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# The Social Value of Information: A Test of a Beauty and Non-Beauty Contest\*

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## Abstract

We develop and apply a procedure to test the welfare implications of a beauty and non-beauty contest based on survey forecasts of interest rates and yields in a large country sample over an extended period of time. In most countries, interest rate forecasts are unbiased and consistent with both models, but are rarely supported by yield forecasts. In half of the countries, a higher precision of public information regarding interest rates increases welfare. During forward guidance, public information is less precise than private information.

**JEL Classification:** D8, E43, E52, E58, G1, G29

**Keywords:** Value of information, beauty contest, interest rate forecasts, bond yield forecasts, strategic forecasts, central bank transparency, forward guidance

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# 1 Introduction

Information about relevant economic fundamentals is widely dispersed, but is imperfectly aggregated in society. Hayek (1945) emphasized that this information cannot be centralized by the government. Society must rely on decentralized mechanisms to use information. This does not suggest that decentralizing the use of information best serves society. Keynes (1936) argued that financial markets are excessively volatile because professional investors are more concerned with forecasting the forecasts of others than forecasting the fundamental value of the assets that they trade. This has become known as Keynes' beauty contest metaphor for financial markets.<sup>1</sup>

More recently, Morris & Shin (2002) (MS) developed a theoretical model of information and coordination among agents to formalize the coordinating role of public information and to examine its implications for welfare. Their analysis is nested in a beauty-contest game in which agents' utility positively depends on correctly forecasting the true (realized) future state of the economy on the one hand and, on the other hand, forecasting as close to the other agents as possible (Keynes's Beauty Contest). Players have two information sources, one is private (an independent signal realization for each player), while the other is public (a common signal realization). Deviations of agents' actions from fundamental values determine social welfare, which, in turn, results from three parameters that reflect the precision of public and private information as well as the motivation for coordinating their actions. As in most beauty-contest models, the information is exogenous.<sup>2</sup>

In this game, public information has a disproportionate effect on equilibrium outcomes relative to what is warranted on the basis of agents' information set for fundamentals alone. This is because agents use public information to predict fundamentals as well as to coordinate their actions. The key implication of the model is that when individual agents have access to heterogeneous private information, more precise public information may be damaging to welfare.

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<sup>1</sup> The "beauty contest" terminology is drawn from a passage from Keynes' General Theory. Keynes describes newspaper-based competitions in which entrants chose the prettiest faces from a set of photographs, where it was optimal to nominate the most popular faces (Keynes 1936, ch. 12, p. 156).

<sup>2</sup> See, for example, Myatt & Wallace (2011) for a model that considers endogenous information acquisition.

Applied to financial markets, when market participants overreact to noisy public news because they help forecast each another's actions, public information can play a role that is similar to a sunspot, which may contribute to increased volatility and decreased welfare.<sup>3</sup> This possibility has been widely interpreted as an objection to more transparency in central banks.<sup>4</sup>

Considerable debate has been prompted by the theoretical MS analysis, for which there is no agreement. An empirical analysis may assist in clarifying views. To the best of our knowledge, there has been no attempt to empirically test the MS model. The empirical problem that must be solved is determining the three exogenous parameters. This paper addresses this issue.

Given the controversial theoretical debate that is related to the MS model, we perform a series of tests and contrast the results with those from a non-beauty contest model in which agents do not second-guess other agents' actions. From several potentially testable models with this feature, we selected the model that was proposed by Veldkamp (2011). The implications of the two models are listed below. In the MS model, higher precision in private information always increases welfare, while there is an ambiguous effect for higher precision in public information. By contrast, in the Veldkamp (2011) model, higher precision in public information always increases welfare, while higher precision in private information can decrease welfare.

Our tests are performed on a large data set of professional forecasts of short-term interest rates and long-term yields that was provided by *Consensus Economics* and includes a sizable set of countries over an extended period of time. We used survey forecasts for two reasons. First, these forecasts can be interpreted as agents' actions. Second, forecasts are important for policymakers and a broad public audience. This is demonstrated by the active monitoring of forecasters' accuracy by market participants, the popular press, and researchers.<sup>5</sup>

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<sup>3</sup> See Angeletos et al. (2016). Elements of this "beauty-contest" characteristic of financial markets have been formalized, for example, in Bacchetta & van Wincoop (2006), Allen et al. (2006), and Angeletos et al. (2007).

<sup>4</sup> Following MS, beauty-contest models have received close attention in other situations, such as investment games (Angeletos & Pavan (2004)), monopolistic competition (Hellwig (2005)), financial markets (Allen et al. (2006)), and additional economic questions (Angeletos & Pavan (2007)). See Myatt & Wallace (2011) for more references.

<sup>5</sup> See Marinovic et al. (2013).

The results that emerge from our analysis are threefold. First, in most countries reported interest rate forecasts are unbiased. This is consistent with both models. For reported yield forecasts, most countries diverge from both models. Second, for reported interest rate forecasts on a 3-month horizon, welfare increases with more precise public information in half of the countries also in the MS model. For these countries, the MS's intriguing theoretical conclusion does not apply. Third, forward guidance tends to be characterized by public information that is less precise than private information. In the [Veldkamp \(2011\)](#) model, this constellation implies that higher precision in private information always increases social welfare. Thus, when there is forward guidance, higher precision in private information always increases welfare regardless of the underlying model. By contrast, we cannot draw any conclusion about the relative precision of signals associated with the publication of central banks' internal interest rate forecasts.

The rest of the paper is organized in the following manner. In [Section 2](#), we provide a brief overview of the related literature. In [Section 3](#), we outline the two models, our method for identifying the errors in public and private information, and derive five hypotheses. [Section 4](#) describes the data set that was used to estimate the model parameters. In [Section 5](#), we embed our procedure in the strategic forecasting literature. In [Section 6](#) we delineate our estimation methodology and present the results. [Section 7](#) discusses two empirical properties of public and private information, which is followed by several conclusions in [Section 8](#).

## 2 Literature review

The primary result of MS is that under certain parameter values, more precise public information reduces welfare. This key finding is related to the possibility that, when individual agents have access to heterogeneous private information, the availability of more precise public information could damage welfare. Subsequent research has raised questions about the validity of applying MS's lessons to a macroeconomic context for two reasons.

First, the practical relevance of their primary finding has been questioned by [Svensson \(2006\)](#), who argues that two strong conditions on the parameters must be satisfied for the MS finding to apply: (i) the incentive for agents to coor-

dinate their actions – the coordination motive – must assume certain values; and (ii) the public-to-private signal ratio – defined as the precision of the public compared to the private signal – must be very low. According to Svensson (2006), these conditions are empirically implausible, which challenges the conclusions of MS. Svensson (2006) contends that for reasonable parameter values, the MS framework even implies that more precise public information increases social welfare. In their response, Morris et al. (2006) acknowledge the validity of Svensson’s argument. Second, in subsequent research, Hellwig (2005), Roca (2010), and Lorenzoni (2010) examined the implications of MS’s findings using neo-Keynesian frameworks and found that better public information is unambiguously beneficial.

However, other studies have identified situations in which welfare may decrease with the provision of public information, which supports MS. For example, Angeletos & Pavan (2007) show that the results are sensitive to the specific type of externality that is assumed in the payoff structure. Indeed, there are conditions under which public information releases decrease welfare. As such, the phenomenon that MS have identified, while not general, may be an important feature for specific economic contexts.

While the models that are used in the literature are usually static and abstract from learning, Amador & Weill (2012) analyze an alternative mechanism based on a dynamic information externality. There are no payoff externalities, but public information slows the diffusion of private information in the population. Agents learn from the actions of others through two channels, public and private. When agents only learn from the public channel, a release of public information increases agents’ total knowledge at all times and increases welfare. However, when there is a private learning channel, this finding is reversed.

Amador & Weill (2010) study the effect of releasing public information about productivity or monetary shocks using a micro-founded macroeconomic model in which agents learn from the distribution of nominal prices. Their results are not driven by any form of payoff externality. Rather, their results are generated from an information externality that makes public information releases welfare reducing by increasing agents’ uncertainty about fundamentals.

Angeletos & Pavan (2009) examine the possible contribution of Pigovian-type corrective taxes for inducing a socially optimal private sector response to heterogeneous information. Using a direct adaptation of MS, they demonstrate that more precise information can reduce welfare in general. However, policies that restore efficiency for the decentralized use of information guarantee a positive social value for any information that is disseminated by policymakers. This can be achieved with an appropriate tax structure which, by influencing private sector agents' incentives to react to information, guarantees that welfare will increase with more information. This is true regardless of whether the initial inefficiency originated in payoff interactions, such as in MS and Angeletos & Pavan (2007), or informational externalities, such as in Amador & Weill (2010, 2012).

James & Lawler (2011) extend the MS analysis to examine the relationship between the quality of public information and social welfare in the presence of stabilization policies in central banks. This modification has significant implications for the desirability of central bank disclosure in an economy that has heterogeneous private information. When policy is conducted according to an optimally designed rule, more precision in the informational content of the policymaker's announcements is detrimental to welfare.

### 3 Two models

This section presents two of the four types of models that are discussed in the literature. According to Angeletos & Pavan (2007), economies can be classified into four types. In type (1), higher precision in both public and private information always increases welfare. In type (2), higher precision in public information can decrease welfare. In type (3), higher precision in private information can decrease welfare. In type (4), higher precision in both public and private information can decrease welfare. We limit the analysis in this paper to type (2) and (3) models. As an example of a type (2) economy, we examine the MS beauty-contest model. As an example of a type (3) economy, we use the non-beauty contest model that was proposed by Veldkamp (2011).<sup>6</sup> In both models the agents' utility functions differ from their social welfare functions.

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<sup>6</sup> Models can be classified along other dimensions. One distinguishes between strategic complementarities (the MS model), strategic substitutability and no strategic interaction (the Veldkamp (2011) model). Another dimension distinguishes between positive and negative externalities for mean action and dispersion on the one hand and no externalities on the other.

In the MS model, agents have an incentive to make as good a forecast as possible and to be close to the other forecasters' actions. However, welfare only depends on how close actions are to the fundamental values of the economy.<sup>7</sup> In the Veldkamp (2011) model, the opposite is true. Forecasters only have an incentive for making an accurate forecast, while welfare depends on both the quality of forecasts and their alignment with each other.

The basic framework of the models is provided by two pieces of information – a public and a private signal – which agents receive and incorporate into an action, for example, they may report a forecast for interest rates. While the private signal is only individually observed and differs for each agent, the public signal is the same for all. Higher precision in both public and private information is defined as a lower variance in the signals' errors.

Determining the parameters in both models is not unambiguously possible in our data set. While we cannot directly measure the signals, our method allows us to separate the errors that are contained in both signals. We derive five hypotheses that implicitly or explicitly arise from the two models, and test these hypotheses using the interest rate and yield forecasts of professional forecasters. We define the public signal as all information that is publicly available – everything that is simultaneously observable by all agents that could indicate the future state of short-term interest rates or yields on long-term bonds.

### 3.1 Socially costly public information: The model of Morris & Shin (2002)

This section formally recaps the MS model, which serves as an example for a type (2) beauty-contest economy. We derive three hypotheses from this model, which we will empirically test in **Section 6**. We begin with the agents' utility function (**Subsection 3.1.1**), followed by their optimal actions (**Subsection 3.1.2**).

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<sup>7</sup> The crucial factor underlying MS's original finding is the presence of a strategic complementarity. However, Angeletos & Pavan (2007) show that a strategic complementarity, per se, is neither necessary nor sufficient for implying that there is excessive weight (relative to the efficient benchmark) on public information for determining individual actions. Rather, what is crucial is what Angeletos & Pavan (2007) refer to as the "equilibrium degree of coordination" relative to the "socially optimal degree of coordination" (for a formal definition, see **Appendix A.1**). In MS, the beauty-contest term in individual payoff functions leads the former to exceed the latter, which increases the possibility that more precision in public information could be damaging.



We then describe our method for identifying the two errors that are contained in public and private information (**Subsection 3.1.3**). Subsequently, we derive what we define as the variance ratio (**Subsection 3.1.4**) and connect it to the model's welfare properties (**Subsection 3.1.5**).

An individual action – a reported forecast in our setting – is not only affected by the (expected) interest rate path that is indicated by the observed signals but also by how the other agents act (what forecasts the other agents are expected to report). This leads to a coordination motive through which agents coordinate and second-guess their peers' actions.<sup>8</sup> By contrast, the social planner seeks to keep agents' actions as close to the future fundamental values of the economy as possible.

We develop three hypotheses from this model. **Hypothesis 1** is that the reported forecasts are unbiased. **Hypothesis 2** and **Hypothesis 3** build on Svensson's (2006) critique. The second hypothesis implies that higher precision in public signals increases social welfare. The third hypothesis postulates that the public signal is less precise than the private signal.

### 3.1.1 Agents' utility function and social welfare

The utility of agent  $i$  is given by

$$u_i(a_i, \bar{a}, \sigma_a, \theta) = - (1 - r) \cdot (a_i - \theta)^2 - r \cdot (a_i - \bar{a})^2 + r \cdot \sigma_a^2 \quad (1)$$

where  $a_i$  is agent  $i$ 's action and  $\theta$  is the realized (future) state of the economy. We interpret an agent's action as a reported forecast of interest rates or yields. MS assume that  $\theta$  is drawn from an (improper) uniform prior over the real line.<sup>9</sup>  $r$  is the parameter of the coordination motive, with  $0 < r < 1$ . The closer  $r$  is to 1, the more utility an agent derives from being close to the other agents' forecast.

The first part of **Equation (1)** reflects the “fundamental” component of the utility function.  $(a_i - \theta)^2$  is the (squared) deviation of agent  $i$ 's action from the realized future state times the weight that is from the coordination motive  $(1 - r)$ . We call the deviation  $(a_i - \theta)$  *action error*. The second component of the utility func-

<sup>8</sup> Agents' actions are a linear function of the signals. This guarantees a unique equilibrium.

<sup>9</sup> Note that an improper prior implies an infinite variance for the state variable, which is implausible. However, this does not affect the MS's theoretical results, as their model also holds for proper priors. See Veldkamp (2011) and **Appendix A.2.5**.

tion reflects Keynes's Beauty Contest, where second-guessing the other agents' actions pays off. The closer an agent to the average action ( $\bar{a}$ ), the better off he is.<sup>10</sup> However, for society, this is a zero sum game because, unlike agents, the social planner only cares about social welfare and seeks to keep all agents' actions close to the true (future) state of the economy.<sup>11</sup> The social welfare function in the discrete case for  $i = \{1, \dots, N\}$  agents is defined as<sup>12</sup>

$$W(\bar{a}, \sigma_a, \theta) = \frac{1}{1-r} \cdot \frac{1}{N} \sum_{i=1}^N u_i(a_i, \bar{a}, \sigma_a, \theta) = -\frac{1}{N} \sum_{i=1}^N (a_i - \theta)^2 \quad (2)$$

This utility and the implied welfare function satisfy the conditions for a beauty contest. We formally demonstrate this in **Appendix A.1.1**.

### 3.1.2 Agents' optimal action

To develop additional testable hypotheses, we begin with the optimal action (a reported forecast in our setting) that is taken by agent  $i$ , which MS established as

$$a_i = \frac{\alpha}{\alpha + \beta(1-r)} \cdot y + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot x_i \quad (3)$$

where  $y$  is the public signal that is observed by all agents, while  $x_i$  reflects the private signal that is observed by agent  $i$ . The unique optimal action ( $a_i$ ) in equilibrium is a weighted average of the two signals ( $x_i$  and  $y$ ). The weights are determined by the precision in the public and private signal ( $\alpha$  and  $\beta$ ) as well as the coordination motive ( $r$ ). MS assume

$$\begin{aligned} y &= \theta + \eta & \eta &\sim iidN(0, 1/\alpha) \\ x_i &= \theta + \varepsilon_i & \varepsilon_i &\sim iidN(0, 1/\beta) \end{aligned}$$

$\eta$  is the error in the public signal. While the private signal contains an individual error  $\varepsilon_i$ , the precision of the private signal ( $\beta$ ) is the same for all agents. MS assume that  $\eta$  and  $\varepsilon_i$  are independent of each other and independent of the future state of the economy  $\theta$ . Consistent with MS, we assume that  $\alpha$ ,  $\beta$  and  $r$  are constant and identical for all agents.

<sup>10</sup> Note that  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / (\partial a_i \partial \bar{a}) > 0$  implies strategic complementarity, while  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / \partial \bar{a} > 0$  and  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / \partial \sigma_a > 0$  are positive externalities for the mean and the dispersion of actions. For an extensive discussion of utility functions, see Angeletos & Pavan (2007).

<sup>11</sup> Note that  $\sigma_a^2$  is the variance for all agents' actions.

<sup>12</sup> Note that while MS use a continuum of agents, our data set has a discrete number of agents. MS normalize social welfare with  $1/(1-r)$ .

### 3.1.3 Method to identify the errors in the two signals

For the empirical analysis, we must identify the errors that are in the two signals. To this end, we plug  $y$  and  $x_i$  into **Equation (3)**. After rearranging, we obtain<sup>13</sup>

$$a_i - \theta = \frac{\alpha}{\alpha + \beta(1 - r)} \cdot \eta + \frac{\beta(1 - r)}{\alpha + \beta(1 - r)} \cdot \varepsilon_i \quad (4)$$

The left-hand side of **Equation (4)** is the *action error* for agent  $i$ . The right-hand side of the equation contains the *action error* as a weighted average of the errors in the two signals.

The ex-post cross-sectional mean *action error*  $(\bar{a} - \theta) | \eta, \varepsilon_1, \varepsilon_2, \dots, \varepsilon_N$  is given by

$$\bar{a} - \theta = \frac{\alpha}{\alpha + \beta(1 - r)} \cdot \eta \quad (5)$$

as  $\varepsilon_i \sim iidN(0, 1/\beta)$ . Because  $\eta$  is (ex-post) the same for all agents at a certain point in time, we conclude that the ex-post cross-sectional mean *action error* comes from the error that is contained in the public signal ( $\eta$ ), the weight that is assigned to the precision of both signals ( $\alpha$  and  $\beta$ ), and the coordination motive  $r$ . We will use this finding to identify the errors that are contained in the signals.

The expected *action error* of agent  $i$  and the expected cross-sectional mean *action error* are unbiased because  $\eta \sim iidN(0, 1/\alpha)$  and  $\varepsilon_i \sim iidN(0, 1/\beta)$ , that is

$$\mathbb{E} [a_i - \theta] = 0 \quad (6)$$

$$\mathbb{E} [\bar{a} - \theta] = 0 \quad (7)$$

This leads to our first hypothesis.

**Hypothesis 1** *The mean forecast error for the reported forecasts is unbiased over time.*

Rejection of **Hypothesis 1** implies rejection of the MS model. We will test this hypothesis in **Subsection 6.1**.

### 3.1.4 Variance ratio

To derive **Hypothesis 2** and **Hypothesis 3**, we must calculate what we call the variance ratio,  $V$ . We define this as the ratio of the variance of the ex-post cross-

<sup>13</sup> All equations are derived in **Appendix A.2**.

sectional mean *action error* ( $V_1$ ) to the variance of agents' deviation from the cross-sectional mean action ( $V_2$ ).  $V_1$  is

$$V_1 = \frac{\alpha}{(\alpha + \beta(1 - r))^2} \quad (8)$$

To derive  $V_2$ , we calculate the errors in the private signal using **Equation (4)** and **Equation (5)**, which yields

$$a_i - \bar{a} = \frac{\beta(1 - r)}{\alpha + \beta(1 - r)} \cdot \varepsilon_i \quad (9)$$

The variance of the agents' deviation from the cross-sectional mean action follows as

$$V_2 = \frac{\beta(1 - r)^2}{(\alpha + \beta(1 - r))^2} \quad (10)$$

Hence, the variance ratio is given as

$$V = \frac{V_1}{V_2} = \frac{\mathbb{V} \left[ (\bar{a} - \theta) \right]}{\mathbb{V} \left[ (a_i - \bar{a}) \right]} = \frac{\alpha/\beta}{(1 - r)^2} \quad (11)$$

The equation shows the relationship between the variance ratio  $V$  and the public-to-private signal ratio  $\alpha/\beta$  as well as the coordination motive  $r$ .  $V$  is large when the public signal is more precise than the private signal, or when the coordination motive  $r$  is large ( $r$  close to 1), *ceteris paribus*. Alternatively, **Equation (11)** can be written as

$$\alpha/\beta = V \cdot (1 - r)^2 \quad (12)$$

which establishes the functional relationship between the public-to-private signal ratio and the coordination motive for a given variance ratio.

### 3.1.5 Social welfare

Next, we present the expected social welfare and the conditions that **Svensson (2006)** postulated for more precision in public signals having an increasing/decreasing effect on welfare. These conditions lead to **Hypothesis 2** and

**Hypothesis 3.** Expected social welfare according to MS is written as

$$\mathbb{E} [W (\bar{a}, \sigma_a, \theta) | \theta] = -\frac{\alpha}{(\alpha + \beta(1 - r))^2} - \frac{\beta(1 - r)}{(\alpha + \beta(1 - r))^2} \quad (13)$$

MS indicate that welfare always increases with higher precision in private signals ( $\partial \mathbb{E} [W (\bar{a}, \sigma_a, \theta) | \theta] / \partial \beta > 0$ ). However, the first derivative with respect to the precision of public signals is

$$\frac{\partial \mathbb{E} [W (\bar{a}, \sigma_a, \theta) | \theta]}{\partial \alpha} = \frac{\alpha - (2r - 1)(1 - r)\beta}{(\alpha + \beta(1 - r))^3} \quad (14)$$

This implies that higher precision in public signals (tantamount to an increase in  $\alpha$ ) increases welfare iff

$$\frac{\alpha}{\beta} \geq (2r - 1)(1 - r)$$

Svensson (2006) establishes the following conditions:

- If  $r < 0.5$ , welfare is increasing with the precision of public signals.
- If  $0.5 < r < 0.75$  and  $\alpha/\beta < (2r - 1)(1 - r)$ , welfare is decreasing with the precision of public signals.
- If  $0.5 < r < 0.75$  and  $\alpha/\beta \geq (2r - 1)(1 - r)$ , welfare is increasing with the precision of public signals.
- If  $0.75 < r$ , welfare is increasing with the precision of public signals.<sup>14</sup>

We incorporate **Equation (12)** into Svensson's conditions, which yields

$$V \begin{matrix} \leq \\ \geq \end{matrix} (2r - 1)/(1 - r) \quad (15)$$

To derive **Hypothesis 2**, we insert the two critical boundary values for  $r$  (0.5 and 0.75) into **Equation (15)** and obtain for  $r = 0.5$  the lower bound  $(2r - 1)/(1 - r) = 0$  and for  $r = 0.75$  the upper bound  $(2r - 1)/(1 - r) = 2$ . When the variance ratio  $V$  is between the lower and the upper bound (0, 2), a higher precision of public signals could decrease welfare. According to Svensson (2006), economies are rarely in a state in which social welfare is decreasing with the precision of public signals. This leads us to **Hypothesis 2**.

