for financial intermediation would be in a position to reveal all available information to the public without the threat of adverse consequences for her market share. The inefficiencies with respect to the supply of public information described above would cease to exist. However, other well-known inefficiencies are bound to arise in the presence of market power.

In the analysis above it is assumed that the information which banks choose to transmit to the markets are verifiable. In practice, banks report summary statistics of aggregated asset positions and risk sensitivities estimated for selected scenarios. These reporting instruments still leave some room for financial window dressing. This may even be intended by regulation as complete transparency is not desirable. On the other hand, information about asset positions is socially valuable to the extent that the risk characteristics of the products held by banks are understood by the public. If opacity results in a competitive advantage, then we should expect banks to invest resources in the development of assets which are hard to understand and to value for competitor banks. Cheng, Dhaliwal and Neamtiu (2008) find that empirically banks that engage in securitization transactions are more opaque than banks with no asset securitizations.

The review of the related literature has demonstrated that existing approaches to bank transparency have found that not only the asset side of banks' balance sheet but also the particularities of their liability structure yields interesting implications for the problem of optimal bank transparency. The model outlined above is sufficiently general to encompass a wide range of financial intermediaries (e.g. mutual funds, hedge funds). Arguably, maturity transformation is a central characteristic of banks and should be incorporated in the analysis in order to study the impact of public disclosure on the stability of banks. After all, the renewed interest in the topic of bank transparency has started with the recent crisis.

The introduction of a fragile liability structure could also shed new light on the related topic of bank contagion. Jones, Lee and Yeager (2012) have demonstrated the tight empirical link between informational opacity and bank contagion. Slovin, Sushka and Polonchek (1999) show that informational contagion occurs more frequently among money center banks which process large financial flows through global networks, and less often among regional banks which service a domestic-based clientele through branches and subsidiaries. This finding is consistent with the notion that fierce competition and information-intensive and complex investment activities in the market of money cen-

ter banks result in increased informational opacity relative to less competitive regional banking markets, where eventual information advantages are limited by the size of the market and the characteristics of available assets.

## A. Proofs and Derivations

### Proposition 3.3

*Proof.* The costs of a marginal investment in information acquisition must be equal to the marginal benefits in terms of a more profitable and safer portfolio. The first order condition for a socially efficient choice of  $g_{t+1}^A$  reads as:

$$\begin{aligned} & \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \mid R_t \right\} \right] \\ &= \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \mid \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \mid R_t \right\} \right] \\ &= \mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \mid \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \mid R_t \right] \right\} = 0. \end{aligned}$$

For a given sample of observations  $\mathbb{Q}_t = \{\hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\}$ , information expenditures must pay off by making this information more reliable and thereby increasing its social value. Let  $\varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t)$  denote the density of  $R_{t+1}$  for a given sample of observations. Then we can rewrite:

$$\begin{aligned} & \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \mid \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \right] \\ &= \frac{\partial}{\partial g_{t+1}^A} \left[ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t) dR_{t+1} \right] \\ &= \int \left[ \frac{\partial}{\partial g_{t+1}^A} \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t) \right. \\ & \quad \left. + \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \frac{\partial \varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t)}{\partial g_{t+1}^A} \right] dR_{t+1} \\ &= \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} \frac{\partial u(c_{t+i}^*)}{\partial g_{t+1}^A} \mid \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \\ & \quad + \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \frac{\partial \varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t)}{\partial g_{t+1}^A} dR_{t+1}. \end{aligned}$$

The first term of this sum captures the consequences of information expenditures in terms of a reallocation of resources, while the second term measures the implied changes in the uncertainty regime which the planner has to face.