<sup>14</sup> **Figure 4** in **Appendix E** illustrates the conditions that were postulated by Svensson (2006).

**Hypothesis 2** *Higher precision in public signals increases welfare if  $2 < V$ .*

**Hypothesis 2** will be tested in **Subsection 6.2**. Note that **Hypothesis 2** is a sufficient, but not necessary, condition for the higher precision of public signals to increase welfare. By contrast, when  $2 > V$ , we cannot assess the effect of higher precision of public signals on welfare as it depends on  $r$ , which we cannot estimate with our data.

Next, we derive **Hypothesis 3**. This includes a condition for the public-to-private signal ratio  $\alpha/\beta$ . There are three cases to distinguish.

**Case 1**  $\alpha/\beta > 1$ : The public signal is more precise than the private signal.

**Case 2**  $\alpha/\beta < 1$ : The public signal is less precise than the private signal.

**Case 3**  $\alpha/\beta = 1$ : Both signals are equally precise.

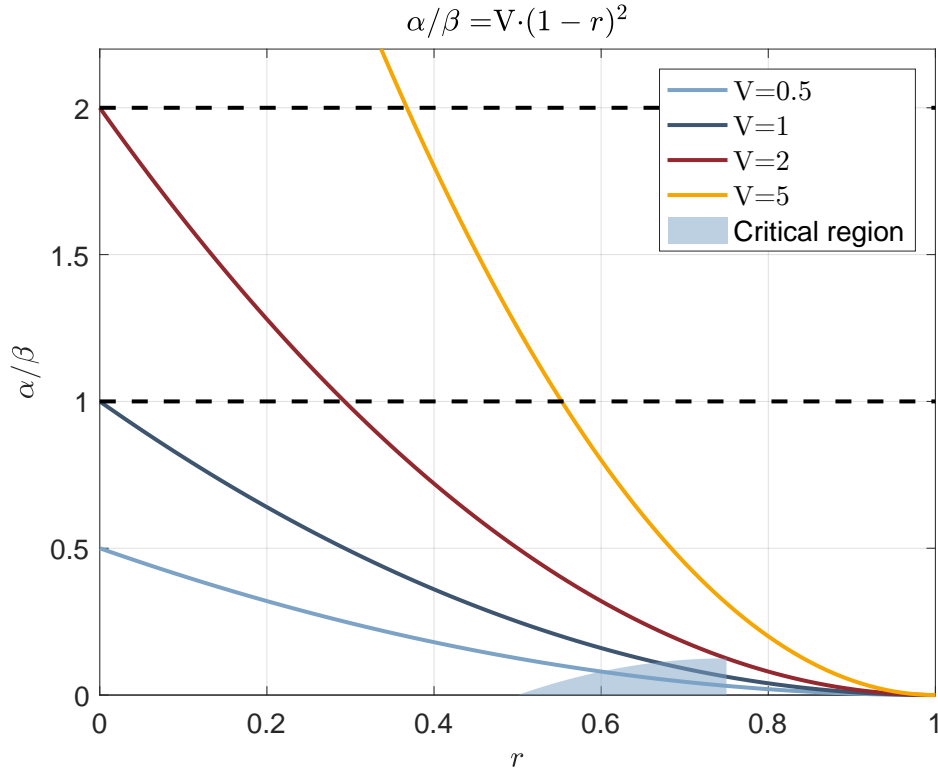
From **Equation (12)**, we can infer that  $\alpha/\beta$  decreases in  $r$ . The maximum value that  $\alpha/\beta$  can assume is when  $r$  equals 0, which yields  $\alpha/\beta = V$ . **Hypothesis 3** summarizes.

**Hypothesis 3** *If  $V < 1$ , the public signal is less precise than the private signal, regardless of the coordination motive  $r$ .*

We will test **Hypothesis 3** in **Subsection 6.3**. Note, **Hypothesis 3** is a sufficient, but not necessary, condition for the public signal to be less precise than the private signal. In other words, if  $V > 1$ , we cannot conclude that the public signal is more precise than the private signal.

As shown in **Appendix A.2.5**, our results for the variance ratio  $V$  exhibit the same interpretation irrespective of whether we assume proper or improper priors.

**Figure 1:** Graphical illustration of **Hypothesis 2** and **Hypothesis 3**



This figure plots the function  $\alpha/\beta = V \cdot (1 - r)^2$ . The dashed black lines show the null for **Hypothesis 2** and **Hypothesis 3**. The shaded blue area illustrates the region in which higher precision in public signals lowers social welfare. This region is defined by Svensson (2006) as  $f(r) \equiv (2r - 1)(1 - r)$  with  $0.5 < r < 0.75$ . If  $\alpha/\beta < f(r)$  and  $0.5 < r < 0.75$ , higher precision in public signals decreases social welfare. If a function does not cross the shaded blue area, we accept **Hypothesis 2**: Higher precision in public signals increases social welfare. If the maximum value of a function is less than one, we accept **Hypothesis 3**: The public signal is less precise than the private signal, regardless of the coordination motive  $r$ .

**Figure 1** provides a graphic illustration of **Hypothesis 2** and **Hypothesis 3** in the  $(r, \alpha/\beta)$ -space. If the function  $\alpha/\beta = V \cdot (1 - r)^2$  (**Equation (12)**) does not cross the blue area, we accept **Hypothesis 2** – higher precision in public signals increases social welfare. If the maximum value of the function is less than one, we accept **Hypothesis 3** – the public signal is less precise than the private signal. As shown in the figure, the yellow curve, for example, never crosses the blue area. This implies that for  $V = 5$ , we accept **Hypothesis 2**. Because the yellow curve’s maximum value is greater than one, we reject **Hypothesis 3**. By contrast, if  $V = 0.5$  (the light blue curve), we reject **Hypothesis 2** and accept **Hypothesis 3**.

## 3.2 Socially costly private information: A model by Veldkamp (2011)

This section presents a model of Veldkamp (2011) as an example of a type (3) non-beauty contest economy. We ask whether socially costly private information (private signals) is possible. As Veldkamp (2011) documents, if there is a positive rather than negative coordination externality, then more precise private signals might decrease social welfare.<sup>15</sup> We recap the model and derive two hypotheses that are based on this model. In **Subsection 3.2.1**, we show the utility function and its corresponding welfare function. **Subsection 3.2.2** derives the agents' optimal action. **Subsection 3.2.3** identifies the parameters. **Subsection 3.2.4** provides the model's variance ratio, while **Subsection 3.2.5** discusses the welfare implications for specific parameter values. We will test the two hypotheses from this model in **Section 6**.

The basic framework of this model is similar to MS. In contrast to MS, this model assumes that agents only have an incentive for reporting the accurate forecast based on their observed signals and not to coordinate with each other. However, social welfare is not only affected by the accuracy of the reported forecasts but also by their dispersion. However, agents do not coordinate, even though this would decrease dispersion and hence increase social welfare.

We develop two hypotheses from this model. **Hypothesis 4** is that the reported forecasts are unbiased. **Hypothesis 5** states that higher precision in private signals increases welfare.

### 3.2.1 Agents' utility function and social welfare

Veldkamp (2011) proposes the following utility function

$$u_i(a_i, \bar{a}, \sigma_a, \theta) = - (1 - r) \cdot (a_i - \theta)^2 - r \cdot \sigma_a^2 \quad (16)$$

with  $0 < r < 1$ .<sup>16</sup> The notation is the same as before.  $a_i$  is agent  $i$ 's action,  $\theta$  is

<sup>15</sup> See Veldkamp (2011), p. 51 ff.

<sup>16</sup> Note that  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / (\partial a_i \partial \bar{a}) = 0$  implies no strategic interactions (neither complementarity nor substitutability), while  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / \partial \bar{a} = 0$  reflects no externality for the mean action and  $\partial u_i(a_i, \bar{a}, \sigma_a, \theta) / \partial \sigma_a < 0$  is a negative externality for the dispersion of actions (the higher the dispersion, the lower utility). This is equivalent to a positive coordination externality (the lower the dispersion, the higher utility). For an extensive discussion of utility functions, see Angeletos & Pavan (2007).



the (realized) future state<sup>17</sup> and  $\sigma_a^2$  is the variance of agents' actions. The model by Veldkamp (2011) is a good model to contrast with MS since **Equation (16)** is nested in **Equation (1)**.

The utility function presented in **Equation (16)** implies that each agent only has an incentive for making his action as close as possible to the unknown state  $\theta$ . Additionally, an agent benefits when all agents' actions are more coordinated ( $\sigma_a^2$  small), which leads to a positive coordination externality. There are  $i = \{1, \dots, N\}$  agents in the economy. Therefore, from an individual agent's perspective,  $\sigma_a^2$  is given if  $N$  is large. The welfare function in the discrete case is written as<sup>18</sup>

$$W(\bar{a}, \sigma_a, \theta) = \frac{1}{N} \sum_{i=1}^N u_i(a_i, \bar{a}, \sigma_a, \theta) = -(1-r) \cdot \frac{1}{N} \sum_{i=1}^N (a_i - \theta)^2 - r \cdot \sigma_a^2 \quad (17)$$

In contrast to MS, welfare increases when agents actions' are close to each other ( $\sigma_a$  small). This utility and welfare function do not satisfy the conditions for a beauty contest. We formally show this in **Appendix A.1.2**.

### 3.2.2 Agents' optimal action

According to Veldkamp (2011), agent's optimal action (a reported forecast in our setting) equals

$$a_i = \frac{\alpha}{\alpha + \beta} \cdot y + \frac{\beta}{\alpha + \beta} \cdot x_i \quad (18)$$

The unique optimal action ( $a_i$ ) in equilibrium is a weighted average of the two signals ( $x_i$  and  $y$ ). The weights are determined by the precision in the public and the private signal ( $\alpha$  and  $\beta$ ). Note that coordination  $r$  has no role in agents' optimal action because their only incentive is making a precise forecast, as  $\sigma_a$  is given from the perspective of an individual forecaster.<sup>19</sup> The structure of both signals ( $y$  and  $x_i$ ) is the same as in MS, see **Subsection 3.1.2**.

### 3.2.3 Method for identifying the errors in the two signals

For the empirical analysis, we need to identify the errors in the two signals. To this end, we incorporate  $y$  and  $x_i$  into **Equation (18)**. After rearranging, we

<sup>17</sup> Similar to MS, Veldkamp (2011) assumes that  $\theta$  is drawn from an (improper) uniform prior over the real line.

<sup>18</sup> Note that while Veldkamp (2011) uses a continuum of agents, our data set has a discrete number of agents.

<sup>19</sup> In contrast to MS, in this model the optimal action corresponds to the most accurate forecast based on agents' exogenous signals.

obtain<sup>20</sup>

$$a_i - \theta = \frac{\alpha}{\alpha + \beta} \cdot \eta + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \quad (19)$$

The left-hand side of **Equation (19)** is the *action error* for agent  $i$ . The right-hand side of the equation presents the *action error* as a weighted average of the error in the two signals. We assume, consistent with Veldkamp (2011), that  $\alpha$  and  $\beta$  are constant and identical for all agents.

The ex-post cross-sectional mean *action error*  $(\bar{a} - \theta)|\eta, \varepsilon_1, \varepsilon_2, \dots, \varepsilon_N$  is given by

$$\bar{a} - \theta = \frac{\alpha}{\alpha + \beta} \cdot \eta \quad (20)$$

because  $\varepsilon_i \sim iidN(0, 1/\beta)$ . As the error contained in the public signal  $\eta$  is (ex post) the same for all agents at a specific point in time, the ex-post cross-sectional mean *action error* results from  $\eta$  and some weight that is provided by the precision of both signals ( $\alpha$  and  $\beta$ ).

However, the expected *action error* for agent  $i$  and the expected cross-sectional mean *action error* are unbiased because  $\eta \sim iidN(0, 1/\alpha)$  and  $\varepsilon_i \sim iidN(0, 1/\beta)$ , that is

$$\mathbb{E} [a_i - \theta] = 0 \quad (21)$$

$$\mathbb{E} [\bar{a} - \theta] = 0 \quad (22)$$

This leads to **Hypothesis 4**.

**Hypothesis 4** *The mean forecast error for the reported forecasts is unbiased over time.*

Hence, if we reject **Hypothesis 4**, we reject the model by Veldkamp (2011). Note that while **Hypothesis 1** and **Hypothesis 4** are mathematically the same, they refer to different model frameworks.

### 3.2.4 Variance ratio

To derive **Hypothesis 5** we must again calculate the variance ratio  $V = V_1/V_2$ .  $V_1$  is the variance for the cross-sectional mean *action error*,  $V_2$  the variance of the

<sup>20</sup> All equations are derived in **Appendix A.3**.

deviation of agents' actions to the cross-sectional mean action. To calculate  $V_1$ , we calculate the variance of **Equation (20)**.  $V_1$  is written as

$$V_1 = \frac{\alpha}{(\alpha + \beta)^2} \quad (23)$$

Note that the theoretical identities change compared to MS. To derive  $V_2$ , we calculate the errors in the private signal using **Equation (19)** and **Equation (20)**, which yields

$$a_i - \bar{a} = \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \quad (24)$$

Hence, the variance of agents' deviation from the mean action is provided by

$$V_2 = \frac{\beta}{(\alpha + \beta)^2} \quad (25)$$

The inverse variance ratio follows as

$$1/V = \frac{V_2}{V_1} = \frac{\mathbb{V} \left[ (a_i - \bar{a}) \right]}{\mathbb{V} \left[ (\bar{a} - \theta) \right]} = \beta/\alpha \quad (26)$$

Note that we use the inverse  $1/V$ . This is purely for the ease of exposition. In contrast to MS,  $r$  has no role in the variance ratio. However,  $r$  is crucial for social welfare.

### 3.2.5 Social welfare

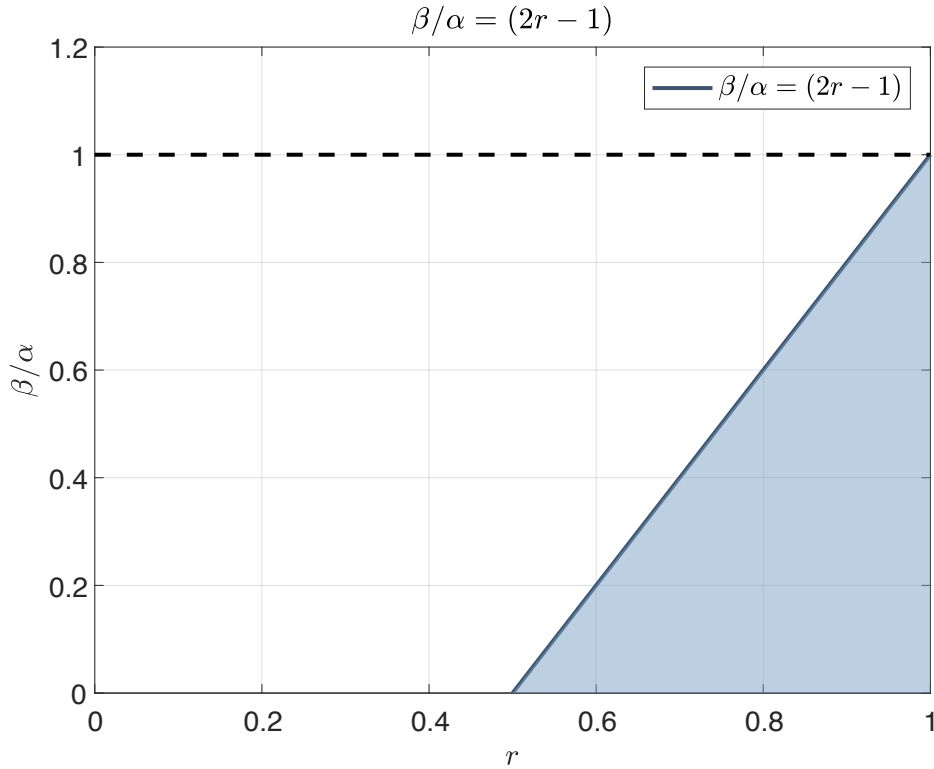
Next, we present social welfare and its properties with respect to information precision to derive **Hypothesis 5**. According to Veldkamp (2011), the expected social welfare corresponds with

$$\mathbb{E} [W(\bar{a}, \sigma_a, \theta) | \theta] = -(1 - r) \cdot \frac{1}{\alpha + \beta} - r \cdot \frac{\beta}{(\alpha + \beta)^2} \quad (27)$$

A more precise public signal always increases welfare ( $\partial \mathbb{E}[W(\bar{a}, \sigma_a, \theta) | \theta] / \partial \alpha > 0$ ). However, the effect of a more precise private signal is ambiguous. The derivative with respect to  $\beta$  is

$$\frac{\partial \mathbb{E} [W(\bar{a}, \sigma_a, \theta) | \theta]}{\partial \beta} = \frac{\beta - \alpha(2r - 1)}{(\alpha + \beta)^3} \quad (28)$$

**Figure 2:** Graphical illustration of **Hypothesis 5**



This figure plots the function  $\beta/\alpha = (2r - 1)$  (blue line). The dashed black line shows the null for **Hypothesis 5**. If  $\beta/\alpha < (2r - 1)$  with  $0.5 < r < 1$  (shaded blue area), higher precision in private signals decreases social welfare. The maximum value of  $(2r - 1)$  in the space  $0 < r < 1$  is  $r = 1$ . Thus, if  $\beta/\alpha > 1$ , higher precision in private signals always increases social welfare irrespective of the value of  $r$ .

Higher precision of private signals decreases welfare iff

$$\beta/\alpha < (2r - 1)$$

If  $\beta/\alpha$  is smaller than  $(2r - 1)$ , welfare decreases with more precise private signals ( $\beta$ ). If  $\beta/\alpha$  is larger than  $(2r - 1)$ , welfare increases with the precision of private signals. Furthermore,  $0 < r < 1$ . Hence, the maximum value of  $(2r - 1)$  equals 1. **Figure 2** illustrates this effect. The blue line corresponds to  $\beta/\alpha = (2r - 1)$ . If a point in the  $(r, \beta/\alpha)$ -space is below the blue line (in the shaded blue area), higher precision in private signals decreases welfare. By contrast, if this point is above the blue line, higher precision in private signals increases welfare.

Next, we combine this finding with the results for  $1/V$ . If  $1/V = \beta/\alpha$  is larger than 1 (or  $V < 1$ ), more precise private signals increase welfare regardless of the value of  $r$ . In other words, if private signals are more precise than public

signals, making private signals even more precise has a socially beneficial effect. However, if  $1/V$  is smaller than 1 ( $V > 1$ ), we would need a value for  $r$  to make a statement about welfare. Because we cannot estimate  $r$ , we cannot establish whether more precise private signals increase or decrease social welfare. This leads to our final hypothesis.

**Hypothesis 5** *Higher precision in private signals is socially beneficial if  $V < 1$ .*

Note, **Hypothesis 5** is a sufficient, but not necessary, condition for more precise private signals to increase welfare. In other words, if  $V > 1$ , we cannot conclude that more precise private signals decrease social welfare.

Furthermore, it is important to note that mathematically **Hypothesis 3** and **Hypothesis 5** are the same. However, while **Hypothesis 5** (if accepted) has a clear-cut conclusion for social welfare, **Hypothesis 3** only makes a statement about the relative precision in the signals.

## 4 Data

After developing the testable implications in the models, we describe the data that are used to test our five hypotheses. We used monthly forecasts of short-term interest rates that were available for 34 countries (primarily for maturity in three months) and forecasts of the yields on ten-year government bonds for 23 countries, which were provided by *Consensus Economics*. The forecasts are made by professionals, such as financial institutions and other forecasting agencies, beginning at the earliest in October 1989 and ending in June 2017. Two forecast horizons are surveyed – 3 and 12 months. We interpret these reported forecasts as actions.

As inferred from **Table 1**, the data set contains approximately 106,000 observations for short-term interest rate forecasts with a forecast horizon of three months, and 101,000 with a forecast horizon of twelve months. For yields, there are 69,000 and 66,000 observations, which reflect a total of 343,000 individual forecasts.<sup>21</sup>

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<sup>21</sup> **Table 7** and **Table 8** in **Appendix B** provide details for these data.

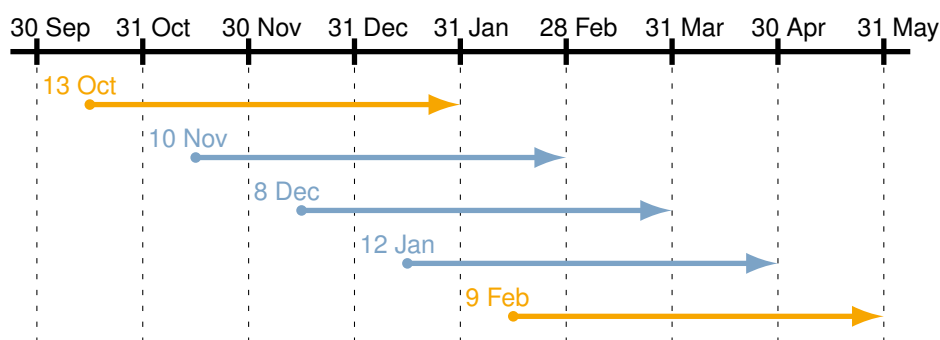
**Table 1:** *Consensus Economics* individual observations

|   |                |
|---|----------------|
| Individual short-term interest rate forecasts (for 34 countries)        |                |
| for 3 month forecast horizon  | 106,428        |
| for 12 month forecast horizon   | 100,967        |
| Individual long-term government bond yield forecasts (for 23 countries) |                |
| for 3 month forecast horizon  | 69,497         |
| for 12 month forecast horizon   | 66,221         |
| Total   | <b>343,113</b> |

To calculate the forecast errors, we employ the realized end-of-month interest rates and government bond yields from Thompson Reuters' Datastream.<sup>22</sup> Several amendments in the forecast variables were made by *Consensus Economics* over time, for example, when an interest rate loses economic relevance. **Table 9** and **Table 10** in **Appendix B** list these changes, the time span and the Datastream tickers in detail. Note that our data represent *business forecasts*, which are not scientific in the sense of Mincer & Zarnowitz (1969), but represent a sample of the prevailing climate of opinions, which allows us to test the formation of opinions in the models.

There are two advantages of using data for interest rates and yields. First, unlike, for example, GDP data, they are not subject to revisions. Second, specifically short-term interest rates are directly controlled by the central bank. More precise public information on short-term rate forecasts can be interpreted as higher (central bank) transparency, consistent with Svensson (2006).

**Figure 3:** Scheme of forecasts with horizon of 3 months from October 2014 to May 2015



<sup>22</sup> There is one exception. We used the PHIBOR – the short-term interest rate for Philippines – from Bloomberg.

**Figure 3** illustrates the forecast scheme for the 3-month horizon. For example, on October 13, 2014, an agent predicted the interest rate for January 31, 2015. Importantly, the forecast error that was made on October 13, 2014 correlates with the forecast errors for November 10, 2014, December 8, 2014 and January 12, 2015.<sup>23</sup> On February 9, 2015, the forecaster can observe the forecast error from October 13, 2014, and accordingly adjusts the upcoming forecast for the end of May.

## 5 Relationship with strategic forecasting literature

Before testing our hypotheses, we relate our empirical procedure to the literature on strategic forecasts. In our context, it is important to differentiate between two possible ways that agents may act when producing their forecasts. According to [Marinovic et al. \(2013\)](#), forecasters are agents who make strategic choices. To interpret the content of their forecasts, it is essential to understand the role of incentives for forecasters. On the one hand, they may want to be perceived as well-informed and may be reluctant to release information that could be inaccurate. These forecasters will shade their forecasts toward the established consensus to avoid unfavorable publicity when they are wrong. This is referred to as *reputational cheap talk* in the literature.

On the other hand, only the most accurate forecaster obtains a disproportionate fraction of public attention, which implies that the payoff for being the best is significantly higher than the second best. Thus, forecasters might exaggerate their true predictions, conditional on getting it right, to stand out from competing forecasters. By exaggerating their private information, these forecasters reduce the probability of winning, but increase their visibility, which is conditional on winning. This behavior is called *forecasting contest*.<sup>24</sup>

While the MS model has a different micro-foundation than the *reputational cheap talk* game, the optimal action in the MS model corresponds to a strategy that is consistent with a *reputational cheap talk* game. Both are characterized by an excessive weight that is given to public information.<sup>25</sup> By contrast, the [Veldkamp \(2011\)](#) model cannot be assigned to either of these two forecasting strategies,

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<sup>23</sup> We accounted for this correlation in the empirical analysis in [Section 6](#).

<sup>24</sup> See also [Ottaviani & Sørensen \(2006a,b\)](#).

<sup>25</sup> We leave the mathematical connection between these two models to future research.

because the optimal behavior is to report the “honest forecast”.<sup>26</sup>

In the literature, it is common to describe a world in which public information is given excessive weight as *herding*. By contrast, a world in which private information is excessively weighed is commonly referred to as *anti-herding*. Thus, while the MS exhibits *herding*, Veldkamp (2011) features neither *herding* nor *anti-herding*.

While reputation induces forecasters to partially disregard their private information and excessively agree with each other (*herding*), competition leads to the opposite – an exaggeration of private information and excessive disagreement (*anti-herding*). Marinovic et al. (2013) developed a framework to analyze the statistical properties of strategic forecasts that result from combining the reputational and the contest objectives. Using data from the *Business Week Investment Outlook*’s reported yearly GNP growth forecasts for the period between 1972 and 2004, they report that forecasters were primarily driven by competitive incentives (*anti-herding*). Their test assumes a constant prior as the only public information, which makes no sense in our setup. However, other papers demonstrate mixed results. Chen & Jiang (2006) and Bernhardt et al. (2006) find evidence of *anti-herding* in the context of financial analysts. By contrast, in the context of recommendations, Jegadeesh & Kim (2010) found that recommendations that are further away from the consensus induce stronger market reactions, which is consistent with *herding*.<sup>27</sup>

Given the mixed evidence in empirical research, any assumption about how the forecasting market weights public and private information appears to be valid. Against this foundation, we test the MS and the Veldkamp (2011) models as two examples of different weighting mechanisms with survey data on financial variables.

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<sup>26</sup> An “honest forecast” refers to a reported forecast that is formed without strategic interaction (neither overweighing nor underweighing the information). See Ottaviani & Sørensen (2006b).

<sup>27</sup> We applied the test by Bernhardt et al. (2006) on our data and found that, specifically for interest rates, there appears to be *herding* behavior. These results are available upon request. Note that this test does not fit into the MS model one-for-one, because this test needs a fixed reference point. The reference point is the reported 12-month forecast. For the tests of the two models in this paper, forecast horizons must be separated from each other.

As shown by Marinovic et al. (2013), when forecasters sufficiently underweight their private information relative to common public information (for example, due to the beauty contests concerns à la Morris & Shin (2002)), an increase in the number of forecasters can lead to a reduction in the informativeness of the consensus forecast. We also tested this with our data. The results, which are available upon request, were mixed.



## 6 Tests of hypotheses

In this section, we test our hypotheses. The section is organized into four subsections. In **Subsection 6.1** to **Subsection 6.3**, we test **Hypothesis 1** to **Hypothesis 5**. In **Subsection 6.4**, we investigate whether forward guidance or the publication of central banks' internal interest rate forecasts changed the relative precision of public and private information that was received by forecasters. **Appendix D** describes our methodology.<sup>28</sup>

In **Section 3**, we presented two theoretical models with different payoff and welfare structures. In MS, agents gain utility from correctly forecasting the future state and from being close to other agents' reported forecasts. Welfare only depends on the accuracy of the reported forecasts. In Veldkamp (2011), agents only obtain utility from correctly forecasting the future state. However, welfare depends on both the accuracy of the reported forecasts and their dispersion. In the context of our dataset, both payoff and welfare structures appear to be valid.<sup>29</sup>

Both models assume that both signals are exogenous. In reality, this may not always be true. In the empirical analysis, we use the signals as given, as we do not know how they came about. We do know that both current signals must be correlated with their past signals, because today's signals contain all previous signals. As such, we account for autocorrelation in our tests. Examples of public signals include the forecasts that were reported in the previous period. They may also reflect newspaper articles, central bank announcements, a public debate about monetary policy, and releases of GDP and inflation data, which, in turn, may shape monetary policy decisions.

In addition, the two models assume that the realized state of the economy  $\theta$  – in our context, realized interest rates and yields – is also exogenous. This is a valid assumption in our dataset, because the reported forecasts (forecasters' actions) minimally affect the fundamentals. This situation may be different for households' actions, for example.<sup>30</sup>

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<sup>28</sup> Note that the MS and Veldkamp (2011) models assume I(0) variables. However, interest rates and yields are usually I(1). Hence, we use the reported forecasts and the realized changes in interest rates and yields that are I(0). Because we only use forecast errors to test our hypotheses, this constraint is automatically satisfied, as  $({}_t a_{i,t+h} - \theta_t) - (\theta_{t+h} - \theta_t) = {}_t a_{i,t+h} - \theta_{t+h}$ , where  $t$  is the time index and  $h$  is the forecast horizon.

<sup>29</sup> We postpone the derivation of the alternative payoff and welfare structures and tests of their applicability to reported forecasts for future research.

<sup>30</sup> We thank an anonymous referee for pointing this out.

## 6.1 Hypothesis 1 and Hypothesis 4

**Hypothesis 1** and **Hypothesis 4** argue that the reported forecasts are unbiased, i.e. they do not include systematic errors. We apply the method of Fama & MacBeth (1973) to estimate a regression for each country and variable, controlling for autocorrelations, based on Petersen (2009).<sup>31</sup> The regression equation is

$${}_t a_{i,t+h} - \theta_{t+h} = b + e_{i,t+h} \quad (29)$$

$t$  is when a forecaster forms his action (reported forecast) and  $h$  is the forecast horizon. The null hypothesis is  $b = 0$ , and the alternative  $b \neq 0$ . If a t-test accepts the null, we conclude that the reported forecasts are unbiased, which allows us to accept both models on empirical grounds. Otherwise, we can reject both models.

**Table 2** and **Table 3** present the results for the reported forecasts of short-term interest rates and long-term yields at the 3- and 12-month horizons, divided into four geographic regions based on the classification of *Consensus Economics*. The first panel reports the forecasts for Western countries, the second for the Asian-Pacific area, the third for Eastern Europe, and the fourth for Latin America (only interest rates). The tables also indicate the individual countries and the beginning month for the time series. The table provides two results.  $\hat{b}$  reflects the intercept of **Equation (29)**, and  $\hat{\sigma}_b$  is its standard deviation. In addition, the table contains  $T$ , which denotes the length of the time series in months and  $NT$  the number of individual forecasts.

**Table 2** provides a clear result. In most countries (28 out of 34) and across all geographical regions, reported interest rate forecasts for the 3-month horizon are unbiased, which supports both models. For the 12-month forecast horizon, most countries' reported interest rate forecasts are unbiased, although this number decreases compared to the short forecast horizon. In six countries, the reported interest rate forecasts are biased for both forecasting horizons: Canada, the Czech Republic, Japan, the Philippines, Sweden, and the US.

**Table 3** presents the results for the reported yield forecasts. In contrast to interest rate forecasts, reported yield forecasts are biased, except for in Italy, India, Indonesia, Hungary, Poland, and Slovakia, for both forecast horizons.<sup>32</sup>

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<sup>31</sup> **Appendix D** provides details.

<sup>32</sup> Robustness checks using sub-periods before and after August 2007, which we equate with the beginning of the financial crisis, result in similar findings for most countries.

**Table 2: Interest rates' test of Hypothesis 1 and Hypothesis 4**

|  |        | <b>h=3</b>          |                  |     |      | <b>h=12</b>         |                  |     |      |
|--|--------|---------------------|------------------|-----|------|---------------------|------------------|-----|------|
|  |        | $\hat{b}$           | $\hat{\sigma}_b$ | $T$ | $NT$ | $\hat{b}$           | $\hat{\sigma}_b$ | $T$ | $NT$ |
| <b>Data set Western Consensus Forecasts</b>        |        |                     |                  |     |      |                     |                  |     |      |
| USA  | Oct-89 | 0.0023 ***          | 0.0006           | 330 | 7846 | 0.0076 ***          | 0.0027           | 321 | 7501 |
| JPN  | Jan-90 | 0.0010 ***          | 0.0004           | 330 | 4965 | 0.0037 **           | 0.0016           | 321 | 4580 |
| DEU  | Oct-89 | 0.0004              | 0.0004           | 330 | 7892 | 0.0032 *            | 0.0018           | 321 | 7614 |
| FRA  | Oct-89 | -0.0003             | 0.0006           | 330 | 5261 | 0.0019              | 0.0019           | 321 | 5049 |
| GBR  | Oct-89 | 0.0005              | 0.0006           | 330 | 7695 | 0.0048 ***          | 0.0020           | 321 | 7508 |
| ITA  | Oct-89 | -0.0002             | 0.0009           | 330 | 3282 | 0.0024              | 0.0024           | 321 | 3162 |
| CAN  | Oct-89 | 0.0014 **           | 0.0007           | 330 | 4819 | 0.0071 ***          | 0.0024           | 321 | 4676 |
| NLD  | Jan-95 | 0.0007              | 0.0006           | 267 | 2331 | 0.0045 **           | 0.0020           | 258 | 2242 |
| NOR  | Jun-98 | 0.0007              | 0.0008           | 226 | 1702 | 0.0040              | 0.0034           | 217 | 1639 |
| ESP  | Jan-95 | 0.0010 *            | 0.0006           | 267 | 3248 | 0.0058 ***          | 0.0023           | 258 | 3110 |
| SWE  | Jan-95 | 0.0014 ***          | 0.0006           | 267 | 2900 | 0.0080 ***          | 0.0023           | 258 | 2801 |
| CHE  | Jun-98 | 0.0009              | 0.0006           | 226 | 2407 | 0.0046 **           | 0.0022           | 217 | 2286 |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |        |                     |                  |     |      |                     |                  |     |      |
| AUS  | Nov-90 | 0.0011              | 0.0007           | 317 | 4849 | 0.0064 **           | 0.0028           | 308 | 4610 |
| CHN  | Jul-03 | 0.0003              | 0.0005           | 165 | 1611 | 0.0019              | 0.0016           | 156 | 1510 |
| HKG  | Dec-94 | 0.0006              | 0.0009           | 268 | 2935 | 0.0044              | 0.0031           | 259 | 2810 |
| IND  | Dec-94 | 0.0000              | 0.0017           | 268 | 1788 | 0.0031              | 0.0039           | 259 | 1562 |
| IDN  | Dec-94 | 0.0025              | 0.0039           | 268 | 1734 | 0.0001              | 0.0106           | 259 | 1680 |
| MYS  | Dec-94 | 0.0008              | 0.0007           | 268 | 2816 | 0.0029              | 0.0023           | 259 | 2700 |
| NZL  | Dec-94 | 0.0006              | 0.0009           | 268 | 3203 | 0.0040              | 0.0030           | 259 | 3082 |
| PHL  | Apr-09 | 0.0075 ***          | 0.0026           | 92  | 263  | 0.0171 ***          | 0.0055           | 83  | 207  |
| SGP  | Dec-94 | 0.0010              | 0.0009           | 268 | 2698 | 0.0033              | 0.0022           | 259 | 2615 |
| KOR  | Dec-94 | 0.0015              | 0.0021           | 268 | 2569 | 0.0055              | 0.0035           | 259 | 2454 |
| TWN  | Dec-94 | -0.0003             | 0.0007           | 268 | 2213 | 0.0041 **           | 0.0020           | 259 | 2106 |
| THA  | Dec-94 | -0.0009             | 0.0028           | 268 | 2094 | 0.0028              | 0.0065           | 259 | 2006 |
| <b>Data set Eastern Europe Consensus Forecasts</b> |        |                     |                  |     |      |                     |                  |     |      |
| CZE  | May-98 | 0.0025 ***          | 0.0006           | 173 | 2239 | 0.0081 ***          | 0.0021           | 164 | 2116 |
| HUN  | May-98 | 0.0010              | 0.0014           | 173 | 1797 | 0.0024              | 0.0047           | 164 | 1708 |
| POL  | May-98 | 0.0009              | 0.0011           | 173 | 2232 | 0.0034              | 0.0036           | 164 | 2097 |
| TUR  | May-98 | -0.0050             | 0.0033           | 149 | 1670 | -0.0017             | 0.0079           | 144 | 1485 |
| SVK  | May-98 | 0.0016              | 0.0010           | 173 | 1434 | 0.0074 ***          | 0.0026           | 164 | 1355 |
| <b>Data set Latin American Consensus Forecasts</b> |        |                     |                  |     |      |                     |                  |     |      |
| ARG  | Apr-01 | 0.0105              | 0.0078           | 192 | 2769 | 0.0132              | 0.0173           | 183 | 2279 |
| BRA  | Apr-01 | -0.0009             | 0.0018           | 192 | 3204 | -0.0059             | 0.0054           | 183 | 2974 |
| CHL  | Apr-01 | 0.0008              | 0.0011           | 190 | 2865 | 0.0062 *            | 0.0037           | 183 | 2723 |
| MEX  | Apr-01 | 0.0023 *            | 0.0014           | 192 | 3379 | 0.0048              | 0.0030           | 183 | 3183 |
| VEN  | Apr-01 | 0.0052              | 0.0056           | 192 | 1718 | 0.0148              | 0.0110           | 183 | 1537 |
| <b>Accept hyp 1 &amp; 4</b>                        |        | <b>28 out of 34</b> |                  |     |      | <b>21 out of 34</b> |                  |     |      |

We run the regression  $({}_t a_{i,t+h} - \theta) = b + e_{i,t+h}$ . The table shows the estimates for  $\hat{b}$  and its standard deviation corrected for serial correlation  $\hat{\sigma}_b$  following Petersen (2009).  $h$  is the forecast horizon, either 3 months or 12 months.  $NT$  is the total number of observations in the cross-section and over time.  $T$  is the number of time periods. While the sample ends in June 2017, the individual starting time for each country is given next to the country's codename. For further details, see Table 7. **Accept hyp 1 & 4** shows the total number of countries for which we accept the null of unbiased actions (reported forecasts) on the 95%-level. If reported forecasts are unbiased, we accept the MS and the Veldkamp (2011) model. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ , using  $\hat{\sigma}_b$ .

**Table 3: Yields' test of Hypothesis 1 and Hypothesis 4**

|  |        | <b>h=3</b>         |                  |     |      | <b>h=12</b>        |                  |     |      |
|--|--------|--------------------|------------------|-----|------|--------------------|------------------|-----|------|
|  |        | $\hat{b}$          | $\hat{\sigma}_b$ | $T$ | $NT$ | $\hat{b}$          | $\hat{\sigma}_b$ | $T$ | $NT$ |
| <b>Data set Western Consensus Forecasts</b>        |        |                    |                  |     |      |                    |                  |     |      |
| USA  | Oct-89 | 0.0020 ***         | 0.0006           | 330 | 7964 | 0.0066 ***         | 0.0013           | 321 | 7527 |
| JPN  | Jan-90 | 0.0013 ***         | 0.0004           | 330 | 5692 | 0.0051 ***         | 0.0009           | 321 | 5180 |
| DEU  | Oct-89 | 0.0017 ***         | 0.0006           | 330 | 7939 | 0.0061 ***         | 0.0014           | 321 | 7642 |
| FRA  | Oct-89 | 0.0014 ***         | 0.0006           | 330 | 5191 | 0.0051 ***         | 0.0014           | 321 | 5008 |
| GBR  | Oct-89 | 0.0017 ***         | 0.0006           | 330 | 7132 | 0.0056 ***         | 0.0015           | 321 | 6883 |
| ITA  | Oct-89 | 0.0004             | 0.0009           | 315 | 3073 | 0.0034             | 0.0024           | 315 | 3050 |
| CAN  | Oct-89 | 0.0020 ***         | 0.0006           | 283 | 4033 | 0.0060 ***         | 0.0016           | 283 | 4018 |
| NLD  | Jan-95 | 0.0020 ***         | 0.0006           | 267 | 2262 | 0.0070 ***         | 0.0015           | 258 | 2173 |
| NOR  | Jun-98 | 0.0017 ***         | 0.0007           | 226 | 1570 | 0.0060 ***         | 0.0020           | 217 | 1509 |
| ESP  | Jan-95 | 0.0016 **          | 0.0008           | 267 | 3144 | 0.0061 **          | 0.0028           | 258 | 3016 |
| SWE  | Jan-95 | 0.0029 ***         | 0.0007           | 267 | 3061 | 0.0090 ***         | 0.0018           | 258 | 2945 |
| CHE  | Jun-98 | 0.0020 ***         | 0.0006           | 226 | 2460 | 0.0062 ***         | 0.0014           | 217 | 2338 |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |        |                    |                  |     |      |                    |                  |     |      |
| AUS  | Nov-90 | 0.0024 ***         | 0.0007           | 270 | 4176 | 0.0063 ***         | 0.0017           | 270 | 4060 |
| IND  | Dec-94 | -0.0002            | 0.0010           | 136 | 1021 | -0.0006            | 0.0016           | 127 | 867  |
| IDN  | Dec-94 | 0.0001             | 0.0017           | 133 | 893  | 0.0008             | 0.0058           | 124 | 810  |
| NZL  | Dec-94 | 0.0018 ***         | 0.0007           | 268 | 3203 | 0.0050 ***         | 0.0016           | 259 | 3089 |
| KOR  | Dec-94 | 0.0019 *           | 0.0010           | 64  | 433  | 0.0075 ***         | 0.0019           | 55  | 379  |
| TWN  | Mar-06 | 0.0013 ***         | 0.0005           | 101 | 664  | 0.0042 ***         | 0.0017           | 92  | 600  |
| THA  | Dec-94 | 0.0013             | 0.0009           | 133 | 834  | 0.0058 ***         | 0.0012           | 124 | 761  |
| <b>Data set Eastern Europe Consensus Forecasts</b> |        |                    |                  |     |      |                    |                  |     |      |
| CZE  | Jan-06 | 0.0018 *           | 0.0010           | 127 | 1429 | 0.0068 ***         | 0.0024           | 118 | 1312 |
| HUN  | Jan-06 | -0.0005            | 0.0014           | 127 | 1155 | -0.0003            | 0.0054           | 118 | 1046 |
| POL  | Jan-06 | 0.0002             | 0.0010           | 127 | 1361 | 0.0024             | 0.0027           | 118 | 1232 |
| SVK  | Jan-06 | 0.0006             | 0.0013           | 123 | 807  | 0.0053 *           | 0.0031           | 118 | 776  |
| <b>Accept hyp 1 &amp; 4</b>                        |        | <b>9 out of 23</b> |                  |     |      | <b>6 out of 23</b> |                  |     |      |

We run the regression  $({}_t a_{i,t+h} - \theta) = b + e_{i,t+h}$ . The table shows the estimates for  $\hat{b}$  and its standard deviation corrected for serial correlation  $\hat{\sigma}_b$  following Petersen (2009).  $h$  is the forecast horizon, either 3 months or 12 months.  $NT$  is the total number of observations in the cross-section and time.  $T$  is the number of time periods. While the sample ends in June 2017, the individual starting time for each country is given next to country's codename. For further details, see Table 8. **Accept hyp 1 & 4** shows the total number of countries for which we accept the null of unbiased actions (reported forecasts) on the 95%-level. If reported forecasts are unbiased, we accept the MS and the Veldkamp (2011) model. \*  $p < 0.10$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ , using  $\hat{\sigma}_b$ .