The envelope theorem allows us to abstract from indirect effects of changes in  $g_{t+1}^A$  which are transmitted through its impact on other choice variables. To see this, consider

the welfare effect of a change in  $b_{t+1}^*$  induced by the variation in  $g_{t+1}^A$ :

$$\begin{aligned} & \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} \frac{\partial u(c_{t+i}^*)}{\partial b_{t+1}^*} \frac{\partial b_{t+1}^*}{\partial g_{t+1}^A} \middle| \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \\ &= \frac{\partial b_{t+1}^*}{\partial g_{t+1}^A} \left[ - \frac{\partial u(c_t^*)}{\partial c_t^*} + \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1}^*)}{\partial c_{t+1}^*} \middle| \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} \right]. \end{aligned}$$

Note that the optimal choice of  $b_{t+1}^* = (\hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t)$  is defined by:

$$\frac{\partial u(c_t^*)}{\partial c_t^*} = \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1}^*)}{\partial c_{t+1}^*} \middle| \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\}.$$

The same reasoning applies to indirect effects of changes in  $g_{t+1}^A$  transmitted through other choice variables, e.g.  $k_{t+1}^*$ . It follows that:

$$\mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} \frac{\partial u(c_{t+i}^*)}{\partial g_{t+1}^A} \middle| \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\} = -\beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1}^*)}{\partial c_{t+1}^*} \middle| \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t \right\}.$$

Increasing investment in information acquisition reduces the resources available at date  $t+1$  for consumption. Now, the first order condition for a socially efficient choice of  $g_t^A$  boils down to:

$$\beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1}^*)}{\partial c_{t+1}^*} \middle| R_t \right\} = \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \frac{\partial \varphi(R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t)}{\partial g_{t+1}^A} dR_{t+1} \middle| R_t \right\}.$$

The density of  $R_{t+1}$  depends on  $g_{t+1}^A$  through its conditional variance as given by:

$$\text{Var}\{R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\} = \frac{\sigma^2 \Sigma_{t+1}^A \Sigma_{t+1}^B}{\sigma^2 \Sigma_{t+1}^A + \sigma^2 \Sigma_{t+1}^B + \Sigma_{t+1}^A \Sigma_{t+1}^B}.$$

Since we know that:

$$\frac{\partial \text{Var}\{R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\}}{\partial g_{t+1}^A} = -\text{Var}\{R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\}^2 f'(g_{t+1}^A),$$

we can rewrite the first order condition for  $g_t^A$  according to:

$$\begin{aligned}
& \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1}^*)}{\partial c_{t+1}^*} \middle| R_t \right\} \\
&= \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t)}{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t\}} \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t\}}{\partial g_{t+1}^A} dR_{t+1} \middle| R_t \right\} \\
&= -\text{Var}\{R_{t+1} | \mathbb{Q}_t\}^2 f'(g_{t+1}^A) \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^*) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t)}{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t\}} dR_{t+1} \middle| R_t \right\},
\end{aligned}$$

where  $\mathbb{Q}_t = \{\hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\}$ . The function  $f(g)$  is increasing, strictly concave and satisfies the Inada conditions, e.g.  $f'(0) = \infty$  and  $f'(\infty) = 0$ . Furthermore,  $u(c)$  is strictly concave. By Jensen's inequality, a mean preserving spread in the distribution of  $R_{t+1}$  lowers expected welfare. It follows that the right hand side of the equation above is strictly positive.

For  $g_{t+1}^A = 0$ , the marginal benefit of increasing information expenses on the right hand side of the equation above exceeds the associated costs on the left hand side. As  $g_{t+1}^A$  goes towards infinity, its marginal benefits shrink while the marginal costs in terms of expected welfare are growing without bounds. Only an interior choice of  $g_{t+1}^{A*}$  can satisfy the first order condition. The analogue reasoning holds for the entirely symmetric problem of selecting  $g_{t+1}^{B*}$ . Concavity of  $f(g)$  implies that the planner will optimally invest equal amounts in the precision of both signals.  $\square$

### Proposition 3.5

*Proof.* In the neighborhood of the optimal level of  $g_{t+1}^A$ , a marginal adjustment must increase households' valuation of bank  $A$  securities just as much as it increases the value of bank  $B$  securities.