## 6.2 Hypothesis 2

**Hypothesis 2** states that higher precision in public signals increases welfare. As such, we calculate the variance ratio  $V$ , which was explained in **Subsection 3.1.4**, as

$$V = \frac{\mathbb{V} \left[ ({}_t\bar{a}_{t+h} - \theta_{t+h}) \right]}{\mathbb{V} \left[ ({}_t a_{i,t+h} - {}_t\bar{a}_{t+h}) \right]} = \frac{\alpha/\beta}{(1-r)^2}$$

corrected for autocorrelation in *action errors* and deviations from the mean actions using estimates of the MA-processes.<sup>33</sup>

**Hypothesis 2** is borne out when  $2 < V$ . We perform an F-test with the null  $V_0 = 2$  and the alternative  $V_A > 2$ . The results, denoted as  $P_2$  and  $F_2$ , are reported in **Table 4** for interest rates and in **Table 5** for yields.  $F_2$  indicates the F-statistics and  $P_2$  denotes their p-values for the null to be true. If  $P_2$  is equal to or less than 0.10, we reject the null and accept the alternative that  $V$  is greater than 2. In other words, if  $P_2$  is equal or below 0.10, then we conclude that higher precision in public signals increases welfare not only in the Veldkamp (2011) model but also in the MS model. However, if  $P_2$  is greater than 0.10, we cannot draw a conclusion for the effect of the precision of public signals on social welfare.

As inferred from **Table 4**, the results indicate that for almost half of the countries in our sample (15 of 34), higher precision in public signals increases welfare for interest rates at the 3-month forecast horizon. **Hypothesis 2** finds support for interest rate forecasts in both horizons in France, Italy, Hong Kong, India, Philippines, and Argentina. For yields (**Table 5**), we cannot draw a clear conclusion.

## 6.3 Hypothesis 3 and Hypothesis 5

**Hypothesis 3** asks whether the public signal is less precise than the private signal. **Hypothesis 5** states that higher precision in private signals increases welfare. **Hypothesis 3** and **Hypothesis 5** hold if  $V < 1$ . We perform an F-test with the null  $V_0 = 1$  and the alternative  $V_A < 1$ . The test procedure is as in **Subsection 6.2**.<sup>34</sup> Rejecting the null indicates that the public signal is less precise than

<sup>33</sup> For further details, see **Appendix D**.

<sup>34</sup> For additional details, see **Appendix D**.

the private signal. In addition, it also suggests that higher precision in private signals is not only socially beneficial in the MS model but also in the model of Veldkamp (2011). However, if the evidence points towards accepting the null, we cannot assess the signal that is more precise. Additionally, if we accept the null, we cannot draw any conclusions about welfare.

**Table 4** presents the results for interest rates, **Table 5** for yields.  $F_{3\&5}$  shows the F-statistics for **Hypothesis 3** and **Hypothesis 5**, with the null  $V_0 = 1$  and the alternative  $V_A < 1$ .  $P_{3\&5}$  shows its p-value. If  $P_{3\&5} \leq 0.10$ , we reject the null and accept the alternatives. This indicates that **Hypothesis 3**: The private signal is more precise than the public and **Hypothesis 5**: Higher precision in private signals is socially beneficial.

We find empirical support for both hypotheses in only four countries for reported interest rate forecasts at the 12-month horizon. For yields, these hypotheses are not confirmed by the data (in no countries at the 3-month horizon and only in two countries at 12-month horizon).<sup>35</sup>

Note that the MS variance ratio  $V = (\alpha/\beta)/(1-r)^2$  is often smaller at the 12-month forecast horizon than at the 3-month forecast horizon. This indicates that either the precision of the public signal ( $\alpha$ ) is lower, the precision of the private signal ( $\beta$ ) is higher, or coordination  $r$  is lower at the 12-month horizon than the 3-month horizon (ceteris paribus).<sup>36</sup> The variance ratio in the Veldkamp (2011) model equals  $V = \alpha/\beta$ . This indicates that either the precision of the public signal ( $\alpha$ ) is lower, or the precision of the private signal ( $\beta$ ) is higher at the 12-month horizon than the 3-month horizon (ceteris paribus).

In sum, the tests of the hypotheses deliver the following messages. First, both models are empirically applicable for short-term interest rates, specifically across a short forecast horizon. Second, more precise public signals, for example greater central bank transparency about short-term interest rates, increase welfare. Third, whether public signals are less precise than private signals remains an open question.

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<sup>35</sup> Robustness checks using sub-periods before and after August 2007, which we equate with the beginning of the financial crisis, yield similar results for most countries. They are available upon request.

<sup>36</sup> We thank Alex Cukierman for pointing this out.

**Table 4:** Interest rates’ test of **Hypothesis 2**, **Hypothesis 3** & **Hypothesis 5** – “Higher precision in public signals is welfare increasing” – “Private signals are more precise than public” – “Higher precision in private signals is socially beneficial”

|  |        | <b>h=3</b>  |                 |                |                      |                      | <b>h=12</b> |                |                |                      |                      |
|--|--------|-------------|-----------------|----------------|----------------------|----------------------|-------------|----------------|----------------|----------------------|----------------------|
|  |        | $\hat{V}$   | F <sub>2</sub>  | P <sub>2</sub> | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | $\hat{V}$   | F <sub>2</sub> | P <sub>2</sub> | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> |
| <b>Data set Western Consensus Forecasts</b>        |        |             |                 |                |                      |                      |             |                |                |                      |                      |
| USA  | Oct-89 | 1.76        | 0.88            | 0.93           | 1.77                 | 1.00                 | 0.68        | 0.34           | 1.00           | 0.68                 | 1.00                 |
| JPN  | Jan-90 | 2.00        | 1.00            | 0.48           | 2.00                 | 1.00                 | 1.38        | 0.69           | 1.00           | 1.38                 | 1.00                 |
| DEU  | Oct-89 | 1.65        | 0.83            | 0.99           | 1.66                 | 1.00                 | 0.98        | 0.49           | 1.00           | 0.98                 | 0.42                 |
| FRA  | Oct-89 | 4.50        | 2.26            | 0.00           | 4.51                 | 1.00                 | 2.71        | 1.36           | 0.00           | 2.72                 | 1.00                 |
| GBR  | Oct-89 | 1.56        | 0.78            | 1.00           | 1.57                 | 1.00                 | 0.68        | 0.34           | 1.00           | 0.69                 | 0.00                 |
| ITA  | Oct-89 | 4.38        | 2.20            | 0.00           | 4.40                 | 1.00                 | 2.61        | 1.31           | 0.00           | 2.61                 | 1.00                 |
| CAN  | Oct-89 | 2.73        | 1.37            | 0.00           | 2.74                 | 1.00                 | 1.60        | 0.80           | 0.99           | 1.61                 | 1.00                 |
| NLD  | Jan-95 | 1.85        | 0.93            | 0.78           | 1.86                 | 1.00                 | 1.44        | 0.72           | 1.00           | 1.44                 | 1.00                 |
| NOR  | Jun-98 | 2.78        | 1.40            | 0.00           | 2.80                 | 1.00                 | 1.45        | 0.73           | 1.00           | 1.46                 | 1.00                 |
| ESP  | Jan-95 | 1.29        | 0.65            | 1.00           | 1.29                 | 1.00                 | 1.02        | 0.51           | 1.00           | 1.02                 | 0.59                 |
| SWE  | Jan-95 | 1.92        | 0.96            | 0.65           | 1.93                 | 1.00                 | 0.92        | 0.46           | 1.00           | 0.92                 | 0.19                 |
| CHE  | Jun-98 | 2.86        | 1.43            | 0.00           | 2.87                 | 1.00                 | 1.10        | 0.55           | 1.00           | 1.10                 | 0.83                 |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |        |             |                 |                |                      |                      |             |                |                |                      |                      |
| AUS  | Nov-90 | 2.12        | 1.06            | 0.22           | 2.13                 | 1.00                 | 1.12        | 0.56           | 1.00           | 1.12                 | 0.92                 |
| CHN  | Jul-03 | 1.83        | 0.92            | 0.74           | 1.84                 | 1.00                 | 1.16        | 0.58           | 1.00           | 1.17                 | 0.91                 |
| HKG  | Dec-94 | 6.57        | 3.30            | 0.00           | 6.59                 | 1.00                 | 3.21        | 1.61           | 0.00           | 3.22                 | 1.00                 |
| IND  | Dec-94 | 4.32        | 2.17            | 0.00           | 4.33                 | 1.00                 | 2.64        | 1.32           | 0.00           | 2.64                 | 1.00                 |
| IDN  | Dec-94 | 1.32        | 0.66            | 1.00           | 1.33                 | 1.00                 | 1.13        | 0.57           | 1.00           | 1.13                 | 0.91                 |
| MYS  | Dec-94 | 1.76        | 0.88            | 0.91           | 1.76                 | 1.00                 | 0.76        | 0.38           | 1.00           | 0.76                 | 0.00                 |
| NZL  | Dec-94 | 2.35        | 1.18            | 0.03           | 2.36                 | 1.00                 | 1.11        | 0.56           | 1.00           | 1.12                 | 0.89                 |
| PHL  | Apr-09 | 6.04        | 3.04            | 0.00           | 6.09                 | 1.00                 | 3.33        | 1.68           | 0.00           | 3.36                 | 1.00                 |
| SGP  | Dec-94 | 1.70        | 0.86            | 0.95           | 1.71                 | 1.00                 | 1.26        | 0.63           | 1.00           | 1.26                 | 1.00                 |
| KOR  | Dec-94 | 2.63        | 1.32            | 0.00           | 2.64                 | 1.00                 | 1.76        | 0.88           | 0.90           | 1.77                 | 1.00                 |
| TWN  | Dec-94 | 1.40        | 0.70            | 1.00           | 1.40                 | 1.00                 | 0.78        | 0.39           | 1.00           | 0.79                 | 0.01                 |
| THA  | Dec-94 | 1.77        | 0.89            | 0.89           | 1.78                 | 1.00                 | 1.38        | 0.69           | 1.00           | 1.39                 | 1.00                 |
| <b>Data set Eastern Europe Consensus Forecasts</b> |        |             |                 |                |                      |                      |             |                |                |                      |                      |
| CZE  | May-98 | 1.57        | 0.79            | 0.98           | 1.58                 | 1.00                 | 1.79        | 0.90           | 0.80           | 1.80                 | 1.00                 |
| HUN  | May-98 | 2.88        | 1.45            | 0.00           | 2.90                 | 1.00                 | 1.62        | 0.81           | 0.95           | 1.63                 | 1.00                 |
| POL  | May-98 | 1.46        | 0.73            | 1.00           | 1.47                 | 1.00                 | 1.46        | 0.74           | 0.99           | 1.47                 | 1.00                 |
| TUR  | May-98 | 2.29        | 1.15            | 0.11           | 2.31                 | 1.00                 | 0.84        | 0.42           | 1.00           | 0.84                 | 0.11                 |
| SVK  | May-98 | 4.32        | 2.17            | 0.00           | 4.34                 | 1.00                 | 1.08        | 0.55           | 1.00           | 1.09                 | 0.77                 |
| <b>Data set Latin American Consensus Forecasts</b> |        |             |                 |                |                      |                      |             |                |                |                      |                      |
| ARG  | Apr-01 | 3.15        | 1.58            | 0.00           | 3.17                 | 1.00                 | 2.48        | 1.24           | 0.02           | 2.49                 | 1.00                 |
| BRA  | Apr-01 | 1.10        | 0.55            | 1.00           | 1.11                 | 0.84                 | 0.74        | 0.37           | 1.00           | 0.75                 | 0.01                 |
| CHL  | Apr-01 | 4.13        | 2.08            | 0.00           | 4.15                 | 1.00                 | 1.59        | 0.80           | 0.97           | 1.59                 | 1.00                 |
| MEX  | Apr-01 | 3.06        | 1.54            | 0.00           | 3.07                 | 1.00                 | 1.75        | 0.88           | 0.87           | 1.76                 | 1.00                 |
| VEN  | Apr-01 | 1.29        | 0.65            | 1.00           | 1.30                 | 0.99                 | 1.00        | 0.50           | 1.00           | 1.01                 | 0.53                 |
| <b>Mean</b>  |        | <b>2.60</b> |                 |                |                      |                      | <b>1.49</b> |                |                |                      |                      |
| <b>Accept hyp 2 (3&amp;5)</b>                      |        |             | <b>15 of 34</b> |                | <b>0 of 34</b>       |                      |             | <b>6 of 34</b> |                | <b>4 of 34</b>       |                      |

We examine  $\hat{V} = \hat{V}_1/\hat{V}_2 = \mathbb{V}[(\bar{a}_{t+h} - \theta_{t+h})] / \mathbb{V}[(\bar{a}_{i,t+h} - \bar{a}_{t+h})]$ , i.e. the ratio of the estimated variance for the cross-sectional mean *action error* and the variance of deviations from the cross-sectional mean action. We correct the estimates for autocorrelation using MA-processes with  $h + 1$  lags.  $h$  is the forecast horizon, either 3 months or 12 months. We execute F-tests for **Hypothesis 2**, **Hypothesis 3** and **Hypothesis 5**.  $F_2$  shows the F-statistics for **Hypothesis 2** with the null  $V_0 = 2$  and the alternative  $V_A > 2$ .  $P_2$  shows its p-value. If  $P_2 \leq 0.10$ , we reject the null and accept the alternative that  $V > 2$  on the 90%-level: “Higher precision in public signals is welfare increasing”.  $F_{3\&5}$  shows the F-statistics for **Hypothesis 3** & **Hypothesis 5** with the null  $V_0 = 1$  and the alternative  $V_A < 1$ .  $P_{3\&5}$  shows its p-value. If  $P_{3\&5} \leq 0.10$ , we reject the null and accept the alternative: **Hypothesis 3** “The private signal is more precise than the public” and **Hypothesis 5** “Higher precision in private signals is socially beneficial”. Degrees of freedom for the F-tests are  $T - h - 1$  and  $NT - h - 1$ .  $T$  and  $NT$  are listed in **Table 7**. **Accept hyp 2 (3&5)** shows the number of countries for which we accept **Hypothesis 2**, **Hypothesis 3** and **Hypothesis 5** on the 90%-level.

**Table 5:** Yields' test of **Hypothesis 2**, **Hypothesis 3** & **Hypothesis 5** – “Higher precision in public signals is welfare increasing” – “Private signals are more precise than public” – “Higher precision in private signals is socially beneficial”

|  |        | h=3         |                |                |                      |                      | h=12        |                |                |                      |                      |
|--|--------|-------------|----------------|----------------|----------------------|----------------------|-------------|----------------|----------------|----------------------|----------------------|
|  |        | $\hat{V}$   | F <sub>2</sub> | P <sub>2</sub> | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | $\hat{V}$   | F <sub>2</sub> | P <sub>2</sub> | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> |
| <b>Data set Western Consensus Forecasts</b>        |        |             |                |                |                      |                      |             |                |                |                      |                      |
| USA  | Oct-89 | 1.98        | 0.99           | 0.53           | 1.98                 | 1.00                 | 1.25        | 0.63           | 1.00           | 1.26                 | 1.00                 |
| JPN  | Jan-90 | 2.04        | 1.02           | 0.38           | 2.04                 | 1.00                 | 1.14        | 0.57           | 1.00           | 1.14                 | 0.95                 |
| DEU  | Oct-89 | 1.85        | 0.93           | 0.82           | 1.85                 | 1.00                 | 1.68        | 0.84           | 0.98           | 1.69                 | 1.00                 |
| FRA  | Oct-89 | 1.72        | 0.86           | 0.96           | 1.72                 | 1.00                 | 1.40        | 0.70           | 1.00           | 1.41                 | 1.00                 |
| GBR  | Oct-89 | 1.61        | 0.81           | 1.00           | 1.61                 | 1.00                 | 1.07        | 0.54           | 1.00           | 1.08                 | 0.83                 |
| ITA  | Oct-89 | 1.87        | 0.94           | 0.77           | 1.87                 | 1.00                 | 1.45        | 0.73           | 1.00           | 1.46                 | 1.00                 |
| CAN  | Oct-89 | 1.46        | 0.73           | 1.00           | 1.47                 | 1.00                 | 0.93        | 0.47           | 1.00           | 0.94                 | 0.24                 |
| NLD  | Jan-95 | 1.84        | 0.92           | 0.80           | 1.85                 | 1.00                 | 1.21        | 0.61           | 1.00           | 1.21                 | 0.98                 |
| NOR  | Jun-98 | 1.56        | 0.78           | 0.99           | 1.56                 | 1.00                 | 1.18        | 0.59           | 1.00           | 1.19                 | 0.96                 |
| ESP  | Jan-95 | 1.42        | 0.71           | 1.00           | 1.42                 | 1.00                 | 1.30        | 0.65           | 1.00           | 1.30                 | 1.00                 |
| SWE  | Jan-95 | 1.61        | 0.81           | 0.99           | 1.62                 | 1.00                 | 1.17        | 0.59           | 1.00           | 1.18                 | 0.96                 |
| CHE  | Jun-98 | 1.82        | 0.91           | 0.81           | 1.82                 | 1.00                 | 1.15        | 0.58           | 1.00           | 1.16                 | 0.93                 |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |        |             |                |                |                      |                      |             |                |                |                      |                      |
| AUS  | Nov-90 | 1.92        | 0.96           | 0.66           | 1.92                 | 1.00                 | 1.84        | 0.92           | 0.79           | 1.85                 | 1.00                 |
| IND  | Dec-94 | 1.67        | 0.84           | 0.89           | 1.69                 | 1.00                 | 0.96        | 0.48           | 1.00           | 0.96                 | 0.41                 |
| IDN  | Dec-94 | 2.95        | 1.48           | 0.00           | 2.97                 | 1.00                 | 2.23        | 1.12           | 0.20           | 2.24                 | 1.00                 |
| NZL  | Dec-94 | 1.43        | 0.72           | 1.00           | 1.43                 | 1.00                 | 0.97        | 0.49           | 1.00           | 0.98                 | 0.41                 |
| KOR  | Dec-94 | 0.80        | 0.41           | 1.00           | 0.81                 | 0.16                 | 0.70        | 0.36           | 1.00           | 0.72                 | 0.10                 |
| TWN  | Mar-06 | 1.42        | 0.72           | 0.98           | 1.43                 | 0.99                 | 0.74        | 0.38           | 1.00           | 0.75                 | 0.06                 |
| THA  | Dec-94 | 2.02        | 1.02           | 0.43           | 2.04                 | 1.00                 | 1.32        | 0.66           | 1.00           | 1.33                 | 0.98                 |
| <b>Data set Eastern Europe Consensus Forecasts</b> |        |             |                |                |                      |                      |             |                |                |                      |                      |
| CZE  | Jan-06 | 2.43        | 1.22           | 0.06           | 2.44                 | 1.00                 | 1.63        | 0.82           | 0.90           | 1.65                 | 1.00                 |
| HUN  | Jan-06 | 2.40        | 1.21           | 0.07           | 2.42                 | 1.00                 | 1.28        | 0.65           | 1.00           | 1.29                 | 0.97                 |
| POL  | Jan-06 | 1.91        | 0.96           | 0.59           | 1.93                 | 1.00                 | 0.92        | 0.47           | 1.00           | 0.93                 | 0.33                 |
| SVK  | Jan-06 | 1.02        | 0.51           | 1.00           | 1.03                 | 0.59                 | 0.85        | 0.43           | 1.00           | 0.85                 | 0.15                 |
| <b>Mean</b>  |        | <b>1.77</b> |                |                |                      |                      | <b>1.23</b> |                |                |                      |                      |
| <b>Accept hyp 2 (3 &amp; 5)</b>                    |        |             | <b>3 of 23</b> |                | <b>0 of 23</b>       |                      |             | <b>0 of 23</b> |                | <b>2 of 23</b>       |                      |

We examine  $\hat{V} = \hat{V}_1 / \hat{V}_2 = \mathbb{V}[(\bar{a}_{t+h} - \theta_{t+h})] / \mathbb{V}[(a_{t,t+h} - \bar{a}_{t+h})]$ , i.e. the ratio of the estimated variance for the cross-sectional mean *action error* and the variance of deviations from the cross-sectional mean action. We correct the estimates for autocorrelation using MA-processes with  $h + 1$  lags.  $h$  is the forecast horizon, either 3 months or 12 months. We execute F-tests for **Hypothesis 2**, **Hypothesis 3** and **Hypothesis 5**.  $F_2$  shows the F-statistics for **Hypothesis 2** with the null  $V_0 = 2$  and the alternative  $V_A > 2$ .  $P_2$  shows its p-value. If  $P_2 \leq 0.10$ , we reject the null and accept the alternative that  $V > 2$ : “Higher precision in public signals is welfare increasing”.  $F_{3\&5}$  shows the F-statistics for **Hypothesis 3** & **Hypothesis 5** with the null  $V_0 = 1$  and the alternative  $V_A < 1$  on the 90%-level.  $P_{3\&5}$  shows its p-value. If  $P_{3\&5} \leq 0.10$ , we reject the null and accept the alternative: **Hypothesis 3** “The private signal is more precise than the public” and **Hypothesis 5** “Higher precision in private signals is socially beneficial”. Degrees of freedom for the F-tests are  $T - h - 1$  and  $NT - h - 1$ .  $T$  and  $NT$  are listed in **Table 7**. **Accept hyp 2 (3 & 5)** shows the number of countries for which we accept **Hypothesis 2**, **Hypothesis 3** and **Hypothesis 5** on the 90%-level.



## 6.4 Case study of **Hypothesis 3** and **Hypothesis 5** – forward guidance vs publication of the central banks’ internal interest rate forecasts

In this subsection, we check whether forward guidance or the publication of central banks’ internal interest rate forecasts affected the relative precision of the public signal. As such, we further investigate **Hypothesis 3** and **Hypothesis 5**.

Six central banks used forward guidance according to Charbonneau & Rennison (2015) – the Bank of Japan from Apr-1999 to Jul-2000 and Oct-2010 to Mar-2013, the Fed from Dec-2008 to Jun-2017, the Bank of Canada from Apr-2009 to Apr-2010, the Riksbank from Apr-2009 to Jul-2010 and Feb-2013 to Dec-2014, the ECB (we use DEU) from Jul-2013 to Jun-2017, and the Bank of England from Aug-2013 to Jun-2017.

Following Svensson (2015), there are five countries in our sample whose central banks published their internal interest rate forecasts – New Zealand from Jun-1997, Norway from Nov-2005, Sweden from Feb-2007, the Czech Republic from Jan-2008, and the US from Jan-2012.

In addition, we use Switzerland (CHE) and Hong Kong (HKG) as counterfactual for countries that had a zero lower bound (ZLB) – equated with interest rates  $< 0.5\%$  – that did not publish their internal interest rate forecasts or resort to forward guidance. Note that forward guidance as an unconventional monetary policy instrument is closely tied to the ZLB. The ZLB period also coincided with the publication of the internal interest rate forecasts. The counterfactual allows us to distinguish between the publication of internal interest rates, forward guidance and the ZLB. The Swiss National Bank’s ZLB period is from Feb-2009 onwards, while Hong Kong Monetary Authority’s ZLB period lasted from May-2009 to Dec-2015.

For each country, we focus on the reported short-term interest rate forecasts with a 3-month horizon due to the direct effect of central banks on short-term rates. We estimate  $V$  for the sub-periods under forward guidance, the publication of internal interest rate forecasts and ZLB periods and compare these with estimates for the periods without forward guidance.

**Table 6** reports the results. The top panel shows that during forward guidance periods, we can accept **Hypothesis 3** that the public signal is significantly less precise than the private signal in the US and the UK. For the periods in which forward guidance was not effective, we have no evidence that the public signal was less precise than the private signal in any country.<sup>37</sup> A public signal that is less precise than the private signal leads to the acceptance of **Hypothesis 5**: Higher precision in private signals is socially beneficial.

The middle panel of **Table 6** compares the results for periods with and without publications of internal interest rate forecasts. Only for the US and the Czech Republic is the public signal significantly less precise than the private signal. However, in the US, the period of publication of interest rate forecasts overlaps with the period for forward guidance. Because forward guidance was initiated before the publication of internal rate forecasts, this finding suggests that forward guidance, and not the publication of rate forecasts, contributed to public signals in the US becoming less precise than private signals. We conclude that there is only evidence that the publication of internal interest rate forecasts made the public signal less precise than the private signal in the Czech Republic.

The bottom panel of **Table 6** shows the results for the ZLB constraint. Based on Switzerland and Hong Kong with ZLB periods combined with neither publication of internal interest rate forecasts nor forward guidance, we cannot draw conclusions about relative precision in the two signals during the ZLB periods.

In summary, there are three emerging conclusions. First, forward guidance periods are characterized by public signals that are less precise than private signals, which indicates that higher precision in private signals is socially beneficial. Second, we can barely assess the relative precision in the signals associated with the publication of internal interest rate forecasts. Third, during the ZLB constraint, we cannot draw clear conclusions about the relative precision of signals.

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<sup>37</sup> In a related paper (Lustenberger & Rossi (2017)), we estimate central bank transparency and communication as well as the effectiveness of forward guidance on private sector forecasts. We found that forward guidance had no significant effect on the accuracy of consensus forecasts for interest rates. However, it improved the accuracy of consensus forecasts of yields in some countries. By contrast, forward guidance appears to decrease the dispersion of interest rate forecasts, but did not affect the dispersion of yield forecasts.

**Table 6:** Interest rate forecasts with 3-month forecast horizon – Forward guidance vs central banks’ publication of internal interest rate forecasts

|     |        | total sample |                      |                      |     |      | no forward guidance |                      |                      |     |      | forward guidance |                      |                      |    |      |
|-----|--------|--------------|----------------------|----------------------|-----|------|---------------------|----------------------|----------------------|-----|------|------------------|----------------------|----------------------|----|------|
|     |        | $\hat{V}$    | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$           | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$        | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T  | NT   |
| USA | Oct-89 | 1.76         | 1.77                 | 1.00                 | 330 | 7846 | 1.77                | 1.78                 | 1.00                 | 231 | 5422 | 0.37             | 0.37*                | 0.00                 | 99 | 2424 |
| JPN | Jan-90 | 2.00         | 2.00                 | 1.00                 | 330 | 4965 | 2.10                | 2.11                 | 1.00                 | 292 | 4516 | 0.95             | 0.97                 | 0.49                 | 38 | 449  |
| DEU | Oct-89 | 1.65         | 1.66                 | 1.00                 | 330 | 7892 | 1.66                | 1.66                 | 1.00                 | 286 | 6946 | 1.37             | 1.41                 | 0.95                 | 44 | 946  |
| GBR | Oct-89 | 1.56         | 1.57                 | 1.00                 | 330 | 7695 | 1.63                | 1.64                 | 1.00                 | 287 | 6939 | 0.44             | 0.45*                | 0.00                 | 43 | 756  |
| CAN | Oct-89 | 2.73         | 2.74                 | 1.00                 | 330 | 4819 | 2.74                | 2.75                 | 1.00                 | 321 | 4704 | 0.32             | 0.39                 | 0.15                 | 9  | 115  |
| SWE | Jan-95 | 1.92         | 1.93                 | 1.00                 | 267 | 2900 | 1.95                | 1.96                 | 1.00                 | 236 | 2616 | 0.74             | 0.76                 | 0.20                 | 31 | 284  |

|     |        | total sample |                      |                      |     |      | no publication |                      |                      |     |      | publication |                      |                      |     |      |
|-----|--------|--------------|----------------------|----------------------|-----|------|----------------|----------------------|----------------------|-----|------|-------------|----------------------|----------------------|-----|------|
|     |        | $\hat{V}$    | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$      | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$   | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   |
| USA | Oct-89 | 1.76         | 1.77                 | 1.00                 | 330 | 7846 | 1.74           | 1.75                 | 1.00                 | 268 | 6277 | 0.43        | 0.44*                | 0.00                 | 62  | 1569 |
| NOR | Jan-90 | 2.78         | 2.80                 | 1.00                 | 226 | 1702 | 3.08           | 3.11                 | 1.00                 | 90  | 820  | 2.23        | 2.25                 | 1.00                 | 136 | 882  |
| SWE | Oct-89 | 1.92         | 1.93                 | 1.00                 | 267 | 2900 | 1.97           | 1.98                 | 1.00                 | 146 | 1691 | 1.51        | 1.52                 | 1.00                 | 121 | 1209 |
| NZL | Jun-98 | 2.35         | 2.36                 | 1.00                 | 268 | 3203 | 2.24           | 2.32                 | 1.00                 | 31  | 388  | 2.64        | 2.65                 | 1.00                 | 237 | 2815 |
| CZE | Jan-95 | 1.57         | 1.58                 | 1.00                 | 173 | 2239 | 2.71           | 2.75                 | 1.00                 | 63  | 934  | 0.69        | 0.70*                | 0.01                 | 110 | 1305 |

|     |        | total sample |                      |                      |     |      | no ZLB    |                      |                      |     |      | ZLB       |                      |                      |    |      |
|-----|--------|--------------|----------------------|----------------------|-----|------|-----------|----------------------|----------------------|-----|------|-----------|----------------------|----------------------|----|------|
|     |        | $\hat{V}$    | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$ | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T   | NT   | $\hat{V}$ | F <sub>3&amp;5</sub> | P <sub>3&amp;5</sub> | T  | NT   |
| CHE | Jun-98 | 2.86         | 2.87                 | 1.00                 | 226 | 2407 | 2.71      | 2.73                 | 1.00                 | 129 | 1319 | 2.11      | 2.13                 | 1.00                 | 97 | 1088 |
| HKG | Dec-94 | 6.57         | 6.59                 | 1.00                 | 268 | 2935 | 7.10      | 7.14                 | 1.00                 | 192 | 2240 | 0.96      | 0.97                 | 0.45                 | 76 | 695  |

We examine  $\hat{V} = \hat{V}_1 / \hat{V}_2 = \mathbb{V} [(i\bar{a}_{t+h} - \theta_{t+h})] / \mathbb{V} [(i a_{i,t+h} - i\bar{a}_{t+h})]$ , that is the ratio of the estimated variance for the cross-sectional mean *action error* and the variance of deviations from the cross-sectional mean action. We correct the estimates for autocorrelation using MA-processes with 3 + 1 lags, since the forecast horizon is 3 months. We execute F-tests for **Hypothesis 3** and **Hypothesis 5**. F<sub>3&5</sub> shows the F-statistics for **Hypothesis 3** and **Hypothesis 5** with the null  $V_0 = 1$  and the alternative  $V_A < 1$ . P<sub>3&5</sub> shows its p-value. If  $P_{3\&5} \leq 0.10$ , we reject the null and accept the alternative  $V < 1$  (\* indicates acceptance of the alternative on the 90%-level): “The public signal is less precise than the private signal” and, additionally, in the Veldkamp (2011) case “Higher precision in private signals is socially beneficial”. Degrees of freedom for the F-tests are  $T - h - 1$  and  $NT - h - 1$ , where  $NT$  is the total number of observations. We run the F-test for the total sample, which starts by the date shown next to countrycodes and ends in Jun-2017, and two subsamples, one with no forward guidance and the other with forward guidance (top panel). We also run the F-test for the period with central banks’ interest rate forecast publications and without (middle panel). Finally, we run the F-test for periods without and with ZLB constraints (bottom panel). **Forward guidance:** We use Charbonneau & Rennison (2015) as source for countries with forward guidance, the USA from Dec-2008 to Jun-2017, JPN from Apr-1999 to Jul-2000 and from Oct-2010 to Mar-2013, ECB (we use reported forecast from DEU) from Jul-2013 to Jun-2017, GBR from Aug-2013 to Jun-2017, CAN from Apr-2009 to Apr-2010, and SWE from Apr-2009 to Jul-2010 and Feb-2013 to Dec-2014. **Publication:** Publication indicates if a country’s central bank publishes its internal interest rate forecasts based on Svensson (2015). Countries are the USA from Jan-2012, NOR from Nov-2005, SWE from Feb-2007, NZL from Jun-1997, and CZE from Jan-2008. **Zero lower bound (ZLB):** We use CHE and HKG as counterfactual for countries which reached the ZLB (interest rate < 0.5%) but did neither introduce forward guidance nor publish their internal interest rate forecasts. ZLB period for CHE is from Feb-2009 onwards and for HKG from May-2009 to Dec-2015.

## 7 Properties of public and private signals

In this section we derive two empirical properties of the signals. The first is related to the question as to whether public signals crowd out private signals in the MS model. The second is associated with the speed with which the agents correct errors that are contained in the two signals.

### 7.1 What is the maximum weight for private signals in the MS model?

Based on MS, we define  $\kappa$  as the measure of the weight that is given to the private signal

$$\kappa = \frac{\beta(1-r)}{\alpha + \beta(1-r)} \quad (30)$$

and  $(1 - \kappa)$  as the measure of the weight that is given to the public signal

$$(1 - \kappa) = \frac{\alpha}{\alpha + \beta(1-r)} \quad (31)$$

We can formulate  $\kappa$  as a function of  $V$  (and  $r$ )<sup>38</sup>

$$\kappa = \frac{1}{(1 + V(1-r))} \quad (32)$$

We take the limits of  $r$  (i.e.  $r \rightarrow 0$  and  $r \rightarrow 1$ ). The results for extreme  $\kappa$  values are reported in **Table 11** for interest rates and yields.<sup>39</sup> The results are very similar. The maximum weight attached to the private signal is obtained when  $r = 0$ . The mean across countries for the maximum weight given to the private signal is 0.31 (0.37) for interest rates (yields) at the 3-month forecast horizon and 0.43 (0.46) at the 12-month horizon.<sup>40</sup> This indicates that at least approximately two-thirds of *action errors* are from public signals.<sup>41</sup> Hence, in the extreme scenario of no coordination ( $r = 0$ ), Svensson's (2006) benchmark case of equal signal precision ( $\alpha/\beta = 1$  leading to  $\kappa = 0.5$ ) holds only weakly.

<sup>38</sup> See **Appendix A.2.4** for its derivation.

<sup>39</sup> See **Appendix C**.

<sup>40</sup> In fact, for interest rates,  $\kappa$  at the 3-month horizon is lower than  $\kappa$  at the 12-month horizon with only two exceptions (CZE and POL). For yields, this is always the case.

<sup>41</sup> For interest rates  $1 - 0.5 \cdot (0.31 + 0.43) = 0.63$  and yields  $1 - 0.5 \cdot (0.37 + 0.46) = 0.58$

## 7.2 How quickly do agents correct errors in the signals?

In the previous subsection, we obtained a high proportion of *action errors* from public signals. This subsection explores how quickly agents correct past errors in the signals over time. As such, we calculate averages of MA-estimates across countries for each time lag (1 to 4 and 13, respectively). **Figure 5** (interest rates) and **Figure 6** (yields) plot the average MA-estimates for each time lag. They suggest that agents rapidly correct errors in the private signal, while errors in the public signal extend over the entire forecast horizon.<sup>42</sup> This corroborates our assumption that agents use forecasts from the last period ( $t - 1$ ) as public signals for the current period ( $t$ ). An error in the private signal from the last period continues in the public signal until the *action error* materializes. In addition, the plots show that using an MA(4) or MA(13) process for *action errors* adequately describes the data. The coefficients are decreasing and the estimate at lag 4 (13) is very low and close to 0.

## 8 Conclusions

We are the first to derive and empirically test three hypotheses that originate from the Morris & Shin (2002) beauty-contest model. In addition, we performed two tests for the non-beauty contest model that was provided by Veldkamp (2011). As such, we compiled a comprehensive data set that included more than 340,000 forecasts of short-term interest rates and long-term yields across several geographical areas from the late 1980s to June 2017. This data is very useful for our purpose. As documented in the strategic forecast literature, forecasters play a game with each other. This allows us to interpret reported forecasts as actions in this type of game, from which we derive testable implications. Three primary results emerge from our analysis.

- 1) We find that most countries produce unbiased interest rate forecasts. This is consistent with both models. By contrast, reported yield forecasts are biased and inconsistent with both models.
- 2) In half of the countries, higher precision in public information induces higher social welfare for interest rates at a 3-month horizon for the Veldkamp (2011) model as well as the MS model. For these countries, the intriguing theoretical

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<sup>42</sup> For the 12-month forecast horizon, we detect spikes in MA processes for both interest rates and yields.

possibility of MS may not apply, which supports Svensson (2006)'s critique that they fare better with more precise public information.

3) It is almost impossible to assess the relative precision of public to private signals. However, limiting the analysis to episodes in which there has been forward guidance, we find that it tends to be characterized by less precise public signals compared to private signals. In a Veldkamp (2011) type of model, it is implied that higher precision in private information always increases social welfare. Thus, when forward guidance is in force, higher precision in private information increases welfare regardless of the model. This also indicates that if forward guidance is understood to be a measure for increasing the precision of public information, our results cast doubts on its effectiveness as a monetary policy instrument in times when there is a binding ZLB constraint.

Future research could use forecasts of other variables, such as the CPI. In addition, studies should examine which of the four types of economies that Angeletos & Pavan (2007) identified is more successful for matching the data. Future contributions could also focus on developing a general empirical test for the types of models that were analyzed in this paper using other utility and welfare specifications. Furthermore, it is debatable whether higher precision in public information is tantamount to greater central bank transparency, as is commonly posited in the literature. This is also a possible avenue for future research. A related question could be how to achieve more precision in private information. Finally, a detailed analysis of how signals are structured over time could also be a promising line for future work.

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# Appendix A Theoretical definitions, identities and derivations

## Appendix A.1 Definition of a beauty contest

For the definition of a beauty contest, we follow Angeletos & Pavan (2007). The utility function is  $u(a_i, \bar{a}, \sigma_a, \theta)$  and the welfare function is provided by

$$W(\bar{a}, \sigma_a, \theta) = u(\bar{a}, \bar{a}, \sigma_a, \theta) + \frac{1}{2}u_{a_i a_i} \sigma_a^2$$

$a_i$  is agent  $i$ 's action,  $\bar{a}$  is the mean and  $\sigma_a$  is the dispersion of actions. Angeletos & Pavan (2007) use the following identities

$$\begin{aligned} \omega_0 &= \frac{-u_{a_i}(0, 0, 0, 0)}{u_{a_i a_i} + u_{a_i \bar{a}}} & \omega_0^* &= \frac{-W_{\bar{a}}(0, 0, 0)}{u_{a_i a_i} + 2u_{a_i \bar{a}} + u_{\bar{a} \bar{a}}} \\ \omega_1 &= \frac{-u_{a_i \theta}}{u_{a_i a_i} + u_{a_i \bar{a}}} & \omega_1^* &= \frac{-W_{\bar{a} \theta}}{u_{a_i a_i} + 2u_{a_i \bar{a}} + u_{\bar{a} \bar{a}}} \\ \lambda &= \frac{u_{a_i \bar{a}}}{-u_{a_i a_i}} & \lambda^* &= 1 - \frac{u_{a_i a_i} + 2u_{a_i \bar{a}} + u_{\bar{a} \bar{a}}}{u_{a_i a_i} + u_{\sigma_a \sigma_a}} \end{aligned}$$

with  $\omega = \omega_0 + \omega_1 \theta$  and  $\omega^* = \omega_0^* + \omega_1^* \theta$ , and define a beauty contest as

$$\omega = \omega^* \text{ and } \lambda > 0 = \lambda^*$$

According Angeletos & Pavan (2007),  $\lambda$  corresponds to the *equilibrium degree of coordination*, while  $\lambda^*$  is the *socially optimal degree of coordination*.

### Appendix A.1.1 MS as a beauty contest

In the MS model we have

$$u_i(a_i, \bar{a}, \sigma_a, \theta) = -(1-r)(a_i - \theta)^2 - r(a_i - \bar{a})^2 + r\sigma_a^2$$

and, therefore  $u_{a_i} = -2(1-r)(a_i - \theta) - 2r(a_i - \bar{a})$ ,  $u_{a_i a_i} = -2$ ,  $u_{a_i \bar{a}} = 2r$ ,  $u_{a_i \theta} = 2(1-r)$ ,  $u_{\bar{a}} = 2r(a_i - \bar{a})$ ,  $u_{\bar{a} \bar{a}} = -2r$ ,  $u_{\sigma_a} = 2r\sigma_a$ , and  $u_{\sigma_a \sigma_a} = 2r$ , leading to the welfare function

$$W(\bar{a}, \sigma_a, \theta) = -(1-r)(\bar{a} - \theta)^2 - (1-r)\sigma_a^2$$

with  $W_{\bar{a}} = -2(1-r)(\bar{a} - \theta)$  and  $W_{\bar{a} \theta} = 2(1-r)$ . In contrast to MS, we refrain from normalizing (without a loss of generality) the welfare function for this proof

with  $1/(1-r)$ . Using the identities and the definition of a beauty contest that is presented in **Appendix A.1**, we obtain

$$\begin{aligned}\omega_0 &= \frac{-0}{-2+2r} = 0 & \omega_0^* &= \frac{0}{-2+2 \cdot 2r - 2r} = 0 \\ \omega_1 &= \frac{-2(1-r)}{-2+2r} = 1 & \omega_1^* &= \frac{-2(1-r)}{-2+2 \cdot 2r - 2r} = 1 \\ \lambda &= \frac{2r}{-(-2)} = r & \lambda^* &= 1 - \frac{-2+2 \cdot 2r - 2r}{-2+2r} = 0\end{aligned}$$

Clearly, MS is a beauty contest model because it satisfies  $\omega = \omega^*$  and  $\lambda > 0 = \lambda^*$ .

### Appendix A.1.2 Veldkamp (2011) as a non-beauty contest

In the Veldkamp (2011) model we have

$$u_i(a_i, \bar{a}, \sigma_a, \theta) = -(1-r)(a_i - \theta)^2 - r\sigma_a^2$$

and, therefore  $u_{a_i} = -2(1-r)(a_i - \theta)$ ,  $u_{a_i a_i} = -2(1-r)$ ,  $u_{a_i \bar{a}} = 0$ ,  $u_{a_i \theta} = 2(1-r)$ ,  $u_{\bar{a}} = 0$ ,  $u_{\bar{a} \bar{a}} = 0$ ,  $u_{\sigma_a} = -2r\sigma_a$ , and  $u_{\sigma_a \sigma_a} = -2r$ . This leads to the welfare function

$$W(\bar{a}, \sigma_a, \theta) = -(1-r)(\bar{a} - \theta)^2 - \sigma_a^2$$

with  $W_{\bar{a}} = -2(1-r)(\bar{a} - \theta)$  and  $W_{\bar{a}\theta} = 2(1-r)$ . Using the identities and the definition of a beauty contest that is presented in **Appendix A.1**, we obtain

$$\begin{aligned}\omega_0 &= \frac{-0}{-2(1-r)+0} = 0 & \omega_0^* &= \frac{-0}{-2(1-r)+2 \cdot 0+0} = 0 \\ \omega_1 &= \frac{-2(1-r)}{-2(1-r)+0} = 1 & \omega_1^* &= \frac{-2(1-r)}{-2(1-r)+2 \cdot 0+0} = 1 \\ \lambda &= \frac{0}{-(-2(1-r))} = 0 & \lambda^* &= 1 - \frac{-2(1-r) - 2r}{-2(1-r) - 2r} \\ & & &= 1 - \frac{-2(1-r)}{-2} = 1 - (1-r) = r\end{aligned}$$

Because  $\omega = \omega^*$  but  $\lambda = 0$  and  $\lambda^* = r > 0$ , we conclude that the Veldkamp (2011) model does not correspond to a beauty-contest framework.