$$\begin{aligned}
& \mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \hat{R}_{t+1}^A, R_t \right\} \right] \middle| R_t \right\} \\
&= \mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^B) \middle| \hat{R}_{t+1}^B, R_t \right\} \right] \middle| R_t \right\}.
\end{aligned}$$

Under complete opacity, the latter term is zero. The first order condition for an optimal choice of  $g_{t+1}^A$  becomes:

$$\mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \hat{R}_{t+1}^A, R_t \right\} \right] \middle| R_t \right\} = 0.$$

Applying the same reasoning as in the proof to Proposition 3.3 above, we can rewrite this first order condition according to:

$$\beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1})}{\partial c_{t+1}} \middle| R_t \right\} = \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | \hat{R}_{t+1}^A, R_t)}{\partial g_{t+1}^A} dR_{t+1} \middle| R_t \right\}.$$

This is equivalent to:

$$\begin{aligned} & \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1})}{\partial c_{t+1}} \middle| R_t \right\} \\ &= - \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}^2 f'(g_{t+1}^A) \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^A)}{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}} dR_{t+1} \middle| R_t \right\}, \end{aligned}$$

where  $\mathbb{Q}_t^A = \{\hat{R}_{t+1}^A, R_t\}$ . Under opacity, bankers face a higher degree of uncertainty than under transparency for given levels of information expenses:

$$\begin{aligned} \text{Var}\{R_{t+1} | \hat{R}_{t+1}^A, R_t\} &= \frac{\sigma^2 \Sigma_{t+1}^A}{\sigma^2 + \Sigma_{t+1}^A} > \\ & \frac{\sigma^2 \Sigma_{t+1}^A \Sigma_{t+1}^B}{\sigma^2 \Sigma_{t+1}^A + \sigma^2 \Sigma_{t+1}^B + \Sigma_{t+1}^A \Sigma_{t+1}^B} = \text{Var}\{R_{t+1} | \hat{R}_{t+1}^A, \hat{R}_{t+1}^B, R_t\}. \end{aligned}$$

Also, household welfare is reduced with respect to the case of exogenous transparency for a given level of  $g_{t+1}^A$ . This is because both households' savings decisions as well as banks' portfolio choice are based on less information now. Non-increasing absolute risk aversion implies that given increases in uncertainty become more costly as expected consumption levels fall. It follows that:

$$0 < g_{t+1}^{A*} = g_{t+1}^{B*} < g_{t+1}^{A**} = g_{t+1}^{B**} < \infty.$$

□

## Lemma 4.1

*Proof.* The first order condition of  $g_{t+1}^A$  is given by:

$$\begin{aligned} & \mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \middle| \mathbb{Q}_t^H \right\} \right] \middle| R_t \right\} \\ &= \mathbb{E} \left\{ \frac{\partial}{\partial g_{t+1}^A} \left[ \mathbb{E} \left\{ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^B) \middle| \mathbb{Q}_t^B \right\} \middle| \mathbb{Q}_t^H \right\} \right] \middle| R_t \right\}. \end{aligned}$$

In the absence of complete opacity, the term on the right hand side of the equation above is generally not zero. The quality of bank  $B$ 's portfolio choice benefits to some degree from the increased precision of bank  $A$ 's private signal. The uncertainty which banker

$B$  faces when she chooses her investment portfolio depends on the precision of bank  $A$ 's signal:

$$\text{Var}\{R_{t+1} | Q_{t+1}^A, \hat{R}_{t+1}^B, R_t\} = \frac{\sigma^2 (\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}) \Sigma_{t+1}^B}{\sigma^2 (\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}) + \sigma^2 \Sigma_{t+1}^B + (\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}) \Sigma_{t+1}^B}.$$

Information expenditures by bank  $A$  reduce this uncertainty:

$$\frac{\partial \text{Var}\{R_{t+1} | Q_{t+1}^A, \hat{R}_{t+1}^B, R_t\}}{\partial g_{t+1}^A} = -\text{Var}\{R_{t+1} | Q_{t+1}^A, \hat{R}_{t+1}^B, R_t\}^2 \left( \frac{\Sigma_{t+1}^A}{\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}} \right)^2 f'(g_{t+1}^A).$$

Note that banker  $B$ 's level of uncertainty is independent of  $g_{t+1}^A$  under complete opacity ( $\hat{\Sigma}_{t+1} = \infty$ ). The dependence on  $g_{t+1}^A$  becomes stronger for higher degrees of transparency and information spillovers. Applying the same reasoning as in the proof to Proposition 3.3 above, we can rewrite the first order condition of  $g_{t+1}^A$  according to:

$$\begin{aligned} & \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1})}{\partial c_{t+1}} \middle| R_t \right\} \\ &= -\text{Var}\{R_{t+1} | Q_t^A\}^2 f'(g_{t+1}^A) \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | Q_t^A)}{\partial \text{Var}\{R_{t+1} | Q_t^A\}} dR_{t+1} \middle| R_t \right\} \\ & \quad + \text{Var}\{R_{t+1} | Q_t^B\}^2 f'(g_{t+1}^A) \left( \frac{\Sigma_{t+1}^A}{\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}} \right)^2 \\ & \quad \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^B) \right) \frac{\partial \varphi(R_{t+1} | Q_t^B)}{\partial \text{Var}\{R_{t+1} | Q_t^B\}} dR_{t+1} \middle| R_t \right\}. \end{aligned}$$

In equilibrium, both banks spend identical amounts on information acquisition. Hence, ex-ante their expected beliefs are identical:

$$\mathbb{E} \left\{ \varphi(R_{t+1} | Q_t^A) \middle| R_t \right\} = \mathbb{E} \left\{ \varphi(R_{t+1} | Q_t^B) \middle| R_t \right\}.$$

Likewise, the symmetry of equilibrium implies:

$$\text{Var}\{R_{t+1} | Q_t^A\} = \text{Var}\{R_{t+1} | Q_t^B\}.$$

Hence, we can rewrite the first order condition of  $g_{t+1}^A$ :

$$\begin{aligned} \beta \mathbb{E} \left\{ \frac{\partial u(c_{t+1})}{\partial c_{t+1}} \middle| R_t \right\} &= -\text{Var}\{R_{t+1} | Q_t^A\}^2 f'(g_{t+1}^A) \left[ 1 - \left( \frac{\Sigma_{t+1}^A}{\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}} \right)^2 \right] \\ & \quad \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | Q_t^A)}{\partial \text{Var}\{R_{t+1} | Q_t^A\}} dR_{t+1} \middle| R_t \right\}. \end{aligned}$$

Under complete transparency ( $\hat{\Sigma}_{t+1} = 0$ ), the right hand side of this equation is always zero and so is the optimal choice of  $g_{t+1}^A$ . As  $\hat{\Sigma}_{t+1}$  is growing, the rival bank participates less and less in improvements to bank  $A$ 's information set.

Note that:

$$\lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \left( \frac{\Sigma_{t+1}^A}{\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}} \right)^2 \right] = \lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} \left[ -2 \frac{\Sigma_{t+1}^A{}^2}{(\Sigma_{t+1}^A + \hat{\Sigma}_{t+1})^3} \right] = 0,$$

and also:

$$\lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\} \right] = \lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} \left[ \left( \frac{\text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}}{\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}} \right)^2 \right] = 0.$$