## Appendix A.2 Derivation of theoretical identities in the MS model

### Appendix A.2.1 Mean *action errors* and *action error* variances

Derivation of **Equation (5)**: Ex-post cross-sectional mean *action error*

$$\begin{aligned}\bar{a} - \theta &= \frac{1}{N} \sum_{i=1}^N [a_i - \theta] \\ &= \frac{1}{N} \sum_{i=1}^N \left[ \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \right] \\ &= \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta\end{aligned}\tag{33}$$

because  $\varepsilon_i \sim iidN(0, 1/\beta)$ , but  $\eta$  is (ex-post) the same for all agents at a specific point in time.

Derivation of **Equation (6)**: Expected *action error* of agent  $i$

$$\begin{aligned}\mathbb{E}[a_i - \theta] &= \mathbb{E} \left[ \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \right] \\ &= 0\end{aligned}\tag{34}$$

since  $\varepsilon_i \sim iidN(0, 1/\beta)$  and  $\eta \sim iidN(0, 1/\alpha)$ .

Derivation of **Equation (7)**: Expected cross-sectional mean *action error*

$$\begin{aligned}\mathbb{E}[\bar{a} - \theta] &= \mathbb{E} \left[ \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta \right] \\ &= 0\end{aligned}\tag{35}$$

## Appendix A.2.2 Variance ratio $V$

Derivation of **Equation (8)**: The variance of the ex-post cross-sectional mean *action errors* is given by

$$\begin{aligned}
 V_1 &= \mathbb{V} \left[ (\bar{a} - \theta) \right] = \mathbb{V} \left[ \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta \right] \\
 &= \mathbb{E} \left[ \left( \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta \right)^2 \right] - \overbrace{\left( \mathbb{E} \left[ \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta \right] \right)^2}^{=0} \\
 &= \left( \frac{\alpha}{\alpha + \beta(1-r)} \right)^2 \cdot \mathbb{E} \left[ \eta^2 \right] = \frac{\alpha^2}{(\alpha + \beta(1-r))^2} \cdot \frac{1}{\alpha} \\
 &= \frac{\alpha}{(\alpha + \beta(1-r))^2} \tag{36}
 \end{aligned}$$

Derivation of **Equation (9)**: The ex-post individual *action error* component (error contained in the private signal) is

$$\begin{aligned}
 a_i - \theta &= \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \\
 &= (\bar{a} - \theta) + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \\
 \Leftrightarrow (a_i - \theta) - (\bar{a} - \theta) &= \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \\
 a_i - \bar{a} &= \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \tag{37}
 \end{aligned}$$

Derivation of **Equation (10)**: The variance of agents' deviation from the cross-sectional mean action follows as

$$\begin{aligned}
 V_2 &= \mathbb{V} \left[ ({}_t a_i - \bar{a}) \right] = \mathbb{V} \left[ \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \right] \\
 &= \mathbb{E} \left[ \left( \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \right)^2 \right] - \overbrace{\left( \mathbb{E} \left[ \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i \right] \right)^2}^{=0} \\
 &= \left( \frac{\beta(1-r)}{\alpha + \beta(1-r)} \right)^2 \cdot \mathbb{E} \left[ \varepsilon_i^2 \right] = \frac{\beta^2(1-r)^2}{(\alpha + \beta(1-r))^2} \cdot \frac{1}{\beta} \\
 &= \frac{\beta(1-r)^2}{(\alpha + \beta(1-r))^2} \tag{38}
 \end{aligned}$$

Derivation of **Equation (11)** and **Equation (12)**: The variance ratio is defined as

$$V = \frac{V_1}{V_2} = \frac{\frac{\alpha}{(\alpha+\beta(1-r))^2}}{\frac{\beta(1-r)^2}{(\alpha+\beta(1-r))^2}} = \frac{\alpha}{\beta(1-r)^2}$$

$$\Leftrightarrow \alpha/\beta = V \cdot (1-r)^2 \quad (39)$$

### Appendix A.2.3 Svensson's conditions related to $V$

Connecting Svensson's conditions to the variance ratio  $V$  (**Equation (15)**)

$$\alpha/\beta = V \cdot (1-r)^2 \stackrel{\leq}{\geq} (2r-1)(1-r)$$

$$\Leftrightarrow V \stackrel{\leq}{\geq} (2r-1)/(1-r) \quad (40)$$

### Appendix A.2.4 Ranges for $\kappa$

We derive ranges for the weight that is given to the private signal  $\kappa$ . As such, we present  $\kappa$  as function of  $r$  and then let  $r$  go to its limits 0 and 1, that is, the boundary values of  $r$  that are provided by MS. We begin with the definition of the weight that is given to the private signal,  $\kappa$ . MS define this as

$$\kappa = \frac{\beta(1-r)}{\alpha + \beta(1-r)} \quad (41)$$

$$(1-\kappa) = \frac{\alpha}{\alpha + \beta(1-r)} \quad (42)$$

**Equation (41)** and **Equation (42)** into **Equation (4)** leads to

$$a_i - \theta = \frac{\alpha}{\alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\alpha + \beta(1-r)} \cdot \varepsilon_i$$

$$= (1-\kappa) \cdot \eta_t + \kappa \cdot \varepsilon_i \quad (43)$$

Therefore, from **Equation (41)**, **Equation (42)**, **Equation (8)** and **Equation (10)**

$$\kappa^2 = \frac{\beta^2(1-r)^2}{(\alpha + \beta(1-r))^2} = \beta \cdot \frac{\beta(1-r)^2}{(\alpha + \beta(1-r))^2} = \beta \cdot V_2 \quad (44)$$

$$(1-\kappa)^2 = \frac{\alpha^2}{(\alpha + \beta(1-r))^2} = \alpha \cdot \frac{\alpha}{(\alpha + \beta(1-r))^2} = \alpha \cdot V_1 \quad (45)$$

Dividing **Equation (45)** by **Equation (44)** and using **Equation (12)**

$$\begin{aligned}
\frac{(1-\kappa)^2}{\kappa^2} &= \frac{\alpha V_1}{\beta V_2} = V(1-r)^2 V = V^2(1-r)^2 \\
\Leftrightarrow \frac{1-\kappa}{\kappa} &= V(1-r) \\
\Leftrightarrow 1 &= V(1-r)\kappa + \kappa \\
1 &= \kappa(V(1-r) + 1) \\
\Leftrightarrow \kappa &= \frac{1}{(1+V(1-r))} \tag{46}
\end{aligned}$$

Before we can take the limit of **Equation (46)**, we must check if  $V$  converges to a constant.

$$\lim_{r \rightarrow 0} V = \lim_{r \rightarrow 0} \frac{\alpha}{\beta(1-r)^2} = \alpha/\beta \tag{47}$$

$$\lim_{r \rightarrow 1} V = \lim_{r \rightarrow 1} \frac{\alpha}{\beta(1-r)^2} = \infty \tag{48}$$

Taking the limits of **Equation (46)** for  $r$  yields

$$\lim_{r \rightarrow 0} \kappa = \frac{1}{V+1} = \frac{1}{\alpha/\beta+1} \tag{49}$$

$$\lim_{r \rightarrow 1} \kappa = 0 \tag{50}$$

### Appendix A.2.5 Proper priors and theoretical identities

Veldkamp (2011) shows that with proper priors, the optimal action taken by agent  $i$  equals

$$\begin{aligned}
a_i &= \frac{\tau}{\tau + \alpha + \beta(1-r)} \cdot \mu + \frac{\alpha + \beta(1-r)}{\tau + \alpha + \beta(1-r)} \cdot \theta \\
&\quad + \frac{\alpha}{\tau + \alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\tau + \alpha + \beta(1-r)} \varepsilon_i \tag{51}
\end{aligned}$$

where the prior equals  $\theta \sim iidN(\mu, 1/\tau)$ .

Rearranging **Equation (51)**, we derive the *action error*

$$\begin{aligned}
a_i - \theta &= \frac{\tau}{\tau + \alpha + \beta(1-r)} \cdot (\mu - \theta) \\
&\quad + \frac{\alpha}{\tau + \alpha + \beta(1-r)} \cdot \eta + \frac{\beta(1-r)}{\tau + \alpha + \beta(1-r)} \varepsilon_i \tag{52}
\end{aligned}$$

The ex-post cross-sectional mean *action error* equals

$$\begin{aligned}\bar{a} - \theta &= \frac{\tau}{\tau + \alpha + \beta(1 - r)} \cdot (\mu - \theta) \\ &\quad + \frac{\alpha}{\tau + \alpha + \beta(1 - r)} \cdot \eta\end{aligned}\tag{53}$$

The expected *action error* of agent  $i$  and the expected cross-sectional mean *action error* are

$$\mathbb{E}[a_i - \theta] = 0\tag{54}$$

$$\mathbb{E}[\bar{a} - \theta] = 0\tag{55}$$

The variance follows as

$$\begin{aligned}\mathbb{V}[\bar{a} - \theta] &= \left(\frac{\tau}{\tau + \alpha + \beta(1 - r)}\right)^2 \cdot \mathbb{V}[\mu - \theta] \\ &\quad + \left(\frac{\alpha}{\tau + \alpha + \beta(1 - r)}\right)^2 \cdot 1/\alpha \\ &= \left(\frac{\tau}{\tau + \alpha + \beta(1 - r)}\right)^2 \cdot 1/\tau \\ &\quad + \left(\frac{\alpha}{\tau + \alpha + \beta(1 - r)}\right)^2 \cdot 1/\alpha \\ &= \frac{\tau + \alpha}{(\tau + \alpha + \beta(1 - r))^2}\end{aligned}\tag{56}$$

Agents' deviation from the cross-sectional mean action equals

$$a_i - \bar{a} = \frac{\beta(1 - r)}{\tau + \alpha + \beta(1 - r)} \cdot \varepsilon_i\tag{57}$$

The variance follows as

$$\begin{aligned}\mathbb{V}[a_i - \bar{a}] &= \left(\frac{\beta(1 - r)}{\tau + \alpha + \beta(1 - r)}\right)^2 \cdot 1/\beta \\ &= \frac{\beta(1 - r)^2}{(\tau + \alpha + \beta(1 - r))^2}\end{aligned}\tag{58}$$

The variance ratio of the public to the private signal follows from **Equation (56)**

and **Equation (58)**.

$$V = \frac{\frac{\tau + \alpha}{(\tau + \alpha + \beta(1-r))^2}}{\frac{\beta(1-r)^2}{(\tau + \alpha + \beta(1-r))^2}} = \frac{\tau + \alpha}{\beta(1-r)^2} \quad (59)$$

We see that what was the precision of the public signal ( $\alpha$ ) has now become the common prior and the precision of the public signal ( $\tau + \alpha$ ). The prior is common knowledge and, therefore, is also a type of public signal. The variance ratio remains the same. In addition, **Veldkamp (2011)** shows that the theoretical results of MS also hold under proper priors. For simplicity, we use the improper prior in the calculations. However, as shown, our results call for the same interpretation as the proper prior framework.

### Appendix A.3 Derivation of theoretical identities in the **Veldkamp (2011)** model

#### Appendix A.3.1 Mean *action errors* and *action error variances*

Derivation of **Equation (20)**: Cross-sectional ex-post mean *action error*

$$\begin{aligned} \bar{a} - \theta &= \frac{1}{N} \sum_{i=1}^N [a_i - \theta] \\ &= \frac{1}{N} \sum_{i=1}^N \left[ \frac{\alpha}{\alpha + \beta} \cdot \eta + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right] \\ &= \frac{\alpha}{\alpha + \beta} \cdot \eta \end{aligned} \quad (60)$$

since  $\varepsilon_i \sim iidN(0, 1/\beta)$ , but  $\eta$  is (ex post) the same for all agents at a specific point in time.

Derivation of **Equation (21)**: Expected *action error* for agent  $i$

$$\begin{aligned} \mathbb{E}[a_i - \theta] &= \mathbb{E} \left[ \frac{\alpha}{\alpha + \beta} \cdot \eta + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right] \\ &= 0 \end{aligned} \quad (61)$$

since  $\varepsilon_i \sim iidN(0, 1/\beta)$  and  $\eta \sim iidN(0, 1/\alpha)$ .



Derivation of **Equation (22)**: Expected cross-sectional mean *action error*

$$\begin{aligned}\mathbb{E}[\bar{a} - \theta] &= \mathbb{E}\left[\frac{\alpha}{\alpha + \beta} \cdot \eta\right] \\ &= 0\end{aligned}\tag{62}$$

### Appendix A.3.2 Variance ratio $V$

Derivation of **Equation (23)**: The variance of the ex-post cross-sectional mean *action errors* is given by

$$\begin{aligned}V_1 &= \mathbb{V}\left[\bar{a} - \theta\right] = \mathbb{V}\left[\frac{\alpha}{\alpha + \beta} \cdot \eta\right] \\ &= \mathbb{E}\left[\left(\frac{\alpha}{\alpha + \beta} \cdot \eta\right)^2\right] - \overbrace{\left(\mathbb{E}\left[\frac{\alpha}{\alpha + \beta} \cdot \eta\right]\right)^2}^{=0} \\ &= \left(\frac{\alpha}{\alpha + \beta}\right)^2 \cdot \mathbb{E}\left[\eta^2\right] = \frac{\alpha^2}{(\alpha + \beta)^2} \cdot \frac{1}{\alpha} \\ &= \frac{\alpha}{(\alpha + \beta)^2}\end{aligned}\tag{63}$$

Derivation of **Equation (24)**: The ex-post individual *action error* component (error contained in the private signal) is

$$\begin{aligned}a_i - \theta &= \frac{\alpha}{\alpha + \beta} \cdot \eta + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \\ &= (\bar{a} - \theta) + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \\ \Leftrightarrow (a_i - \theta) - (\bar{a} - \theta) &= \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \\ a_i - \bar{a} &= \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i\end{aligned}\tag{64}$$

Derivation of **Equation (25)**: The variance of agents' deviation from the cross-

sectional mean action follows as

$$\begin{aligned}
V_2 &= \mathbb{V} \left[ (a_i - \bar{a}) \right] = \mathbb{V} \left[ \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right] \\
&= \mathbb{E} \left[ \left( \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right)^2 \right] - \overbrace{\left( \mathbb{E} \left[ \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right] \right)^2}^{=0} \\
&= \left( \frac{\beta}{\alpha + \beta} \right)^2 \cdot \mathbb{E} \left[ \varepsilon_i^2 \right] = \frac{\beta^2}{(\alpha + \beta)^2} \cdot \frac{1}{\beta} \\
&= \frac{\beta}{(\alpha + \beta)^2} \tag{65}
\end{aligned}$$

Derivation of **Equation (26)**: The variance ratio is defined as

$$1/V = \frac{V_2}{V_1} = \frac{\frac{\beta}{(\alpha + \beta)^2}}{\frac{\alpha}{(\alpha + \beta)^2}} = \frac{\beta}{\alpha} \tag{66}$$

Derivation of **Equation (27)**: Using **Equation (17)** and **Equation (19)** welfare writes

$$\begin{aligned}
\mathbb{E} [W(\bar{a}, \sigma_a, \theta) | \theta] &= \mathbb{E} \left[ -(1 - r) \cdot \frac{1}{N} \sum_{i=1}^N \left( \frac{\alpha}{\alpha + \beta} \cdot \eta + \frac{\beta}{\alpha + \beta} \cdot \varepsilon_i \right)^2 - r \cdot \sigma_a^2 \right] \\
&= -(1 - r) \cdot \frac{1}{\alpha + \beta} - r \cdot \frac{\beta}{(\alpha + \beta)^2} \tag{67}
\end{aligned}$$

Derivation of **Equation (28)**: Taking the first derivative of **Equation (27)** with

respect to  $\beta$

$$\begin{aligned}
\frac{\partial \mathbb{E} [W(\bar{a}, \sigma_a, \theta) | \theta]}{\partial \beta} &= (1-r) \cdot \frac{1}{(\alpha+\beta)^2} - r \cdot \frac{(\alpha+\beta)^2 - 2\beta(\alpha+\beta)}{(\alpha+\beta)^4} \\
&= (1-r) \cdot \frac{\alpha+\beta}{(\alpha+\beta)^3} - r \cdot \frac{\alpha+\beta-2\beta}{(\alpha+\beta)^3} \\
&= \frac{(1-r)(\alpha+\beta) - r(\alpha+\beta) + 2r\beta}{(\alpha+\beta)^3} \\
&= \frac{\alpha+\beta - r\alpha - r\beta - r\alpha - r\beta + 2r\beta}{(\alpha+\beta)^3} \\
&= \frac{\alpha+\beta - r\alpha - r\alpha}{(\alpha+\beta)^3} \\
&= \frac{\alpha(1-2r) + \beta}{(\alpha+\beta)^3} \\
&= \frac{\beta - \alpha(2r-1)}{(\alpha+\beta)^3} \tag{68}
\end{aligned}$$

### Appendix A.3.3 Proper priors and theoretical identities

**Appendix A.2.5** shows that the variance ratio does not depend on whether we assume proper or improper priors in the MS model. The same result holds in the Veldkamp (2011) model. We refrain from showing this finding as the proof is similar to **Appendix A.2.5**.

## Appendix B Data description and sources

We perform the tests with log-transformed data

$${}^t a_{i,t+h} = \log \left[ 1 + \frac{{}^t \hat{a}_{i,t+h}}{100} \right] \tag{69}$$

$$\theta_{t+h} = \log \left[ 1 + \frac{\hat{\theta}_{t+h}}{100} \right] \tag{70}$$

where the reported forecast  ${}^t \hat{a}_{i,t+h}$  and the realization  $\hat{\theta}_{t+h}$  are observed.  $t$  is the time period in which an action (reported forecast) is formed, while  $h$  is the forecast horizon.  $i$  indexes the forecasters.

**Table 7:** Observations for reported short-term interest rate forecasts

|  | <b>h=3</b> |     |             |             |      | <b>h=12</b> |     |             |             |      |
|--|------------|-----|-------------|-------------|------|-------------|-----|-------------|-------------|------|
|  | Start      | $T$ | $\bar{N}_t$ | $N^{Total}$ | $NT$ | Start       | $T$ | $\bar{N}_t$ | $N^{Total}$ | $NT$ |
| <b>Data set Consensus Forecasts</b>                |            |     |             |             |      |             |     |             |             |      |
| USA  | Oct-89     | 330 | 23.8        | 76.0        | 7846 | Oct-89      | 321 | 23.4        | 76          | 7501 |
| JPN  | Oct-89     | 330 | 15.0        | 50.0        | 4965 | Oct-89      | 321 | 14.3        | 50          | 4580 |
| DEU  | Oct-89     | 330 | 23.9        | 53.0        | 7892 | Oct-89      | 321 | 23.7        | 52          | 7614 |
| FRA  | Oct-89     | 330 | 15.9        | 52.0        | 5261 | Oct-89      | 321 | 15.7        | 52          | 5049 |
| GBR  | Oct-89     | 330 | 23.3        | 74.0        | 7695 | Oct-89      | 321 | 23.4        | 71          | 7508 |
| ITA  | Oct-89     | 330 | 9.9         | 39.0        | 3282 | Oct-89      | 321 | 9.9         | 39          | 3162 |
| CAN  | Oct-89     | 330 | 14.6        | 42.0        | 4819 | Oct-89      | 321 | 14.6        | 41          | 4676 |
| NLD  | Jan-95     | 267 | 8.7         | 33.0        | 2331 | Jan-95      | 258 | 8.7         | 33          | 2242 |
| NOR  | Jun-98     | 226 | 7.5         | 28.0        | 1702 | Jun-98      | 217 | 7.6         | 27          | 1639 |
| ESP  | Jan-95     | 267 | 12.2        | 30.0        | 3248 | Jan-95      | 258 | 12.1        | 30          | 3110 |
| SWE  | Jan-95     | 267 | 10.9        | 35.0        | 2900 | Jan-95      | 258 | 10.9        | 34          | 2801 |
| CHE  | Jun-98     | 226 | 10.7        | 20.0        | 2407 | Jun-98      | 217 | 10.5        | 20          | 2286 |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |            |     |             |             |      |             |     |             |             |      |
| AUS  | Nov-90     | 317 | 15.3        | 46.0        | 4849 | Nov-90      | 308 | 15.0        | 46          | 4610 |
| CHN  | Jul-03     | 165 | 9.8         | 32.0        | 1611 | Jul-03      | 156 | 9.7         | 32          | 1510 |
| HKG  | Dec-94     | 268 | 11.0        | 47.0        | 2935 | Dec-94      | 259 | 10.8        | 48          | 2810 |
| IND  | Dec-94     | 268 | 6.7         | 46.0        | 1788 | Dec-94      | 259 | 6.0         | 46          | 1562 |
| IDN  | Dec-94     | 268 | 6.5         | 45.0        | 1734 | Dec-94      | 259 | 6.5         | 45          | 1680 |
| MYS  | Dec-94     | 268 | 10.5        | 52.0        | 2816 | Dec-94      | 259 | 10.4        | 53          | 2700 |
| NZL  | Dec-94     | 268 | 12.0        | 30.0        | 3203 | Dec-94      | 259 | 11.9        | 30          | 3082 |
| PHL  | Apr-09     | 92  | 2.9         | 15.0        | 263  | Apr-09      | 83  | 2.5         | 13          | 207  |
| SGP  | Dec-94     | 268 | 10.1        | 44.0        | 2698 | Dec-94      | 259 | 10.1        | 44          | 2615 |
| KOR  | Dec-94     | 268 | 9.6         | 38.0        | 2569 | Dec-94      | 259 | 9.5         | 38          | 2454 |
| TWN  | Dec-94     | 268 | 8.3         | 40.0        | 2213 | Dec-94      | 259 | 8.1         | 40          | 2106 |
| THA  | Dec-94     | 268 | 7.8         | 48.0        | 2094 | Dec-94      | 259 | 7.7         | 48          | 2006 |
| <b>Data set Eastern Europe Consensus Forecasts</b> |            |     |             |             |      |             |     |             |             |      |
| CZE  | May-98     | 173 | 12.9        | 41.0        | 2239 | May-98      | 164 | 12.9        | 41          | 2116 |
| HUN  | May-98     | 173 | 10.4        | 37.0        | 1797 | May-98      | 164 | 10.4        | 37          | 1708 |
| POL  | May-98     | 173 | 12.9        | 45.0        | 2232 | May-98      | 164 | 12.8        | 44          | 2097 |
| TUR  | May-02     | 149 | 11.2        | 46.0        | 1670 | Sep-01      | 144 | 10.3        | 46          | 1485 |
| SVK  | May-98     | 173 | 8.3         | 30.0        | 1434 | May-98      | 164 | 8.3         | 30          | 1355 |
| <b>Data set Latin American Consensus Forecasts</b> |            |     |             |             |      |             |     |             |             |      |
| ARG  | Apr-01     | 192 | 14.4        | 51.0        | 2769 | Apr-01      | 183 | 12.5        | 44          | 2279 |
| BRA  | Apr-01     | 192 | 16.7        | 49.0        | 3204 | Apr-01      | 183 | 16.3        | 48          | 2974 |
| CHL  | Jun-01     | 190 | 15.1        | 38.0        | 2865 | Apr-01      | 183 | 14.9        | 39          | 2723 |
| MEX  | Apr-01     | 192 | 17.6        | 50.0        | 3379 | Apr-01      | 183 | 17.4        | 50          | 3183 |
| VEN  | Apr-01     | 192 | 8.9         | 28.0        | 1718 | Apr-01      | 183 | 8.4         | 25          | 1537 |
| Total  | 106,428    |     |             |             |      | 100,967     |     |             |             |      |

This Table summarizes the number of individual forecasts for short-term interest rates per country. Start is the begin of the sample for a country. All samples end in June 2017.  $T$  is the number of time periods (months).  $\bar{N}_t$  is the average number of forecasts at a point in time (the cross-section).  $N^{Total}$  is the total number of different forecasters.  $NT$  gives the total number of individual forecasts.  $h$  indicates the forecast horizon, either 3 months or 12 months.