For high values of opacity, the signal-to-noise ratio of banks' public signals becomes less and less responsive to additional changes in opacity. This is reflected by the vanishing dependence of the optimal choice of  $g_{t+1}^A$  on the degree of information spillovers:

$$\lim_{\hat{\Sigma}_{t+1} \rightarrow \infty} g'(\hat{\Sigma}_{t+1}) = 0.$$

□

## Proposition 4.2

*Proof.* The first order condition for a socially optimal choice of  $\hat{\Sigma}_{t+1}$  is given by:

$$\frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \mathbb{E} \left\{ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \mid \mathbb{Q}_t^A \right\} \mid \mathbb{Q}_t^H \right\} \right] = 0.$$

A change in opacity has two effects on welfare: (1.) uncertainty for households varies with the informational content of  $\mathbb{Q}_t^H = \{Q_{t+1}^A, Q_{t+1}^B, R_t\}$ , and (2.) the uncertainty for banks is affected through  $\mathbb{Q}_t^A = \{\hat{R}_{t+1}^A, Q_{t+1}^B, R_t\}$ . This can be seen from rewriting:

$$\begin{aligned} & \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \mathbb{E} \left\{ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \mid \mathbb{Q}_t^A \right\} \mid \mathbb{Q}_t^H \right\} \right] \\ &= \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \mid \mathbb{Q}_t^A \right\} \varphi(R_{t+1} | \mathbb{Q}_t^H) dR_{t+1} \right]. \end{aligned}$$



From the product rule, it follows that:

$$\begin{aligned}
& \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \varphi(R_{t+1} | \mathbb{Q}_t^H) dR_{t+1} \right] \\
= & \int \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \right] \varphi(R_{t+1} | \mathbb{Q}_t^H) dR_{t+1} \\
& + \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^H)}{\partial \hat{\Sigma}_{t+1}} dR_{t+1} \\
= & \mathbb{E} \left\{ \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \right] \middle| \mathbb{Q}_t^H \right\} \\
& + \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^H)}{\partial \hat{\Sigma}_{t+1}} dR_{t+1}.
\end{aligned}$$

The first term of this sum captures households' expectations about how the change in opacity will affect the precision of bank  $A$ 's forecast of  $R_{t+1}$ :

$$\begin{aligned}
& \mathbb{E} \left\{ \frac{\partial}{\partial \hat{\Sigma}_{t+1}} \left[ \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \right] \middle| \mathbb{Q}_t^H \right\} \\
& = \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^A)}{\partial \hat{\Sigma}_{t+1}} dR_{t+1} \middle| \mathbb{Q}_t^H \right\}.
\end{aligned}$$

Hence, the first order condition for  $\hat{\Sigma}_{t+1}$  becomes:

$$\begin{aligned}
& \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^A)}{\partial \hat{\Sigma}_{t+1}} dR_{t+1} \middle| \mathbb{Q}_t^H \right\} \\
& + \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^H)}{\partial \hat{\Sigma}_{t+1}} dR_{t+1} = 0.
\end{aligned}$$

Opacity affects the beliefs of banker  $A$  (first term of the sum above) as well as the expectations of households (second term). This effect works through the induced variations in uncertainty. Households' uncertainty is given by:

$$\text{Var}\{R_{t+1} | \mathbb{Q}_t^H\} = \frac{\sigma^2(\Sigma_{t+1}^A + \hat{\Sigma}_{t+1})(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1})}{\sigma^2(\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}) + \sigma^2(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}) + (\Sigma_{t+1}^A + \hat{\Sigma}_{t+1})(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1})}.$$

This uncertainty responds to changes in opacity in the following way:

$$\begin{aligned} & \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}}{\partial \hat{\Sigma}_{t+1}} \\ &= \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}^2 \frac{\left(\frac{\partial \Sigma_{t+1}^A}{\partial \hat{\Sigma}_{t+1}} + 1\right) \left(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}\right)^2 + \left(\frac{\partial \Sigma_{t+1}^B}{\partial \hat{\Sigma}_{t+1}} + 1\right) \left(\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}\right)^2}{\left(\Sigma_{t+1}^A + \hat{\Sigma}_{t+1}\right)^2 \left(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}\right)^2}. \end{aligned}$$