**Table 8:** Observations for reported long-term yield forecasts

|  | <b>h=3</b> |     |             |             |        | <b>h=12</b> |     |             |             |        |
|--|------------|-----|-------------|-------------|--------|-------------|-----|-------------|-------------|--------|
|  | Start      | $T$ | $\bar{N}_t$ | $N^{Total}$ | $NT$   | Start       | $T$ | $\bar{N}_t$ | $N^{Total}$ | $NT$   |
| <b>Data set Consensus Forecasts</b>                |            |     |             |             |        |             |     |             |             |        |
| USA  | Oct-89     | 330 | 24.1        | 76          | 7964   | Oct-89      | 321 | 23.4        | 76          | 7527   |
| JPN  | Oct-89     | 330 | 17.2        | 50          | 5692   | Oct-89      | 321 | 16.1        | 50          | 5180   |
| DEU  | Oct-89     | 330 | 24.1        | 52          | 7939   | Oct-89      | 321 | 23.8        | 51          | 7642   |
| FRA  | Oct-89     | 330 | 15.7        | 52          | 5191   | Oct-89      | 321 | 15.6        | 52          | 5008   |
| GBR  | Oct-89     | 330 | 21.6        | 74          | 7132   | Oct-89      | 321 | 21.4        | 70          | 6883   |
| ITA  | Jan-91     | 315 | 9.8         | 39          | 3073   | Apr-90      | 315 | 9.7         | 39          | 3050   |
| CAN  | Sep-93     | 283 | 14.3        | 40          | 4033   | Dec-92      | 283 | 14.2        | 39          | 4018   |
| NLD  | Jan-95     | 267 | 8.5         | 32          | 2262   | Jan-95      | 258 | 8.4         | 32          | 2173   |
| NOR  | Jun-98     | 226 | 6.9         | 29          | 1570   | Jun-98      | 217 | 7.0         | 27          | 1509   |
| ESP  | Jan-95     | 267 | 11.8        | 30          | 3144   | Jan-95      | 258 | 11.7        | 30          | 3016   |
| SWE  | Jan-95     | 267 | 11.5        | 35          | 3061   | Jan-95      | 258 | 11.4        | 34          | 2945   |
| CHE  | Jun-98     | 226 | 10.9        | 19          | 2460   | Jun-98      | 217 | 10.8        | 19          | 2338   |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |            |     |             |             |        |             |     |             |             |        |
| AUS  | Oct-94     | 270 | 15.5        | 40          | 4176   | Jan-94      | 270 | 15.0        | 40          | 4060   |
| IND  | Dec-05     | 136 | 7.5         | 29          | 1021   | Dec-05      | 127 | 6.8         | 28          | 867    |
| IDN  | Mar-06     | 133 | 6.7         | 20          | 893    | Mar-06      | 124 | 6.5         | 20          | 810    |
| NZL  | Dec-94     | 268 | 12.0        | 30          | 3203   | Dec-94      | 259 | 11.9        | 30          | 3089   |
| KOR  | Dec-11     | 64  | 6.8         | 16          | 433    | Dec-11      | 55  | 6.9         | 16          | 379    |
| TWN  | Mar-06     | 101 | 6.6         | 18          | 664    | Mar-06      | 92  | 6.5         | 16          | 600    |
| THA  | Mar-06     | 133 | 6.3         | 21          | 834    | Mar-06      | 124 | 6.1         | 21          | 761    |
| <b>Data set Eastern Europe Consensus Forecasts</b> |            |     |             |             |        |             |     |             |             |        |
| CZE  | Jan-06     | 127 | 11.3        | 29          | 1429   | Jan-06      | 118 | 11.1        | 27          | 1312   |
| HUN  | Jan-06     | 127 | 9.1         | 27          | 1155   | Jan-06      | 118 | 8.9         | 26          | 1046   |
| POL  | Jan-06     | 127 | 10.7        | 30          | 1361   | Jan-06      | 118 | 10.4        | 28          | 1232   |
| SVK  | Sep-06     | 123 | 6.6         | 17          | 807    | Jan-06      | 118 | 6.6         | 17          | 776    |
| Total  |            |     |             |             | 69,497 |             |     |             |             | 66,221 |

This Table summarizes the number of individual forecasts for long-term yields per country. Start is the begin of the sample for a country. All samples end in June 2017.  $T$  is the number of time periods (months).  $\bar{N}_t$  is the average number of forecasts at a point in time (the cross-section).  $N^{Total}$  is the total number of different forecasters.  $NT$  gives the total number of individual forecasts.  $h$  indicates the forecast horizon, either 3 months or 12 months.

**Table 9: Monthly short-term interest rates: Consensus Economics forecasts with horizon of 3 and 12 months and Datastream tickers**

| Country                                     | Short | Name Consensus Economics       | Time span            | Ticker      | Name Ticker                                    |
|---|-------|--------------------------------|----------------------|-------------|--|
| <b>Data set Western Consensus Forecasts</b> |       |                                |                      |             |  |
| USA   | USA   | 3 Month Treasury Bill Rate (%) | Oct 1989 to Jun 2017 | FRTBS3M(IR) | US T-BILL SEC MARKET 3 MONTH (D) - MIDDLE RATE |
| Japan                                       | JPN   | 3 Month Yen Cert of Deposit    | Oct 1989 to May 2010 | JAPCD3M(IR) | JAPAN CD 3 MONTH DISC - BID RATE               |
|   |       | 3 Month Yen TIBOR Rate %       | Jun 2010 to Jun 2017 | JPIBK3M(IO) | JAPAN INTERBANK JPY 3M - OFFERED RATE          |
| Germany                                     | DEU   | 3 Month Euro-Dm Rate (%)       | Oct 1989 to Dec 1998 | ECWGM3M(IR) | BD EU-MARK 3M DEPOSIT (FT/TR) - MIDDLE RATE    |
|   |       | 3 Month Euro Rate (%)          | Jan 1999 to Jun 2017 | EIBOR3M(IO) | EBF EURIBOR 3M DELAYED - OFFERED RATE          |
| France                                      | FRA   | 3 Month Euro-Ffr Rate (%)      | Oct 1989 to Dec 1998 | ECFFR3M(IR) | FR EU-FRANC 3M DEPOSIT (FT/TR) - MIDDLE RATE   |
|   |       | 3 Month Euro Rate (%)          | Jan 1999 to Jun 2017 | EIBOR3M(IO) | EBF EURIBOR 3M DELAYED - OFFERED RATE          |
| UK  | GBR   | 3 Month Interbank Rate (%)     | Oct 1989 to Jun 2017 | BGBFP3M(IO) | IBA GBP IBK. LIBOR 3M DELAYED - OFFERED RATE   |
| Italy                                       | ITA   | 3 Month Treasury Bill Rate (%) | Oct 1989 to Dec 1998 | ITBT03G(IR) | ITALY T-BILL AUCT. GROSS 3 MONTH - MIDDLE RATE |
|   |       | 3 Month Euro Rate (%)          | Jan 1999 to Jun 2017 | EIBOR3M(IO) | EBF EURIBOR 3M DELAYED - OFFERED RATE          |
| Canada                                      | CAN   | 3 Month Treasury Bill Rate (%) | Oct 1989 to Jun 2017 | CN13884(IR) | CANADA TREASURY BILL 3 MONTH - MIDDLE RATE     |
|   |       | 3 Month Euro-Guilder Rate (%)  | Oct 1989 to Dec 1998 | ECNLG3M(IR) | NL EU-GUILDER 3M DEPOSIT (FT/TR) - MIDDLE RATE |
| Netherlands                                 | NLD   |                                |                      |             |  |
| Norway                                      | NOR   | 3 Month Euro-Krone Rate (%)    | Jun 1998 to Feb 2004 | GSNOK3M(IR) | TR NORWEGIAN KRONE 3M DEPOSIT - MIDDLE RATE    |
|   |       | Norwegian interbank rate       | Mar 2004 to Apr 2015 | NWIBK3M(IO) | NORWAY INTERBANK 3 MONTH - OFFERED RATE        |
| Spain                                       | ESP   | 3 Month Euro-Peseta Rate (%)   | Oct 1989 to Dec 1998 | ECESP3M(IR) | ES EU-PESETA 3M DEPOSIT (FT/TR) - MIDDLE RATE  |
|   |       | 3 Month Euro Rate (%)          | Jan 1999 to Jun 2017 | EIBOR3M(IO) | EBF EURIBOR 3M DELAYED - OFFERED RATE          |

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Table 9 – continued from previous page

| Country  | Short | Name Consensus Economics   | Time span   | Ticker                        | Name Ticker  |
|--|-------|--|---|-------------------------------|--|
| Sweden   | SWE   | 3 Month Euro Kronor Interest Rate (%), (end period)<br>Swedish Deposit Rate<br>Interbank rate      | Nov 1989 to Feb 2004<br>Mar 2004 to Jul 2005<br>Aug 2005 to Apr 2015            | GSSEK3M(IR)<br>SIBOR3M(IO)    | TR SWEDISH KRONA 3M DEPOSIT - MIDDLE RATE<br>SWEDEN INTERBANK 3M DELAYED - OFFERED RATE                  |
| Switzerland                                      | CHE   | 3 Month Euro-Franc Interest Rate, % (end period)   | Jun 1998 to Jun 2017  | SWSNBLB(IR)                   | SWISS 3 MONTH LIBOR (SNB) - MIDDLE RATE  |
| <b>Data set Asia Pacific Consensus Forecasts</b> |       |  |   |                               |  |
| Australia  | AUS   | 90-Day Bank Bill Rate<br>Dealer Bill Rate  | Nov 1990 to Aug 2002<br>Sept 2002 to Jun 2017                                   | ADBR090(IR)                   | AUSTRALIA DEALER BILL 90 D - MIDDLE RATE   |
| China  | CHN   | 1-year Base Lending Rate for Working Capital (%)   | Jul 2003 to Jun 2017  | CHLD1Y                        | CHINA LENDING RATE 6M TO 1Y - MIDDLE RATE  |
| Hong Kong  | HKG   | 3-Month Interbank Rate   | Jan 1995 to Jun 2017  | HKIBF3M(IO)                   | HONG KONG INTERBANK 3M - OFFERED RATE  |
| India  | IND   | 91-day Treasury Bill Rate  | Feb 1995 to Jun 2017<br>Change because time series finished (disc. By reuters)  | INTB91D<br>INDTB3M(IRY)       | INDIA T-BILL SECONDARY DISC - RED. YIELD<br>INDIA T-BILL 3 MONTH - RED. YIELD                            |
| Indonesia  | IDN   | 3-Month Deposit Rate   | Jan 1995 to Jun 2017  | IDDEF3M(IR)                   | INDONESIA DEPOSIT 3 MONTH DISC - MIDDLE RATE   |
| Malaysia   | MYS   | 3-Month Interbank Rate (%)   | Change because time series finished (start in Nov 2010)<br>Jan 1995 to Jun 2017 | IDRDP3M(IR)<br>MYIBK3M(IR)    | TR INDONESIAN RUPIAH 3M DEPOSIT - MIDDLE RATE<br>MALAYSIA INTERBANK 3 MONTH - MIDDLE RATE                |
| New Zealand                                      | NZL   | 90-day Bank Bill Rate (%)  | Jan 1995 to Jun 2017  | NZBB90D(IR)                   | NEW ZEALAND 90 DAY BANK BILL - MIDDLE RATE   |
| Philippines                                      | PHI   | 3-Month PHIBOR Interbank Rate (from Bloomberg)<br>91-Day Treasury Bill Rate                        | Apr 2009 to Jul 2013<br>Aug 2013 to Jun 2017                                    | PHINBR3M Index<br>PHTBL3M(IR) | Bankers Association of the Phi<br>PHILIPPINE TREASURY BILL 91D - MIDDLE RATE                             |
| Singapore  | SGP   | 3-Month S\$ Interbank Rate<br>decided to add two series to one, since difference seems to be small | Jan 1992 to Dec 2013<br>Jan 2014 to Jun 2017                                    | SGIBK3M(IR)<br>SISGD3M(IR)    | SINGAPORE INTERBANK 3 MONTH (M DISC - MIDDLE RATE)<br>SINGAPORE INTERBANK 3M SIBOR ABS DE. - MIDDLE RATE |

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Table 9 – continued from previous page

| Country  | Short | Name  | Consensus Economics | Time span             | Ticker      | Name   | Ticker |
|--|-------|---|---------------------|-----------------------|-------------|--|--------|
| South Korea  | KOR   | 91-day Certificate of Deposit               |                     | Jan 1995 to Jun 2017  | KOCD91D(IR) | KOREA NCD 91 DAYS - MIDDLE RATE                    |        |
| Taiwan   | TWN   | 91-day Commercial Paper Rate (%)            |                     | Jan 1995 to Jun 2017  | TAMM90D(IR) | TAIWAN MONEY MARKET 90 DAYS - MIDDLE RATE          |        |
| Thailand   | THA   | 3-Month Interbank Rate (%)                  |                     | Jan 1995 to Jun 2017  | THBB1B3(IO) | THAILAND INTERBANK 3 MTH (BB) - OFFERED RATE       |        |
| <b>Data set Eastern Europe Consensus Forecasts</b> |       |   |                     |                       |             |  |        |
| Czech Republic                                     | CZE   | 3 Month PRIBOR Interbank Deposit Rate (%)   |                     | May 1998 to Jul 2010  | PRIBK3M(IR) | CZECH REPUBLIC IBK. 3M - MIDDLE RATE               |        |
|  |       | We do not change interest rate.             |                     | Aug 2010 to Jun 2017  |             |  |        |
| Hungary  | HUN   | 90 day Treasury Bill Rate (%)               |                     | May 1998 to Jun 2017  | HNTBA3M(RY) | HUNGARY DISC. T-BILL AUCTION - 3 MTH. - RED. YIELD |        |
| Poland   | POL   | 3 Month Interbank Deposit Rate (%)          |                     | May 1998 to Jun 2017  | POIBK3M(IR) | TR POLISH ZLOTY 3M DEPOSIT - MIDDLE RATE           |        |
| Turkey   | TUR   | Overnight Interbank Interest Rate (%)       |                     | May 1998 to Jan 2014  | TKIBKON(IO) | TURKEY INTERBANK O/N - OFFERED RATE                |        |
|  |       | Overnight Lending Rate (%)                  |                     | Feb 2014 to Jun 2017  | TKBLRON(IR) | TURKEY OVERNIGHT LENDING RATE - MIDDLE RATE        |        |
| Slovakia   | SVK   | 3-Month BRIBOR Interbank Deposit Rate       |                     | May 1998 to Dec 2008  | SXIBK3M(IO) | SL 3M INTBK DELAYED SEE EIBOR3M - OFFERED RATE     |        |
|  |       | 3-Month Euro Interbank Rate                 |                     | Jan 2009 to Jun 2017  | EIBOR3M(IO) | EBF EURIBOR 3M DELAYED - OFFERED RATE              |        |
| <b>Data set Latin American Consensus Forecasts</b> |       |   |                     |                       |             |  |        |
| Argentina  | ARG   | 30-Day Peso Certificates of Deposit (%)     |                     | Apr 2001 to Jun 2017  | AG30DPP(IR) | ARGENTINA DEPOSIT 30 DAYS (PA.) - MIDDLE RATE      |        |
| Brazil   | BRA   | Overnight Interbank Interest Rate SELIC (%) |                     | Apr 2001 to Jun 2017  | BRSELIC(IR) | BRAZIL SELIC TARGET RATE - MIDDLE RATE             |        |
| Chile  | CHL   | Real Central Bank 90-Day Bill Rate (%)      |                     | Apr 2001 to Aug 2001  | CLMONPR     | CLMONPR  |        |
|  |       | Nominal Central Bank 90-Day Bill Rate (%)   |                     | Sept 2001 to Jun 2017 |             |  |        |
| Mexico   | MEX   | 28-Day CETES Rate (%)                       |                     | Apr 2001 to Jun 2017  | MXCTC28(IR) | MEXICO CETES 28 DAY CLOSING - MIDDLE RATE          |        |
| Venezuela  | VEZ   | 30-Day Deposit Rate (%)                     |                     | Apr 2001 to Jun 2017  | VEDP30D(IR) | VENEZUELA 30 DAY DEPOSIT RATE - MIDDLE RATE        |        |



**Table 10: Monthly long-term government bond yields: Consensus Economics forecasts with horizon of 3 and 12 months and Datastream tickers**

| Country                                     | Short | Name Consensus Economics        | Time span            | Ticker      | Name Ticker  |
|---|-------|---------------------------------|----------------------|-------------|--|
| <b>Data set Western Consensus Forecasts</b> |       |                                 |                      |             |  |
| USA   | USA   | 10 Year Treasury Bond Yield     | Oct 1989 to Jun 2017 | USBD10Y(RY) | US TREAS.BENCHMARK BOND 10 YR (DS) - RED. YIELD    |
| Japan                                       | JPN   | 10 Year Govt Bond Yield         | Oct 1989 to Jun 2017 | BMJP10Y(RY) | JP BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Germany                                     | DEU   | 10 Year German Govt Bond Yield  | Oct 1989 to Jun 2017 | BMBD10Y(RY) | BD BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| France                                      | FRA   | 10 Year French Govt Bond Yield  | Oct 1989 to Jun 2017 | BMFR10Y(RY) | FR BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| UK  | GBR   | 10 Year Gilt Yield              | Oct 1989 to Jun 2017 | BMUK10Y(RY) | UK BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Italy                                       | ITA   | 10 Year Italian Govt Bond Yield | Oct 1989 to Jun 2017 | BMIT10Y(RY) | IT BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Canada                                      | CAN   | 10 Year Govt Bond Yield         | Oct 1989 to Jun 2017 | CNBB10Y(RY) | CANADA GOVT. BNCHMK. BOND 10 YR (BOC) - RED. YIELD |
| Netherlands                                 | NLD   | 10 Year Dutch Govt Bond Yield   | Dec 1994 to Jun 2017 | BMNL10Y(RY) | NL BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Norway                                      | NOR   | 10 Year Govt Bond Yield         | Jun 1998 to Jun 2017 | BMNW10Y(RY) | NW BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Spain                                       | ESP   | 10 Year Spanish Govt Bond Yield | Dec 1994 to Jun 2017 | BMES10Y(RY) | ES BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Sweden                                      | SWE   | 10 Year Govt Bond Yield         | Dec 1994 to Jun 2017 | BMSD10Y(RY) | SD BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Switzerland                                 | CHE   | 10 Year Govt Bond Yield         | Jun 1998 to Jun 2017 | BMSW10Y(RY) | SW BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |

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Table 10 – continued from previous page

| Country  | Short | Name Consensus Economics      | Time span            | Ticker      | Name Ticker  |
|--|-------|-------------------------------|----------------------|-------------|--|
| <b>Data set Asia Pacific Consensus Forecasts</b>   |       |                               |                      |             |  |
| Australia  | AUS   | 10 Year Government Bond Yield | Jan 1995 to Jun 2017 | BMAU10Y(RY) | AU BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| India  | IND   | Prime Lending Rate            | Jan 1995 to Nov 2005 |             |  |
| Indonesia  | IDN   | 10 Year Government Bond Yield | Dec 2005 to Jun 2017 | INDBD10(RY) | INDIA T-BOND 10 YEAR - RED. YIELD                  |
|  |       | Prime Lending Rate            | Jan 1995 to Feb 2006 |             |  |
| New Zealand  | NZD   | 10 Year Government Bond Yield | Mar 2006 to Jun 2017 | TRID10T(RY) | TR INDONESIA GVT BMK BID YLD 10Y(INR) - RED. YIELD |
|  |       | 10 Year Government Bond Yield | Jan 1995 to Jun 2017 | NZGBY10(RY) | NEW ZEALAND GOVT.BD. YIELD 10 YEAR - RED. YIELD    |
| South Korea  | KOR   | 3 Year Corporate Bond Yield   | Jan 1995 to Jul 2006 |             |  |
|  |       | 5 Year Government Bond Yield  | Aug 2006 to Nov 2011 |             |  |
| Taiwan   | TWN   | 10 Year Government Bond Yield | Dec 2011 to Jun 2017 | KOBDY10(RY) | KOREA TREASURY BOND 10Y - RED. YIELD               |
|  |       | 10 Year Government Bond Yield | Mar 2006 to Jun 2017 | TWGBD10(IR) | TAIWAN GOVT. BOND 10 YEARS - MIDDLE RATE           |
| Thailand   | THA   | Minimum Leinding Rate         | Jan 1995 to Feb 2006 |             |  |
|  |       | 10 Year Government Bond Yield | Mar 2006 to Jun 2017 | TRTH10C(RY) | TR THAILAND GVT BID YLD 10Y TB - RED. YIELD        |
| <b>Data set Eastern Europe Consensus Forecasts</b> |       |                               |                      |             |  |
| Czech Republic                                     | CZE   | 10 Year Government Bond Yield | Jan 2006 to Jun 2017 | BMCZ10Y(RY) | CZ BENCHMARK 10 YEAR DS GOVT. INDEX - RED. YIELD   |
| Hungary  | HUN   | 10 Year Government Bond Yield | Jan 2006 to Jun 2017 | HNGBATY(RY) | HUNGARY GOVT. BOND AUCTION - 10 YR. - RED. YIELD   |
| Poland   | POL   | 10 Year Government Bond Yield | Jan 2006 to Jun 2017 | TRPO10T(RY) | TR POLAND GVT BMK BID YLD 10Y (PZ) - RED. YIELD    |
| Slovakia   | SVK   | 10 Year Government Bond Yield | Jan 2006 to Jun 2017 | TRSXZ10(ZY) | TR SLOVAKIA GVT ZERO 10Y - ZERO YIELD              |

## Appendix C Further results

**Table 11:** Interest rates and yields – Maximum weights given to the private signal

|  | Interest rates |             | Yields      |             |
|--|----------------|-------------|-------------|-------------|
|  | $h = 3$        | $h = 12$    | $h = 3$     | $h = 12$    |
| <b>Data set Western Consensus Forecasts</b>        |                |             |             |             |
| USA  | 0.36           | 0.60        | 0.34        | 0.44        |
| JPN  | 0.33           | 0.42        | 0.33        | 0.47        |
| DEU  | 0.38           | 0.51        | 0.35        | 0.37        |
| FRA  | 0.18           | 0.27        | 0.37        | 0.42        |
| GBR  | 0.39           | 0.59        | 0.38        | 0.48        |
| ITA  | 0.19           | 0.28        | 0.35        | 0.41        |
| CAN  | 0.27           | 0.38        | 0.41        | 0.52        |
| NLD  | 0.35           | 0.41        | 0.35        | 0.45        |
| NOR  | 0.26           | 0.41        | 0.39        | 0.46        |
| ESP  | 0.44           | 0.50        | 0.41        | 0.44        |
| SWE  | 0.34           | 0.52        | 0.38        | 0.46        |
| CHE  | 0.26           | 0.48        | 0.35        | 0.46        |
| <b>Data set Asia Pacific Consensus Forecasts</b>   |                |             |             |             |
| AUS  | 0.32           | 0.47        | 0.34        | 0.35        |
| CHN  | 0.35           | 0.46        |             |             |
| HKG  | 0.13           | 0.24        |             |             |
| IND  | 0.19           | 0.28        | 0.37        | 0.51        |
| IDN  | 0.43           | 0.47        | 0.25        | 0.31        |
| MYS  | 0.36           | 0.57        |             |             |
| NZL  | 0.30           | 0.47        | 0.41        | 0.51        |
| PHL  | 0.14           | 0.23        |             |             |
| SGP  | 0.37           | 0.44        |             |             |
| KOR  | 0.28           | 0.36        | 0.56        | 0.59        |
| TWN  | 0.42           | 0.56        | 0.41        | 0.57        |
| THA  | 0.36           | 0.42        | 0.33        | 0.43        |
| <b>Data set Eastern Europe Consensus Forecasts</b> |                |             |             |             |
| CZE  | 0.39           | 0.36        | 0.29        | 0.38        |
| HUN  | 0.26           | 0.38        | 0.29        | 0.44        |
| POL  | 0.41           | 0.41        | 0.34        | 0.52        |
| TUR  | 0.30           | 0.54        |             |             |
| SVK  | 0.19           | 0.48        | 0.50        | 0.54        |
| <b>Data set Latin American Consensus Forecasts</b> |                |             |             |             |
| ARG  | 0.24           | 0.29        |             |             |
| BRA  | 0.48           | 0.57        |             |             |
| CHL  | 0.19           | 0.39        |             |             |
| MEX  | 0.25           | 0.36        |             |             |
| VEN  | 0.44           | 0.50        |             |             |
| <b>Mean</b>  | <b>0.31</b>    | <b>0.43</b> | <b>0.37</b> | <b>0.46</b> |

The table shows the maximum weight given to the private signal ( $\kappa$  when  $r \rightarrow 0$ ) while the minimum weight is always 0 (this is when  $r \rightarrow 1$ ).  $h$  is the forecast horizon, either 3 months or 12 months.

## Appendix D Empirical methods

### Appendix D.1 Method for testing **Hypothesis 1** and **Hypothesis 4**: Fama & MacBeth (1973)

To test **Hypothesis 1** and **Hypothesis 4**, we run the following regression

$${}^t a_{i,t+h} - \theta_{t+h} = b + e_{i,t+h} \quad (71)$$

As such, we apply the Fama & MacBeth (1973) approach. The estimate is

$$\hat{b} = \frac{1}{T} \sum_{t=1}^T \hat{b}_t = \frac{1}{T} \sum_{t=1}^T \left( \frac{\sum_{i=1}^{N_t} X_{i,t} Y_{i,t}}{\sum_{i=1}^{N_t} X_{i,t}^2} \right) \quad (72)$$

The variance of the coefficients is

$$\hat{\sigma}_{b,c}^2 = \frac{1}{T} \sum_{t=1}^T \frac{(\hat{b}_t - \hat{b})^2}{T} \quad (73)$$

Note that we divide by  $1/T^2$  because we are estimating sample means. This is the variance of the coefficients when there is no serial correlation. However, this is not the case in our data set. A forecast (action) that is reported today correlates with at least the lags of the forecast horizon because agents cannot learn their *action errors* before they have materialized. As shown in **Figure 3**, there is a forecaster's effect ('firm's effect') that leads to a variance that is too low. However, we assume that this effect only applies until the forecaster has identified the misspecification in his reported forecasts. We chose 4 lags of serial correlation when the forecast horizon is 3 months ( $h = 3$ ) and 13 lags for horizons of 12 months ( $h = 12$ ). Petersen (2009) suggests the following method for correcting for serial correlation

$$\hat{\sigma}_b^2 = \hat{\sigma}_{b,c}^2 + 2 \cdot \frac{1}{T} \sum_{j=1}^{h+1} \text{COV}(\hat{b}_t, \hat{b}_{t-j}) \quad (74)$$

We could also introduce a HAC estimator with weights for the lags, for example Newey & West, among others. However, this would lead to smaller variance estimates (assuming positive correlations among lags). Therefore, we use  $\hat{\sigma}_b^2$  as an upper estimate of the variance for  $\hat{b}$ .

## Appendix D.2 Method to test **Hypothesis 2**, **Hypothesis 3**, and **Hypothesis 5**

To test **Hypothesis 2**, **Hypothesis 3**, and **Hypothesis 5**, we estimate two variances and calculate their ratio

$$\widehat{V} = \frac{\widehat{V}_1}{\widehat{V}_2} = \frac{\mathbb{V} \left[ ({}_t\bar{a}_{t+h} - \theta_{t+h}) \right]}{\mathbb{V} \left[ ({}_t a_{i,t+h} - {}_t\bar{a}_{t+h}) \right]} \quad (75)$$

Because *action errors* are correlated over the forecast horizon, we correct for this when estimating the variance. In both models, *action errors* arise from errors that are contained in the signals. Errors in private ( $\epsilon_{i,t}$ ) and public ( $\eta_t$ ) signals cannot be completely determined by agents until the *action error* materializes. Therefore, errors may survive in the signals until the realization of the state ( $\theta_{t+h}$ ). Thus, both models explain the correlation of *action errors* across forecast horizons. To correct for this issue, we calculate MA(4) and MA(13) processes for forecast horizons of 3 and 12 months, which yields<sup>43</sup>

$${}_t\bar{a}_{t+h} - \theta_{t+h} = \phi_1 \epsilon_{t-1} + \phi_2 \epsilon_{t-2} + \dots + \phi_{h+1} \epsilon_{t-h-1} + \epsilon_t \quad (76)$$

$${}_t a_{i,t+h} - {}_t\bar{a}_{t+h} = \phi_1 \epsilon_{t-1} + \phi_2 \epsilon_{t-2} + \dots + \phi_{h+1} \epsilon_{t-h-1} + \epsilon_t \quad (77)$$

We use the estimated variance of the innovations in the MA-processes  $\widehat{\sigma}_\epsilon^2$  as the estimates of variances  $\widehat{V}_1$  and  $\widehat{V}_2$ .

From F-tests, we accept **Hypothesis 2**, **Hypothesis 3**, and **Hypothesis 5**. Following Forbes et al. (2010) (p. 105), we know that the ratio of two estimated variances for *iid* normally distributed variables follow an F distribution. This is

$$\frac{\widehat{V} (T - h - 1) \cdot (NT - h - 2)}{V_0 (T - h - 2) \cdot (NT - h - 1)} \sim F(T - h - 1, NT - h - 1), \quad (78)$$

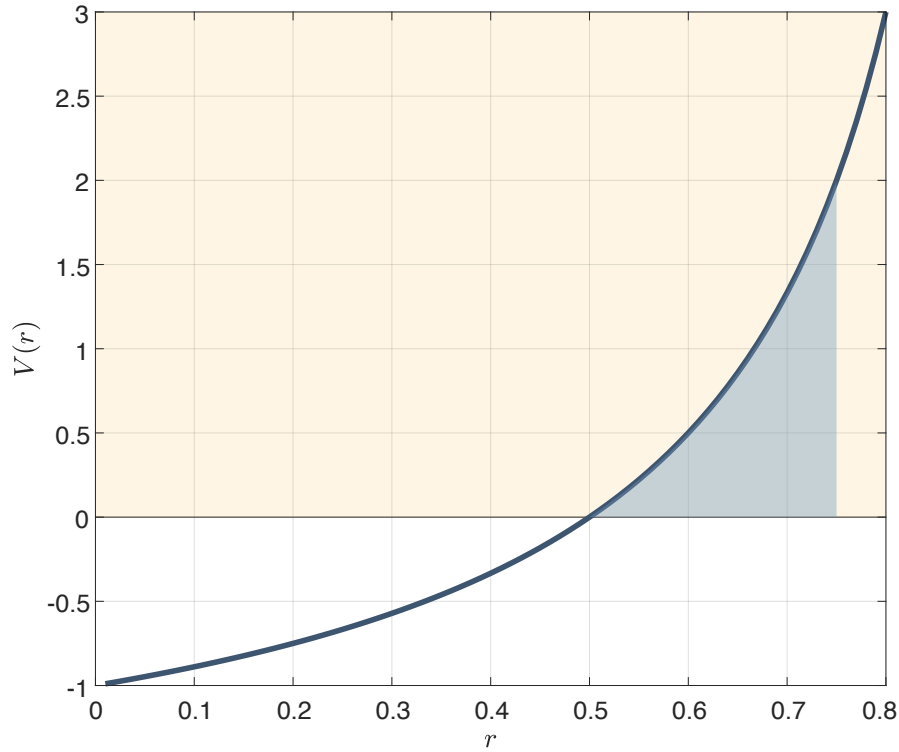
with  $NT = \sum_{t=1}^T N_t$

where  $V_0$  represents the null. We subtract  $h + 1$  from the numbers of observations because we lose  $h + 1$  observations due to estimating the MA( $h+1$ )-processes.

<sup>43</sup> In fact, forecast errors from stationary, trend-stationary, and unit root processes follow MA( $h$ ) processes. (See, for example, Hamilton (1994), p. 440 ff.). It is fair to assume that *action errors* that are made by the participants in the *Consensus Economics* survey follow this pattern. Hence, the individual *action error* follows an MA( $h+1$ ) process. We conclude that the cross-sectional mean *action error* follows an MA( $h+1$ ) process. Note that we derive individual deviations from the cross-sectional mean action as follows  ${}_t a_{i,t+h} - \theta_{t+h} - ({}_t\bar{a}_{t+h} - \theta_{t+h}) = {}_t a_{i,t+h} - {}_t\bar{a}_{t+h}$ . We deduce that  ${}_t a_{i,t+h} - {}_t\bar{a}_{t+h}$  (individual deviations from the cross-sectional mean action) also follow an MA( $h+1$ ) process, because the cross-sectional sum of two MA( $h+1$ ) processes follows an MA( $h+1$ ) process.

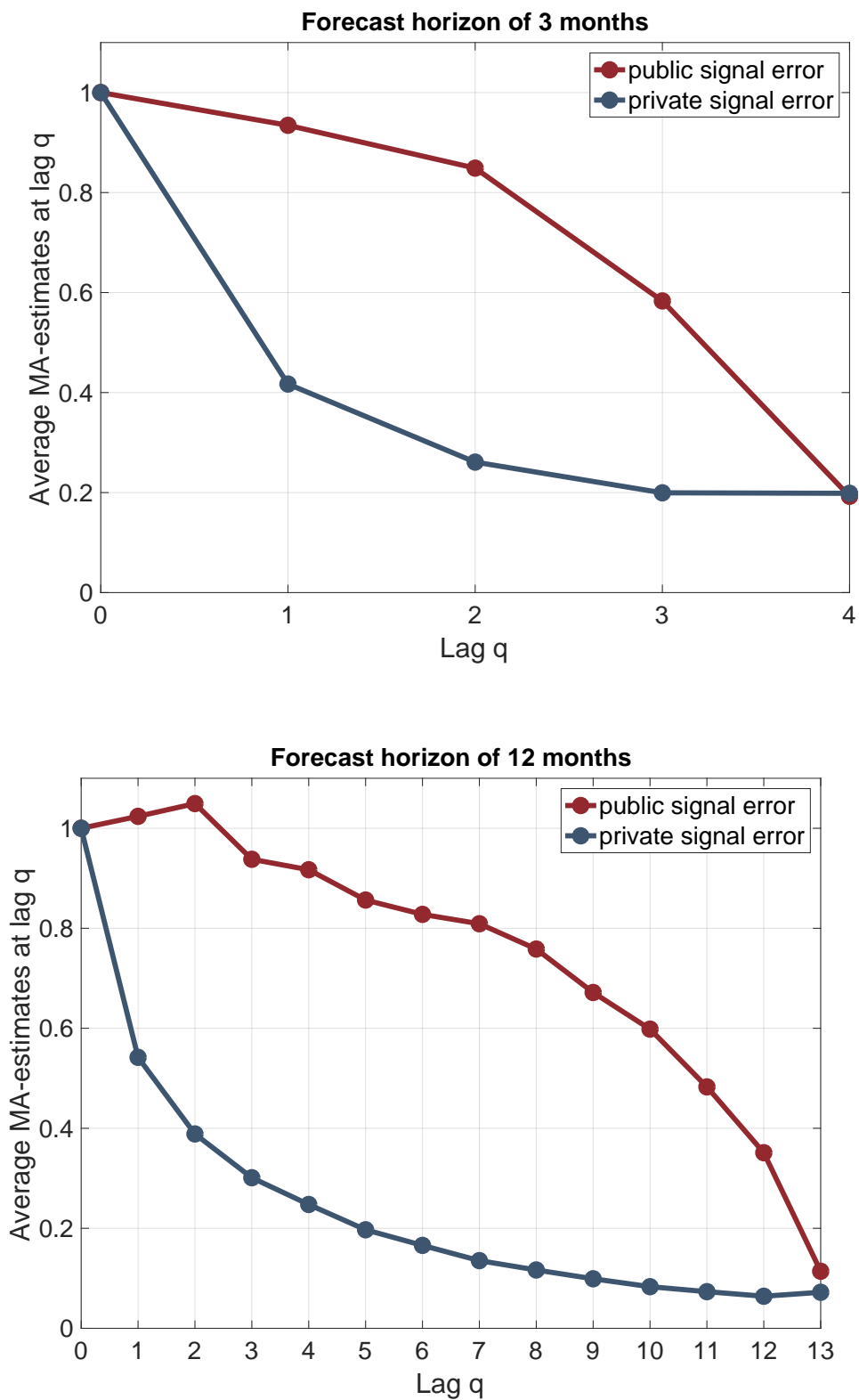
## Appendix E Figures

**Figure 4:**  $F(r)$  as a boundary for  $V$



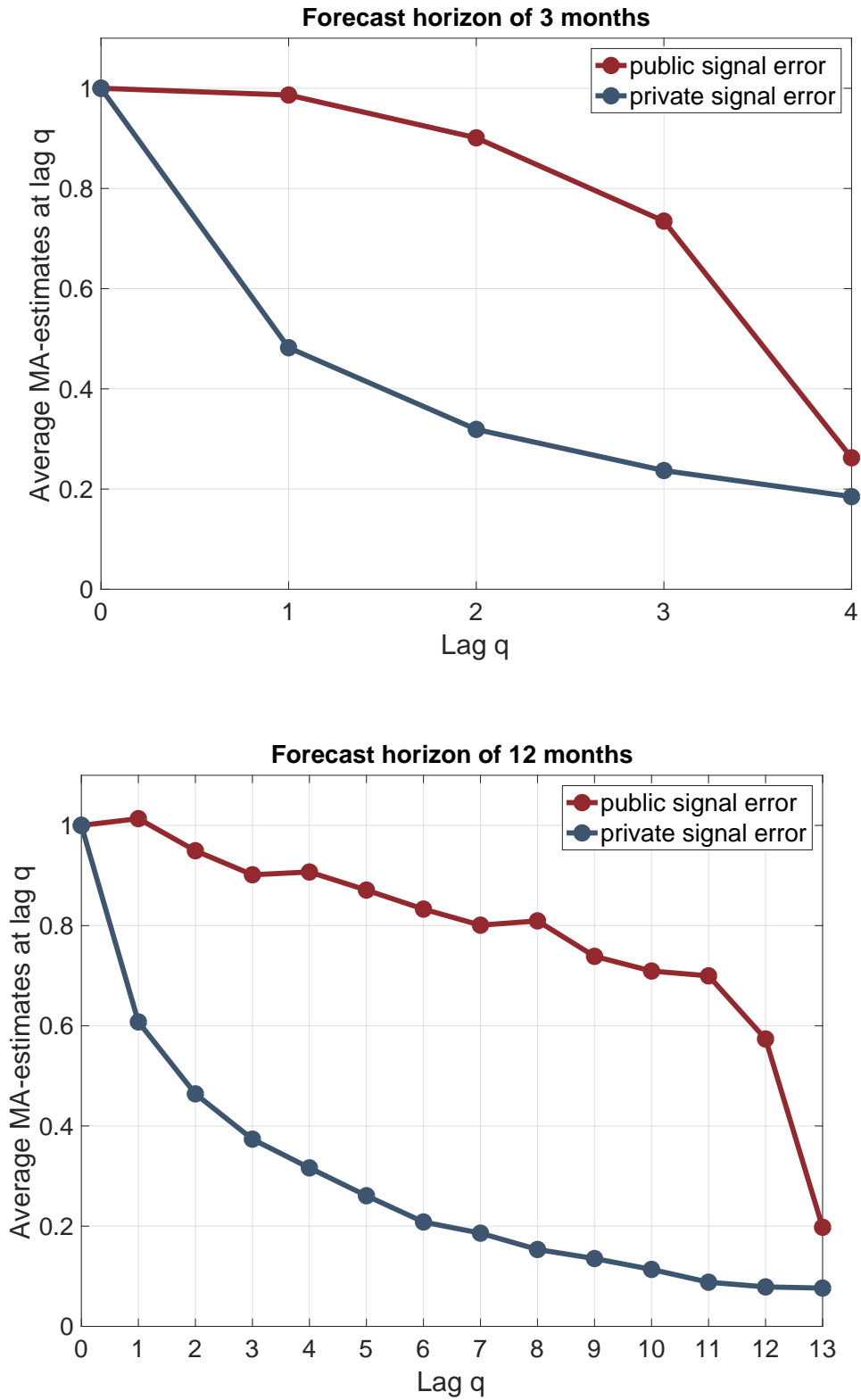
The figure illustrates the conditions that were postulated by Svensson (2006). It plots the function  $F(r) = (2r - 1)/(1 - r)$  for  $0 < r < 0.8$  (the blue line).  $F(r)$  is a boundary for  $V$ . If  $0 < V \leq F(r)$ , it could be that a higher precision in public signals lowers social welfare. Welfare, then, only depends on  $r$ . The blue shaded area shows the values of  $V$ , for which higher precision in public signals decreases social welfare. This occurs when  $0.5 < r < 0.75$ . However, if  $2 < V$ , we can rule out a welfare reducing effect from higher precision in public signals. Further, note that the ratio  $V = \mathbb{V} [({}_t\bar{a}_{t+h} - \theta_{t+h})] / \mathbb{V} [({}_t a_{i,t+h} - {}_t\bar{a}_{t+h})]$  cannot be negative, because it is a ratio of two variances. The orange shaded area shows possible values of  $V \in \mathbb{R}_+^*$ .

Figure 5: Interest rates: Average MA estimates



The figure plots the average MA-estimates for each lag.

Figure 6: Yields: Average MA estimates



The figure plots the average MA-estimates for each lag.