In the absence of positive effects on information production, households' uncertainty would always increase in opacity. What about banks' uncertainty?

$$\text{Var}\{R_{t+1} | \mathbb{Q}_t^A\} = \frac{\sigma^2 \Sigma_{t+1}^A (\Sigma_{t+1}^B + \hat{\Sigma}_{t+1})}{\sigma^2 \Sigma_{t+1}^A + \sigma^2 (\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}) + \Sigma_{t+1}^A (\Sigma_{t+1}^B + \hat{\Sigma}_{t+1})}.$$

Also banks' uncertainty varies with opacity:

$$\frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}}{\partial \hat{\Sigma}_{t+1}} = \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}^2 \frac{\frac{\partial \Sigma_{t+1}^A}{\partial \hat{\Sigma}_{t+1}} \left(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}\right)^2 + \left(\frac{\partial \Sigma_{t+1}^B}{\partial \hat{\Sigma}_{t+1}} + 1\right) \Sigma_{t+1}^A{}^2}{\Sigma_{t+1}^A{}^2 \left(\Sigma_{t+1}^B + \hat{\Sigma}_{t+1}\right)^2}.$$

Again, in the absence of positive effects on information production, banks' uncertainty would always increase in opacity. But note that:

$$\frac{\partial \Sigma_{t+1}^j}{\partial \hat{\Sigma}_{t+1}} = - \Sigma_{t+1}^j{}^2 f'(g_{t+1}^j) g'(\hat{\Sigma}_{t+1}),$$

which is always negative. By Lemma 4.1, this term converges to zero as opacity tends towards infinity. At  $\hat{\Sigma}_{t+1} = 0$ , its value is  $-\infty$ . Information production is highly responsive for low levels of opacity. This sensitivity falls as opacity is increased.

This implies for the uncertainty of households and bankers, respectively:

$$\frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}}{\partial \hat{\Sigma}_{t+1}} < 0 \quad , \text{ and } \quad \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}}{\partial \hat{\Sigma}_{t+1}} < 0 \quad , \text{ for } \hat{\Sigma}_{t+1} = 0.$$

In the neighborhood of complete transparency, a local increase in opacity actually *decreases* uncertainty. This is because the positive effect of opacity on information production outweighs the increase in noise of banks' public signals. The opposite is true for high levels of opacity:

$$\frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}}{\partial \hat{\Sigma}_{t+1}} > 0 \quad , \text{ and } \quad \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}}{\partial \hat{\Sigma}_{t+1}} > 0 \quad , \text{ for } \hat{\Sigma}_{t+1} = \infty.$$

In the neighborhood of complete opacity, a marginal reduction of opacity reduces aggregate uncertainty for households without affecting information production by banks

in any significant way. Reconsider now the first order condition of  $\hat{\Sigma}_{t+1}$ :

$$\begin{aligned} & \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}}{\partial \hat{\Sigma}_{t+1}} \mathbb{E} \left\{ \int \left( \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \right) \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^A)}{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^A\}} dR_{t+1} \middle| \mathbb{Q}_t^H \right\} \\ & + \frac{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}}{\partial \hat{\Sigma}_{t+1}} \int \mathbb{E} \left\{ \sum_{i=0}^{\infty} \beta^{t+i} u(c_{t+i}^A) \middle| \mathbb{Q}_t^A \right\} \frac{\partial \varphi(R_{t+1} | \mathbb{Q}_t^H)}{\partial \text{Var}\{R_{t+1} | \mathbb{Q}_t^H\}} dR_{t+1} = 0. \end{aligned}$$

It becomes clear that the social benefits of increasing opacity are positive at  $\hat{\Sigma}_{t+1} = 0$ . The opposite is true for  $\hat{\Sigma}_{t+1} = \infty$ .  $\square$

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